RESEARCH THEME REPORTS from April 1, 2019 – March 31, 2020

PI	AWARD #	PROJECT #	TITLE	START	END	THEME
Bikos	NA19OAR4320073	5310506	VISIT - CIRA Support of the Virtual Institute for Satellite Integration Training (VISIT)	7/1/2019	6/30/2020	Various
Brummer	NA19OAR4320073	5310562	CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting	7/1/2019	7/1/2020	Sat Algor
Chirokova	NA19OAR4320073	5310517	CIRA Support to a GOES-R Proving Ground for National Weather Service Forecaster Readiness and Training	7/1/2019	7/2/2020	Sat Algor
Chirokova	NA19OAR4320073	5310524	JPSS-PGRR TC ATMS CIRA Support to Proving Ground Risk Reduction	7/1/2019	7/3/2020	Sat Algor
Chirokova	NA19OAR4320073	5310533	CIRA Support to the Time-Resolved Observations of Precipitation structure and storm intensity with a Constellation of Smallsats (TROPICS)	7/1/2019	7/4/2022	Sat Algor
Chirokova	NA19OAR4320073	5310537	CIRA Support for the Hurricane Intensity and Structure Algorithm (HISA) Migration to STAR Enterprise System	7/1/2019	7/5/2020	Sat Algor
Connell	NA19OAR4320073	5310509	CIRA Support to JPSS Proving Ground Risk Reduction Training Activities	7/1/2019	7/6/2020	Various
Connell	NA19OAR4320073	5310512	JPSS PGRR VLAB CIRA Support to JPSS Proving Ground Risk Reduction Training Activities	7/1/2019	7/7/2020	Various

Connell	NA19OAR4320073	5310518	GOES-R PG TR - CIRA Support to a GOES-R Proving Ground for National Weather Service Forecaster Readiness and Training	7/1/2019	7/8/2020	Sat Algor
Connell	NA19OAR4320073	5310541	SHyMet - CIRA support to GOES-R Training: The Satellite Hydro-Meteorology (SHyMet) Education and Outreach Program & GOES-R commitment to the WMO CGMS Intl VLab & GOES-R FDTD Satellite Training Liaison	7/1/2019	7/10/2020	Sat Algor
Connell	NA19OAR4320073	5310542	GOES-R VLAB- CIRA support to GOES-R Training: The Satellite Hydro-Meteorology (SHyMet) Education and Outreach Program & GOES-R commitment to the WMO CGMS Int VLab & GOES-R FDTD Satellite Training Liaison	7/1/2019	7/11/2020	Sat Algor
Connell	NA19OAR4320073	5310543	GOES-R FDTE Sat Training Liaison - CIRA support to GOES-R Training: The Satellite Hydro-Meteorology (SHyMet) Education and Outreach Program & GOES-R commitment to the WMO CGMS Intl VLab & GOES-R FDTD	7/1/2019	7/12/2020	Sat Algor
Cutler	NA19OAR4320073	5301866	AQPI Economic Impacts Study	7/1/2019	7/13/2020	Societal/Economic Impact
Dostalek	NA19OAR4320073	5310504	CIRA Support for Upgrade to the Multi-Platform Satellite Tropical Cyclone Surface Wind Analysis Product	7/1/2019	7/14/2020	Sat Algor

Dostalek	NA19OAR4320073	5310526	JPSS-PGRR NUCAPS Data Fusion CIRA Support to Proving Ground Risk Reduction	7/1/2019	7/15/2020	Sat Algor
Dostalek	NA19OAR4320073	5310527	JPSS-PGRR Gridded NUCAPS in AWIPS CIRA Support to Proving Ground Risk Reduction	7/1/2019	7/16/2020	Sat Algor
Fletcher	NA19OAR4320073	5301886	Joint GOES-R, JPSS, and NASA Summer Workshop on the Theory and Use of Satellite Data	7/1/2019	7/17/2020	Education and Outreach
Forsythe	NA19OAR4320073	5310528	Merged Water Vapor CIRA Support to Proving Ground Risk Reduction	7/1/2019	7/18/2020	Sat Algor
Forsythe	NA19OAR4320073	5310539	CIRA support to ATMS Precipitable Water Algorithms and Products (MIRS)	7/1/2019	7/19/2020	Sat Algor
Forsythe	NA19OAR4320073	5310552	GOESR Water Vapor Products CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting	7/1/2019	7/20/2020	Sat Algor
Haynes	NA19OAR4320073	5310551	ABI (CLP) CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting	7/1/2019	7/21/2020	Sat Algor
Hilburn	NA19OAR4320073	5310547	GOES-R ML ABI Airmass - CIRA Support for GOES-R Risk Reduction projects using GOESR ABI Data combined with Machine Learning Techniques	7/1/2019	7/22/2021	Sat Algor

Hill	NA14OAR4320125	5301294	Estimating the Economic Value of Improved Weather Forecasts Resulting from NOAA - GSD Research and Technology Transfer	7/1/2018	6/30/2020	Societal/Economic Impact
Jones	NA19OAR4320073	5310532	CIRA support to Metop-C Readiness for Blended Hydrometeorological Products	7/1/2019	7/23/2020	Sat Algor
Jones	NA19OAR4320073	5310544	NDE Transition for Blended Hydrometeorological Products	7/1/2019	7/24/2020	Sat Algor
Kummerow	NA19OAR4320073	5302466	Cooperative Institute for Research in the Atmosphere	7/1/2019	6/30/2024	Task I
Kummerow	NA19OAR4320073	5310534	CIRA Support to Connecting GOES-R with Rapid-Update Numerical Forecast Models for Advanced Short-Term Prediction and Data Fusion Capabilities	7/1/2019	7/25/2020	Sat Algor
Kummerow	NA19OAR4320073	5310536	CIRA Support for Assessment of New Calibrated NNP and NOAA-20 ATMS Window and Water Vapor Channel Radiance and JPSS-2	7/1/2019	7/26/2020	Sat Algor
Kummerow	NA14OAR4320125	5302385	Evaluation of Small-Satellite Architectures to Address the Future Needs of the NOAA Enterprise and its Stakeholders	8/1/2018	6/30/2020	Sat Algor
Miller	NA19OAR4320073	5310516	GOES-R PG MS - CIRA Support to a GOES-R Proving Ground for National Weather Service Forecaster Readiness and Training	7/1/2019	7/27/2020	Sat Algor
Miller	NA19OAR4320073	5310503	NWS OPG - CIRA Support to the NOAA NWS	7/1/2019	7/28/2020	Sat Algor

			Operations Proving Ground			
Miller	NA19OAR4320073	5310507	DayNightImager - CIRA Science Support to the Day-Night Imager Sensor	7/1/2019	7/29/2020	Sat Algor
Miller	NA19OAR4320073	5310521	JPSS-PGRR DNB VADER CIRA Support to JPSS Proving Ground Risk Reduction	7/1/2019	7/30/2020	Sat Algor
Miller	NA19OAR4320073	5310538	CIRA Support to the JPSS STAR Science Program: S-NPP/JPSS VIIRS EDR Imagery Algorithm and Validation Activities and S-NPP/JPSS VIIRS Cloud Validation	7/1/2019	7/31/2020	Sat Algor
Miller	NA19OAR4320073	5310548	CIRA - AOML Research Team (CART)	7/1/2019	8/1/2020	Various
Miller	NA19OAR4320073	5310549	CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting	7/1/2019	8/2/2020	Sat Algor
Miller	NA19OAR4320073	5310563	NEAT - CIRA Support to NESDIS Environmental Applications Team (NEAT)	7/1/2019	8/4/2020	Sat Algor
Musgrave	NA19OAR4320073	5310525	NHC Satellite Application Developer - CIRA Support to a GOES-R Proving Ground for National Weather Service Forecaster Readiness and Training	7/1/2019	7/9/2020	Sat Algor
Musgrave	NA19OAR4320073	5310545	CIRA Support for Tropical Cyclone Model and Product Development (HFIP)	7/1/2019	8/3/2020	Climate
Musgrave	NA19OAR4320073	5310535	CIRA Support to Connecting GOES-R with Rapid-Update Numerical Forecast Models for	7/1/2019	8/5/2020	Sat Algor

			Advanced Short-Term Prediction and Data Fusion Capabilities			
Noh	NA19OAR4320073	5310523	JPSS-PGRR Nighttime CCL CIRA Support to Proving Ground Risk Reduction	7/1/2019	8/6/2020	Sat Algor
Rutledge	NA19OAR4320073	5310558	COLMA CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting	7/1/2019	8/7/2020	Sat Algor
Seaman	NA19OAR4320073	5310501	CIRA Support for the Generation of Multispectral Imagery Products from Metop-SG METImage	7/1/2019	8/8/2020	Sat Algor
Seaman	NA19OAR4320073	5310522	JPSS-PGRR VIIRS Multispec CIRA Support to JPSS Proving Ground Risk Reduction	7/1/2019	8/9/2020	Sat Algor
Slocum	NA19OAR4320073	5310531	CIRA Support to Upgrade the Tropical Cyclone Formation Probability (TCFP) Product	7/1/2019	8/10/2020	Sat Algor
Slocum	NA19OAR4320073	5310546	GOES-R ML TC - CIRA Support for GOES-R Risk Reduction projects using GOESR ABI Data combined with Machine Learning Techniques	7/1/2019	8/11/2021	Sat Algor
Strong	NA19OAR4320073	5302474	ENVIRONMENTAL APPLICATIONS RESEARCH	7/1/2019	8/12/2024	Education and Outreach
Strong	NA19OAR4320073	5310564	Research Support to the NWS NTC in Support of the office of the Chief Learning Officer Data Assimilation and Dissemination Next-Generation	7/1/2019	8/13/2024	Education and Outreach

			Radar and Advance Weather Inter			
Strong	NA19OAR4320073	5310565	CIRA Research Collaborations with the NWS Meteorological Development Lab	7/1/2019	8/14/2024	Data Dist
Strong	NA19OAR4320073	5310566	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed and the Aviation Weather Research Program	7/1/2019	8/15/2024	Sat Algor
Venkatachalam	NA19OAR4320073	5301865	Hydrometeorological and Water Resources Research	7/1/2019	8/16/2020	Various
Vonderhaar	NA19OAR4320073	5310529	JPSS-PGRR History CIRA Support to Proving Ground Risk Reduction	7/1/2019	8/17/2020	Sat Algor
Vonderhaar	NA19OAR4320073	5310559	ADEB Support CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting	7/1/2019	8/18/2020	Sat Algor
Vonderhaar	NA19OAR4320073	5310561	GOES History CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting	7/1/2019	8/19/2020	Sat Algor
Zupanski	NA19OAR4320073	5310555	DA of GLM in HWRF/GSI CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting	7/1/2019	8/20/2020	Sat Algor

NOAA Competitive						
Apodaca-Martinez	NA16OAR4590233	5301468	Accounting for Non-Gaussianity in the Background Error Distributions Associated with Cloud-related Variables in Hybrid Data Assimilation for	10/1/2016	3/31/2020	Data Dist
Barnes	NA16OAR4310090	5301429	Investigating the Underlying Mechanisms and Predictability of the MJO - NAM Linkage in the NMME Phase-2 Models	7/1/2016	6/30/2020	Climate
Barnes	NA18OAR4310296	5302353	Skillfully Predicting Atmospheric Rivers and Their Impacts in Weeks 2-5 Based on the State of the MJO and QBO	8/1/2018	7/31/2020	Data Assim
Barnes	NA19OAR4590151	5310511	MJO and QBO Contributions to U.S. Precipitation Skill at S2S Leads	9/1/2019	8/31/2022	Climate
Barnes	NA16OAR4310064	5301453	Forecasting North Pacific Blocking and Atmospheric River Probabilities: Sensitivity to Model Physics and the MJO	7/1/2016	6/30/2020	Climate
Barnes	NA19OAR4310289	5310569	Identifying Varying Patterns of Combined Change over the 21st Century with Neural Networks	9/1/2019	8/31/2021	Climate
Beck	NA19OAR4590130	5365004	Implementation and testing of stochastic perturbations within a stand-alone regional (SAR) FV3 ensemble using the Common Community Physics Package (CCPP)	7/1/2019	6/30/2022	Regional to Global Modeling
Bolinger	NA19OAR4310373	5310571	Identifying Drought-related Triggers and Impacts on Decision Calendars for the Ski Industry	9/1/2019	8/31/2020	Climate
Chirokova	NA17OAR4590138	5301757	Improvements to Operational	8/1/2017	7/31/2020	Sat Algor

			Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors			
Demott	NA16OAR4310094	5301424	Collaborative Research: Assessing Oceanic Predictability Sources for MJO Propagation	7/1/2016	6/30/2020	Climate
Demott	NA18OAR4310407	5301336	Improved Understanding of air-sea interaction processes and biases in the Tropical Western Pacific using observation sensitivity experiments and global forecast models	9/1/2018	8/31/2020	Regional and Climate
Farmer	NA17OAR4310010	5301798	Near-field Characterization of Biomass Burning Plumes	7/1/2017	6/30/2020	Climate
Fenton	NA18OAR4590374	5344505	Improving Convection-Permitting Ensemble Based Uncertainty Communication for Decision Support using the Weather Archive and Visualization Environment (WAVE)	10/1/2018	9/30/2020	Various
Fletcher	NA16NWS4680012	5301471	Implementation and Testing of Lognormal Humidity and Cloud-related Control Variables for the NCEP GSI Hybrid EnVar Assimilation Scheme	9/1/2016	8/31/2019	Data Assim
Forsythe	NA17OAR4590121	5301752	Comparison of model versus observationally-driven water vapor profiles for forecasting heavy precipitation events	7/1/2017	6/30/2020	Sat Algor (Regional & Climate)

Hardin	NA19OAR0220124	5302427	Hurricane Supplemental 1C Proposal (3A-4)	5/1/2019	7/31/2021	Data Dist
Hardin	NA19OAR4590228	5399039	Hazard Services: National Center Evolve	9/1/2019	8/31/2021	Data Dist
Jankov	NA17OAR4590181	5301792	Use of the Stochastic-dynamic Approach in a Single Dynamic-Core Storm-Scale Ensemble for Improved Spread and Reliability of QPF and Surface Variables	8/1/2017	7/31/2020	Regional
Jathar	NA17OAR4310003	5301783	Modeling the Complex and Dynamic Physico-chemical Evolution of Primary and Secondary Organic Aerosol from Wildfire Smoke	7/1/2017	6/30/2020	Regional (Climate)
Maloney	NA18OAR4310268	5301337	An Open Framework for Process-Oriented Diagnostics	8/1/2018	7/31/2021	Climate
Maloney	NA18OAR4310299	5302351	Understanding the role of the diurnal cycle and the mean state on the propagation of the intraseasonal variability over the Maritime Continent	9/1/2018	8/31/2021	Climate
Musgrave	NA19OAR0220086	5310505	Accelerate Improvements in National Hurricane Center Forecast Techniques - Statistical Techniques and Advanced Model Diagnostic Tools	7/1/2019	6/30/2021	Climate
Pierce	NA17OAR4310001	5301769	Aerosol Size Distribution and Composition Evolution during FIREX Activities: Closure Analyses and Climate Impacts	7/1/2017	6/30/2020	Regional (Climate)
Randall	NA19OAR4590155	5310508	S2S Forecasting of North American Precipitation	9/1/2019	8/31/2022	Climate

			Anomalies: Using Empirical Forecasts to Challenge Dynamical Forecasts			
Schumacher,A.	NA18NWS4680056	5302382	Using dynamically-based probabilistic forecast systems to improve the National Hurricane Center wind speed probability products	9/1/2018	8/31/2020	Regional
Schumacher,R.	NA16OAR4590238	5301472	Improving Probabilistic Forecasts of Extreme Rainfall through Intelligent Processing of High-resolution Ensemble Predictions	10/1/2016	9/30/2019	Climate
Schumacher,R.	NA18OAR4590308	5302381	Multi-disciplinary investigation of concurrent tornado and flash flood threats in landfalling tropical cyclones	10/1/2018	9/30/2020	Various
Schumacher,R.	NA18OAR4590378	5344504	Intelligent post-processing of convection-allowing model output to inform Weather Prediction Center outlooks and forecasts	9/1/2018	8/31/2020	Various
Strong	NA19OAR0220099	5310502	Diagnostics of Poor-skill events in FV3GFS and FV3-GEFS, Hurricane Supplemental, 4b-1-1b	7/1/2019	6/30/2022	Data Assim
Strong	NA19OAR0220101	5399012	Development of FSOI EFSOI for the Regional FV3 based Model Hurricane Supplemental 4b-1-2c	8/1/2019	7/31/2022	Data Assim
Wu	NA18NWS4680059	5302377	Enabling Cloud Condensate Cycling for All-Sky Radiance Assimilation in HWRF	9/1/2018	8/31/2020	Climate

PROJECT TITLE: Accelerate Improvements in National Hurricane Center Forecast Techniques – Statistical Techniques and Advanced Model Diagnostic Tools

PRINCIPAL INVESTIGATOR: Kate Musgrave

RESEARCH TEAM: Kate Musgrave, S. Stevenson, Galina Chirokova, Alan Brammer, J. Valancy, R. Zelinsky

NOAA TECHNICAL CONTACT: Mark DeMaria NOAA/NWS/NHC

NOAA RESEARCH TEAM: John Knaff NESDIS/STAR/RAMMB

PROJECT OBJECTIVES:

The major goals and objectives of this project fall into two categories: 1) to extend the National Hurricane Center (NHC) guidance suite, specifically the Wind Speed Probabilities (WSP) and the Statistical Hurricane Intensity Prediction Scheme (SHIPS) and the Logistic Growth Equation Model (LGEM) from five to seven days; and 2) to develop three-dimensional model visualization packages for post-season tropical cyclone analysis and for forecaster assessment of real-time tropical cyclones.

PROJECT ACCOMPLISHMENTS SUMMARY:

SHIPS/LGEM 7 day extension:

- SHIPS/LGEM developmental code has been generalized to 7 days
- Upgrades to SHIPS/LGEM real-time code are underway for 7 day option
- Code is being updated into operational WCOSS structure to allow for single developmental and real-time source code for future upgrades

WSP 7 day extension:

- WSP developmental code has been generalized for 7 day forecasts
- WSP main subroutine has been updated to support a 7 day forecast option
- WSP driver has been updated to support a 7 day option
- Additional updates to the WSP main subroutine have been incorporated and are being tested

3-D model visualization:

- Rachel Zelinsky, a post-doctoral fellow, was hired to complete work on the 3-D model visualization real-time and post-season analysis packages
- Vapor was selected as the software package for both real-time and post-season analysis
- Several test case animations of 3-D visualization of tropical cyclones have been produced with Vapor and presented to forecasters for feedback
    - A frame from a sample test case is shown in Figure 1, where it was determined that the time between frames is critical, as a too long period (for example 3 hours) between forecast times is too long to produce a coherent animation.

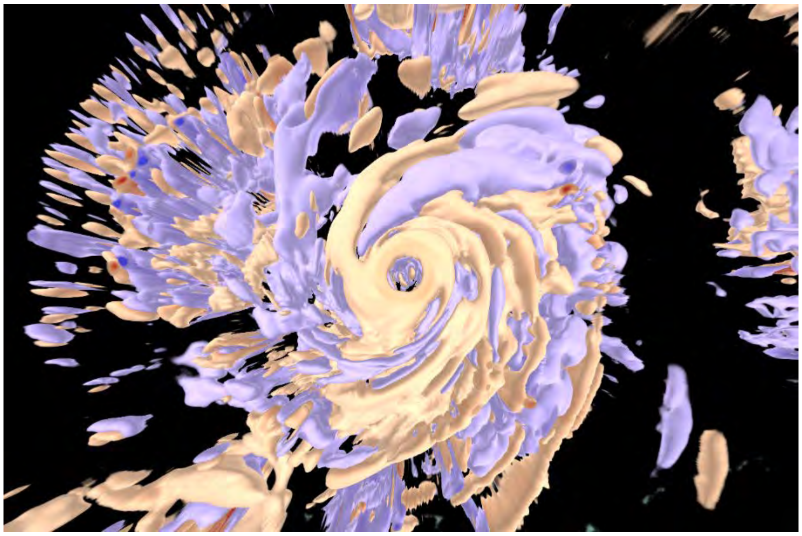


Figure 1. Single frame depicting the vertical velocity in Hurricane Dorian (2019) from the Hurricane Weather Research and Forecasting (HWRF) model.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: An Open Framework for Process-Oriented Diagnostics

PRINCIPAL INVESTIGATOR: Eric D. Maloney

RESEARCH TEAM: Hien Bui, Kai-Chih Tseng

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

[A] Develop an application Programming Interface (API) for process-oriented diagnostics to be applied to climate models

[B] Develop new process-oriented diagnostics related to convection and the moist static energy budget for entrainment into the API listed in [A]

PROJECT ACCOMPLISHMENTS SUMMARY:

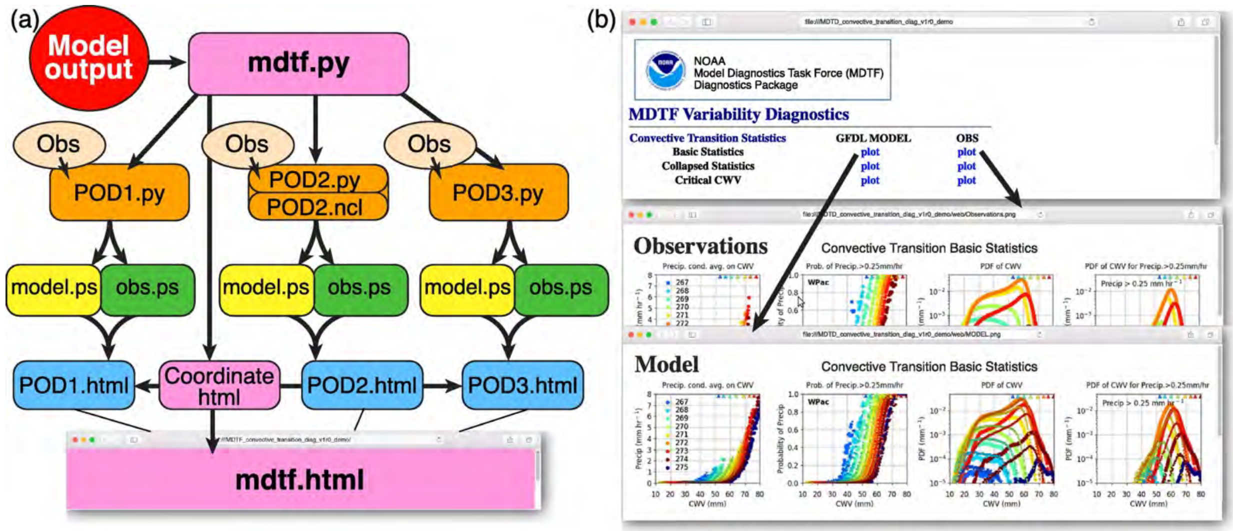


Figure 1. Schematic of MDTF PODs framework (mdtf.py). (a) Workflow under the API. The model output is that of a candidate version that the development team wants to compare to observations under the various diagnostics. The observations for each POD are supplied in analyzed form within the module. (b) Example web page (edited for brevity and clarity) for one POD, described in the "Convective transition statistics" subsection.

[A] *A framework for process-oriented evaluation of climate and weather forecasting models.* Realistic climate and weather prediction models are necessary to produce confidence in projections of future climate over many decades and predictions for days to seasons. These models must be physically justified and validated for multiple weather and climate processes. A key opportunity to accelerate model improvement is greater incorporation of process-oriented diagnostics (PODs) into standard packages that can be applied during the model development process, allowing the application of diagnostics to be repeatable across multiple model versions and used as a benchmark for model improvement. A POD characterizes a specific physical process or emergent behavior that is related to the ability to simulate an observed phenomenon. This paper describes the outcomes of activities by the Model Diagnostics Task Force (MDTF) under the NOAA Climate Program Office (CPO) Modeling, Analysis, Predictions and Projections (MAPP) program to promote development of PODs and their application to climate and weather prediction models. MDTF and modeling center perspectives on the need for expanded process-oriented diagnosis of models are presented. Multiple PODs developed by the MDTF are summarized, and an open-source software framework developed by the MDTF to aid application of PODs to centers' model development is presented in the context of other relevant community activities (**Figure 1**). The paper closes by discussing paths forward for the MDTF effort and for community process-oriented diagnosis. Maloney et al. (2019)

[B] *Convective Transition Statistics over Tropical Oceans for Climate Model Diagnostics: GCM Evaluation* To assess deep convective parameterizations in a variety of GCMs and examine the fast-time-scale convective transition, a set of statistics characterizing the pickup of precipitation as a function of column water vapor (CWV), PDFs and joint PDFs of CWV and precipitation, and the dependence of the moisture–precipitation relation on tropospheric temperature is evaluated using the hourly output of two versions of the GFDL Atmospheric Model, version 4 (AM4), NCAR CAM5 and superparameterized CAM (SPCAM). The 6-hourly output from the MJO Task Force (MJOTF)/GEWEX Atmospheric System Study (GASS) project is also analyzed. Contrasting statistics produced from individual models that primarily differ in representations of moist convection suggest that convective transition statistics can substantially distinguish differences in convective representation and its interaction with the large-scale flow, while models that differ only in spatial–temporal resolution, microphysics, or ocean–atmosphere coupling result in similar statistics. Most of the models simulate some version of the observed sharp increase in precipitation as CWV exceeds a critical value, as well as that convective onset occurs at higher CWV but at lower column RH as temperature increases. While some models quantitatively capture these observed features and associated probability distributions, considerable intermodel spread and departures from observations in various aspects of the precipitation–CWV relationship are noted. For instance, in many of the models, the transition from the low-CWV, nonprecipitating regime to the moist regime for CWV around and above critical is less abrupt than in observations. Additionally, some models overproduce drizzle at low CWV, and some require CWV higher than observed for strong precipitation. For many of the models, it is particularly challenging to simulate the probability distributions of CWV at high temperature. Kuo et al. (2020)

[B] *MJO teleconnections over the PNA region in climate models. Part I: Performance- and process-based skill metrics.* We propose a set of MJO teleconnection diagnostics that enables an objective evaluation of model simulations, a fair model-to-model comparison, and a consistent tracking of model improvement. Various skill metrics are derived from teleconnection diagnostics including five performance-based metrics that characterize the pattern, amplitude, east–west position, persistence, and consistency of MJO teleconnections and additional two process-oriented metrics that are designed to characterize the location and intensity of the anomalous Rossby wave source (RWS). The proposed teleconnection skill metrics are used to compare the characteristics of boreal winter MJO teleconnections (500-hPa geopotential height anomaly) over the Pacific–North America (PNA) region in 29 global climate models (GCMs). The results show that current GCMs generally produce MJO teleconnections that are stronger, more persistent, and extend too far to the east when compared to those observed in reanalysis. In general, models simulate more realistic teleconnection patterns when the MJO is in phases 2–3 or phases 7–8, which are characterized by a dipole convection pattern over the Indian Ocean and western to central Pacific. The higher model skill for phases 2, 7, and 8 may be due to these phases producing more consistent teleconnection patterns between individual MJO events than other phases, although the consistency is lower in most models than observed. Models that simulate realistic RWS patterns better reproduce MJO teleconnection patterns. Wang et al. (2020)

[B] *The MJO and changes in basic state due to climate change:* Recent studies have shown that Madden-Julian oscillation (MJO) precipitation anomaly amplitude tends to increase while associated circulations weaken at the end of 21st century in Coupled Model Intercomparison Project phase 5 models under Representative Concentration Pathway 8.5. Transient changes of MJO characteristics earlier in the 21st century have received less attention. In this study, changes of MJO precipitation and circulation amplitude during these interim time periods under Representative Concentration Pathway 8.5 are examined in Coupled Model Intercomparison Project phase 5 models. Multimodel mean changes in MJO precipitation and circulation amplitude are not individually detectable in the early and middle 21st century relative to the historical period (1986–2005). However, robust multimodel mean decreases in the ratio of MJO wind to precipitation anomalies occur even early in the 21st century. This decreased ratio is explained by increasingly large tropical static stability as the climate warms, which under weak temperature gradient balance mandates that a diabatic heating anomaly is balanced by an increasingly weaker circulation anomaly. These results suggest the robustness of weak temperature gradient theory for explaining MJO dynamics, not only in an equilibrium climate but also in the transient response. Bui and Maloney (2019 a,b).

[B] *The consistency of MJO teleconnection patterns on interannual timescales* The Madden-Julian Oscillation (MJO) excites strong variations in extratropical geopotential heights which modulate extratropical weather, making the MJO an important predictability source on subseasonal to seasonal timescales (S2S). Previous research demonstrates a strong similarity of teleconnection patterns across MJO events for certain MJO phases (i.e. pattern consistency) and increased model ensemble agreement during these phases that is beneficial for extended numerical weather forecasts. However, the MJO's ability to modulate extratropical weather varies greatly on interannual timescales, which brings extra uncertainty in leveraging the MJO for S2S prediction. Few studies have investigated the mechanisms responsible for variations in the consistency of MJO tropical-extratropical teleconnections on interannual timescales. This study uses reanalysis data, ensemble simulations of a linear baroclinic model, and a Rossby wave ray tracing algorithm to demonstrate that two mechanisms largely determine the interannual variability of MJO teleconnection consistency. First, the meridional shift of stationary Rossby wave ray paths indicate increases (decreases) in the MJO's extratropical modulation during La Niña (El Niño) years. Second, a previous study proposed that the constructive interference of Rossby wave signals caused by a dipole Rossby wave source pattern across the subtropical jet during certain MJO phases produces a consistent MJO teleconnection. However, this dipole feature is less clear in both El Niño and La Niña years due to the extension and contraction of MJO convection, respectively, which would decrease the MJO's influence in the extratropics. Hence, considering the joint influence of the basic state and MJO forcing, this study suggests a diminished potential to leverage the MJO for S2S prediction in El Niño years. Tseng et al. (2020)

PROJECT PUBLICATIONS:

Maloney, E. D., A. Gettelman, Y. Ming, J. D. Neelin, D. Barrie, A. Mariotti, C.-C. Chen, D. R. B. Coleman, Y.-H. Kuo, B. Singh, H. Annamalai, A. Berg, J. F. Booth, S. J. Camargo, A. Dai, A. Gonzalez, J. Hafner, X. Jiang, X. Jing, D. Kim, A. Kumar, Y. Moon, C. M. Naud, A. H. Sobel, K. Suzuki, F. Wang, J. Wang, A. A. Wing, X. Xu, and Ming Zhao, 2019: Process-oriented evaluation of climate and weather forecasting models. *Bull. Amer. Meteor. Soc.*, **100**, 1665–1686.

Bui, H. X., and E. D. Maloney, 2019a: Transient response of MJO precipitation and circulation to greenhouse gas forcing. *Geophys. Res. Lett.*, **46**, 13546-13555.

Bui, H. X., and E. D. Maloney, 2019b: Mechanisms for global warming impacts on Madden-Julian Oscillation precipitation amplitude. *J. Climate*, **32**, 6961-6975.

Kuo, Y.-H., J. D. Neelin, C.-C. Chen, W.-T. Chen, L. Donner, A. Gettelman, X. Jiang, K.-T. Kuo, E. Maloney, C. Mechoso, Y. Ming, K. Schiro, C. Seman, C.-M. Wu, and M. Zhao, 2020: Convective transition statistics over tropical oceans for climate model diagnostics: GCM evaluation. *J. Atmos. Sci.*, **77**, 379-403.

Tseng, K.-C., E. Maloney, and E. A. Barnes, 2020: The consistency of MJO teleconnection patterns on interannual timescales. *J. Climate*, in press.

Wang, J., H. Kim, D. Kim, S. A. Henderson, C. Stan, and E. D. Maloney, 2020: MJO teleconnections over the PNA region in climate models. Part I: Performance- and process-based skill metrics. *J. Climate*, **33**, 1051–1067.

PROJECT PRESENTATIONS/CONFERENCES:

Maloney, E., A. Adames, and H. Bui, 2019: How Will the Madden-Julian Oscillation Change in a Warmer Climate? Abstract EGU2019-4425 presented at the *2019 EGU General Assembly*, 7-12 April, 2019, Vienna, Austria.

Maloney, E., A. Adames, and H. Bui, 2019: How Will the Madden-Julian Oscillation Change in a Warmer Climate? *U.S. CLIVAR Workshop on Atmospheric Convection and Air-Sea Interactions over the Tropical Oceans*, 7-9 May 2019, Boulder, CO.

Maloney, E., A. Adames, and H. Bui, 2019: How Will the Madden-Julian Oscillation Change in a Warmer Climate? *AMOS Annual Meeting 2019 and the International Conference on Tropical Meteorology and Oceanography*, 11-14 June 2019, Darwin Convention Centre, Australia.

Tseng, K.-C., E. D. Maloney, and E. A. Barnes, 2020: The Consistency of MJO Teleconnection Patterns on Interannual Time Scales. *2020 AMS Annual Meeting*, 12-16 January, 2020, Boston, Massachusetts.

14th NOAA Climate and Global Change Postdoctoral Fellowship Summer Institute, Steamboat Springs, CO, July 14 - 18, 2019, "Recent Progress on Tropical-Extratropical Interactions: Current and Future Climate" (invited).

ESMEI REU research seminar, Department of Atmospheric Science, Colorado State University, July 23, 2019, Title: A survey of the tropics and recent field programs.

WMO MJO Task Force Meeting, July 31, Singapore. Talk: "Recent CSU work on MJO teleconnections and S2S prediction" (remote presentation).

PROJECT TITLE: CIRA Support for Tropical Cyclone Model Diagnostics and Product Development (HFIP)

PRINCIPAL INVESTIGATOR: Kate Musgrave

RESEARCH TEAM: Kate Musgrave, Chris Slocum, Galina Chirokova, J. Schwietert Livingston, Ben Trabing, Alan Brammer, J. Rogers, Ray Zehr

NOAA TECHNICAL CONTACT: D. Koch NOAA/NWS/OSTI

NOAA RESEARCH TEAM: John Knaff

PROJECT OBJECTIVES:

The National Oceanic and Atmospheric Administration (NOAA) initiated the Hurricane Forecast Improvement Project (HFIP) to reduce the errors in tropical cyclone track and intensity forecasts. This reduction will be accomplished through improved coupled ocean-atmosphere numerical hurricane models, better use of observations through advanced data assimilation techniques and ensemble forecasts. Model diagnostic techniques will also be developed to determine the sources of model errors and guide future improvements. The CIRA team performed tasks for six objectives that contribute to this HFIP effort. Details on these tasks are described in the next section. The CIRA HFIP activities directly address NOAA's Weather Ready Nation objectives. This research falls within the NOAA-defined CIRA thematic area of Satellite Algorithm Development.

PROJECT ACCOMPLISHMENTS SUMMARY:

SHIPS/LGEM/RII/SPICE Improvements:

- The satellite databases have been updated to include the 2019 season based off preliminary track information, and will be updated with the final best tracks once they become available.
- Upgrading the SPICE model is underway, starting with the diagnostics.
  - SPICE was evaluated over the 2019 season, with the East Pacific showing a dramatic difference between SPICE and the regional hurricane models HWRF and HMON (see Figure 1)

- Assessing changing the sea surface temperature (SST) from Reynolds Weekly/Daily SST to GeoPolar Blended SST in SHIPS/LGEM/RII is underway.

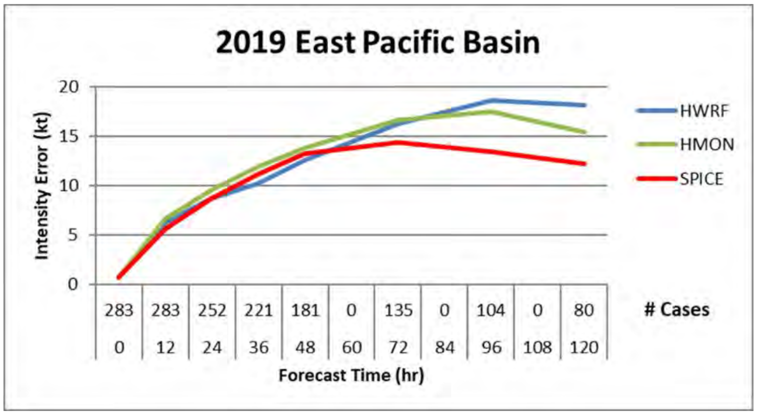


Figure 1. Preliminary verification the mean absolute error (in kt) of SPICE, HWRF, and HMON for the 2019 East Pacific hurricane season.

Dynamical Model Evaluation and Comparison with GOES-R Series Satellites:

- Exploring comparison of GOES-R series satellites with GFS-FV3 and HWRF synthetic satellite fields

Developing Statistical Products for Rapid Intensification Forecasting:

- RIPA was run globally in real-time starting July 2019
    - Graphics provided on TC Realtime website (https://rammb-data.cira.colostate.edu/tc_realtime/)
    - Text products delivered to demonstration website (http://rammb.cira.colostate.edu/research/tropical_cyclones/ripa/)
- Ran preliminary verification for the 2019 season (see Figure 2) – with just one season sample sizes are small but RIPA shows promising results, especially when all basins are combined to provide the largest sample.

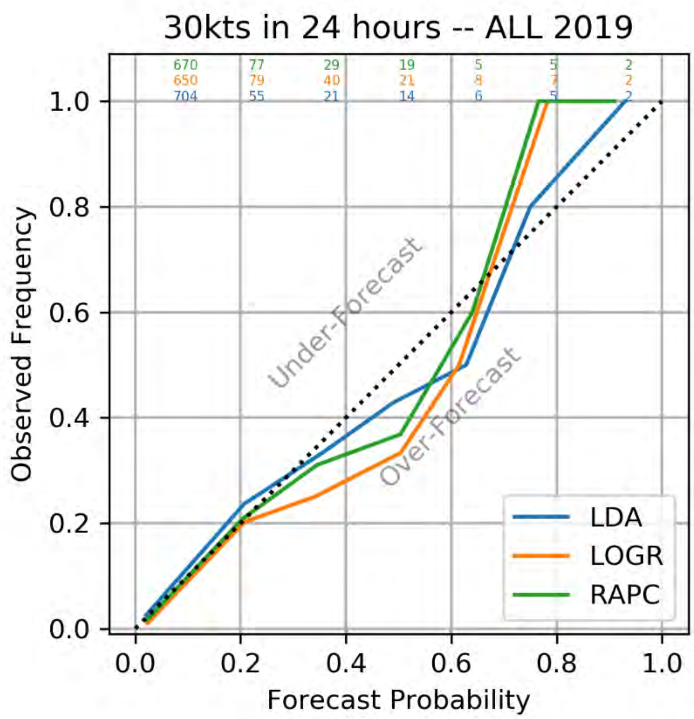


Figure 2. Reliability diagram for RI threshold of 30 kt in 24 hr for all global basins in July-December 2019. RIPA is RAPC - the consensus of the linear discriminant analysis (LDA) and logistic regression (LOGR) techniques.

Developing GIS and Graphical Products for the National Hurricane Center:

- Modified the land dataset used extensively by NHC; created a global version shown in Figure 3
- Upgraded the Be Ready By graphic
- Upgraded the Monte Carlo analysis graphic and code
- Upgraded the TCR graphic code for ArcGIS 10.7

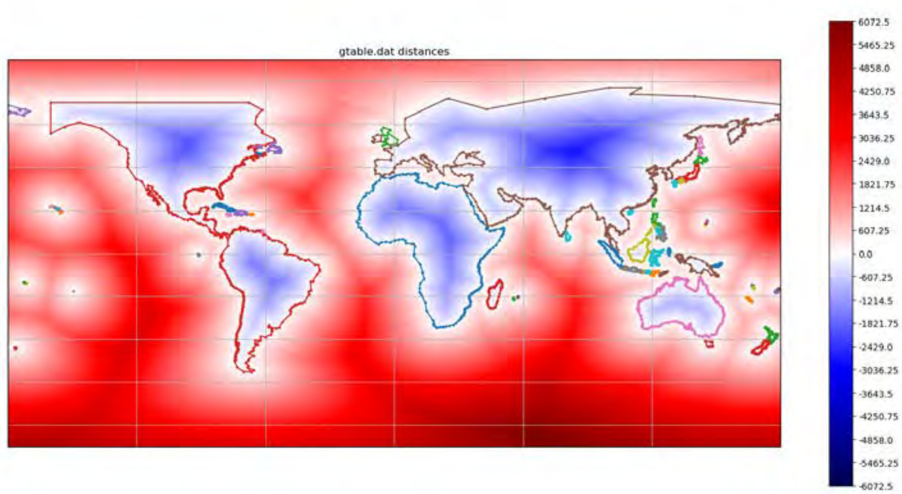


Figure 3. Global map of distance to land calculated from updated global land polygon file; each individual land mass is outlined in different-colored polygon.

Evaluating Model Guidance for the National Hurricane Center:

- Hired Ben Trabing to work at NHC on the evaluation and development of model-based guidance
- Evaluating the impact of aircraft reconnaissance (G-IV) dropsondes on the GEFS
- Evaluated the new experimental version of HMON, which improved versus the operational version in both track and intensity skill, and also improved the intensity consensus at almost all forecast times (see Figure 4)

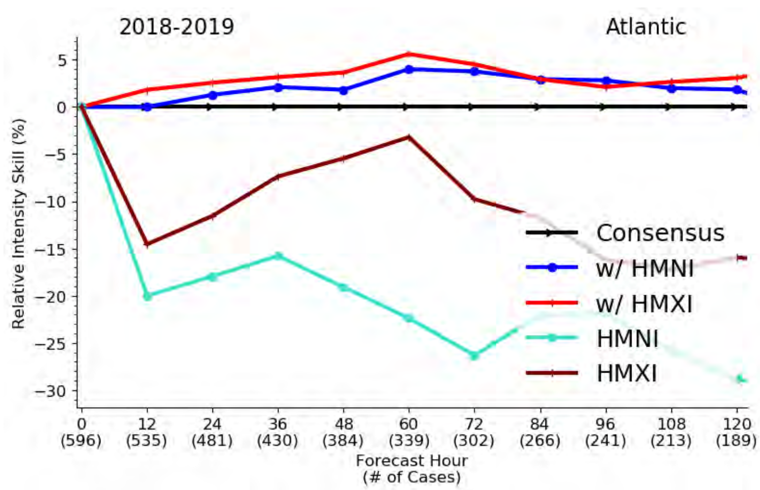


Figure 4. The intensity skill relative to the consensus for the current version of HMON (HMNI), the new experimental version (HMXI), and the impact of each on the consensus during the 2018-2019 Atlantic season.

Joint Hurricane Testbed Facilitation:

- Coordinated with six active JHT projects through the 2019 hurricane season, and began collaboration with three new JHT projects
- Deployed a real-time website to track and access all JHT (and related) real-time demonstrations (http://rammb.cira.colostate.edu/research/tropical_cyclones/jht/)
- Verified the real-time demonstrations and presented the results to NHC
- Developed a containerized environment to facilitate testing of implementation
- Transitioned FSU TCLOGG to pseudo-operations at NHC

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Brammer, A., K. Musgrave, M. DeMaria, 2020: Evaluation, Verification, and Deployment of Real-Time Experimental Tropical Cyclone Applications (Poster #802). AMS 100th Annual Meeting, January 2020, Boston, MA.

Brammer, A., 2019: JHT Real-time Demonstrations and Verification, NHC 2019, Miami, FL.

Halperin, D., R. Hart, and A. Brammer, 2020: Transitioning the Tropical Cyclone Logistic Guidance for Genesis (TCLOGG) Forecast Tool to the National Hurricane Center via the Joint Hurricane Testbed AMS Annual Meeting, January 2020, Boston, MA.

Musgrave, K. D., C. J. Slocum, M. DeMaria, J. A. Knaff, and B. McNoldy, 2019: Model diagnostics of tropical cyclone structure and environment (Invited Presentation). NOAA Global Systems Division Seminar, July 2019, Boulder, Colorado.

Musgrave, K. D., 2019: Rapid intensification guidance from an ensemble of statistical-dynamical models. Front Range Tropical Cyclone Workshop, April 2019, Boulder, Colorado.

Musgrave, K. D., J. A. Knaff, C. R. Sampson, and A. Brammer, 2020: A preliminary analysis of the RIPA and SPICE models for the 2019 hurricane season (Poster). AMS 100th Annual Meeting, January 2020, Boston, Massachusetts.

Trabing, B., 2019: NHC HMON 2020 Verification, HMON EMC CCB, 6 March 2020, Remote.

PROJECT TITLE: Collaborative Research: Assessing Oceanic Predictability Sources for MJO Propagation

PRINCIPAL INVESTIGATORS: Charlotte A. DeMott and Nicholas P. Klingaman

RESEARCH TEAM: Charlotte A. DeMott

NOAA TECHNICAL CONTACT: Annarite Mariotta

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

Objective 1: Evaluate S2S database ensemble prediction skill for three types of Madden–Julian Oscillation (MJO) events—strong propagating, weak propagating, and eastward-decaying—with regards to atmospheric and oceanic precursor signals.

Objective 2: Test the roles of specific oceanic feedback processes for MJO prediction skill using coupled models with a demonstrated ability to simulate the MJO.

Objective 3: Adapt a set of MJO air–sea interaction diagnostics developed by the PIs for analysis of climate simulations to hindcast simulations.

PROJECT ACCOMPLISHMENTS SUMMARY:

Objective 1:

- MJO forecast skill as a function of ocean initial state was evaluated using data from the five S2S database forecast models. We compared MJO forecast skill for the top and bottom quartile of initial sea surface temperature (SST) patterns. We found that MJO forecast skill was significantly higher during the first 1-7 days for the top SST quartile forecasts versus the bottom SST quartile forecasts. This finding suggests that realistic ocean initialization contributes to improved MJO forecast skill.
- We examined the effect of Indian Ocean SST variability on MJO amplitude. Intraseasonal (20-100 day) SST variability in the Indian Ocean is dominated by a zonal band of SST perturbations that alternate between warm and cold phases. Observed MJO events that develop during the warm phase of this pattern develop statistically significant larger amplitudes than events developing during the cold phase of this pattern. Forecast models were not able to reproduce

this behavior (Figure 1). Current work is focused on understanding if the lack of skill is rooted in biases in atmospheric or oceanic model components.

- A manuscript describing these results is under preparation.

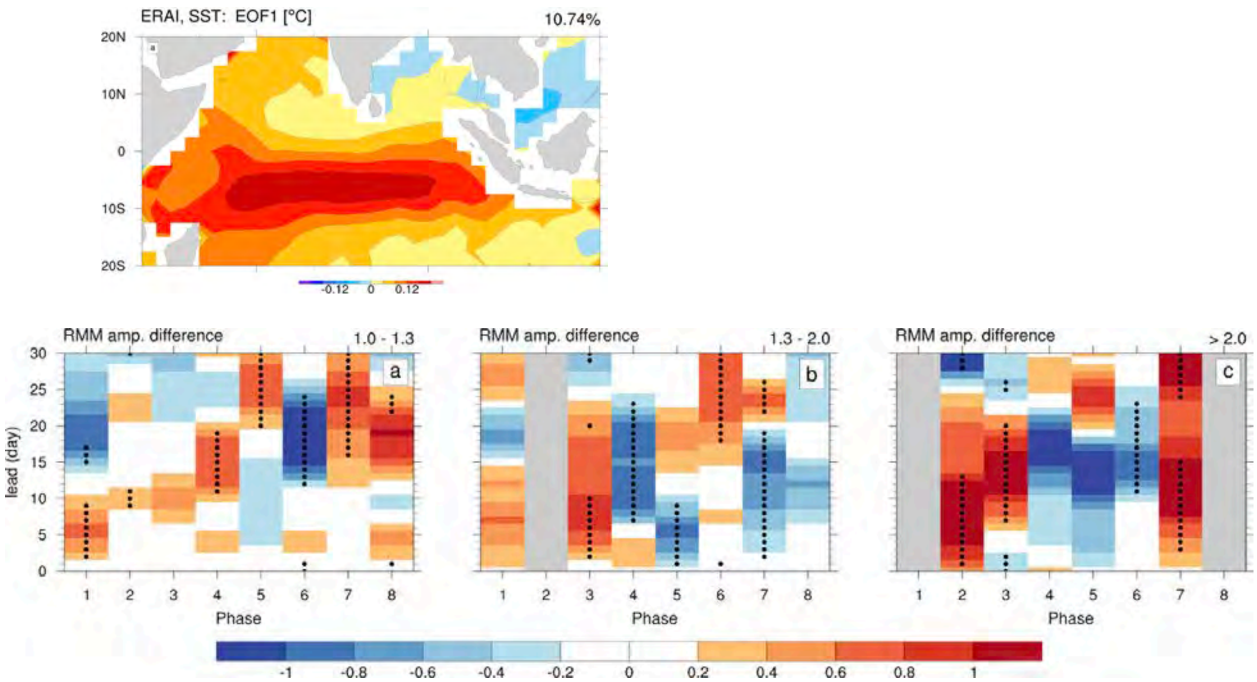


Figure 1: Top) Warm phase of the leading EOF of November-April intraseasonal (20-100 day) SST anomalies. The pattern alternates between warm and cold phases. Bottom) Differences in observed MJO amplitude for warm-minus-cold SST patterns as a function of phase and lead time for events for initially a) weak, b) moderate, and c) strong MJO events. Statistically significant (p=0.05) differences are marked with stippling. Gray stripes denote phases with no events.

Objective 2:

- Specific ocean feedback processes were tested with sensitivity tests using the Met Office Unified Model (MetUM) coupled to many columns of a 1-dimensional ocean mixing model. Various aspects of SST perturbations (i.e., temporal or spatial perturbations) were “hidden” while calculating either surface sensible or latent heat fluxes to test specific ocean feedback processes to the MJO: boundary layer destabilization by diurnal SST perturbations, boundary layer convergence forced by anomalous SST gradients, amplification of MJO convection by SST-modulated surface latent heat fluxes. We found a greater role for surface sensible heat fluxes on MJO forecast skill than previously assumed, suggesting an important role for SST perturbations in convective initiation.
- A manuscript describing these results is under preparation.

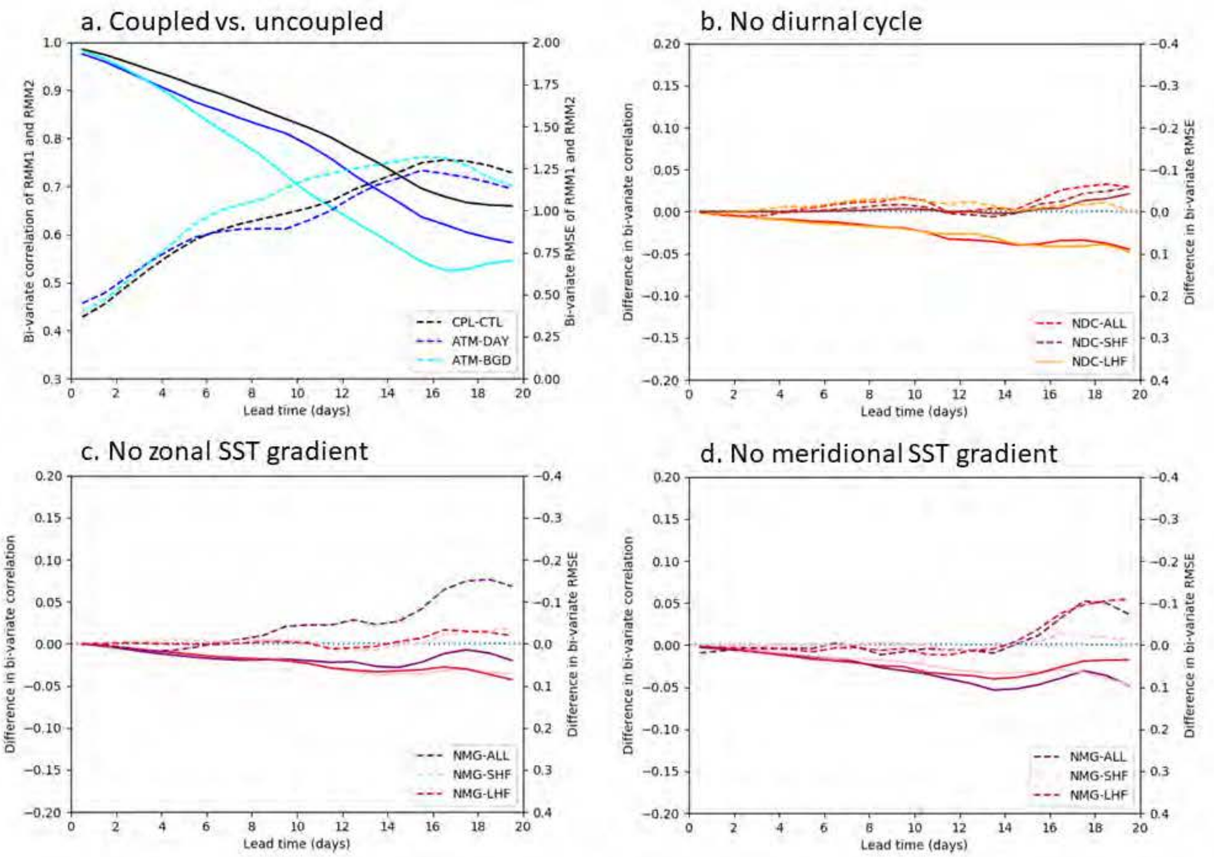


Figure 2: (a) RMM bivariate correlation (solid, left-hand axis) and RMSE (dashed, right-hand axis) from (black) coupled control, (blue) atmosphere-only with realistic persisted SST, (cyan) atmosphere-only with background (61-day running mean removed) persisted SST; (b-d) difference in RMM bivariate correlation and RMSE relative to coupled control for coupled simulations with (b) diurnal cycle of SST removed, (c) zonal gradient of SST removed and (d) meridional gradient of SST removed. In (b-d), the three experiments show the effects of removing the diurnal cycle or SST gradient from (-ALL) both SHF and LHF (-SHF) SHF only and (-LHF) LHF only.

PROJECT PUBLICATIONS:

DeMott, C. A., Wolding, B. O., Maloney, E. D., & Randall, D. A. (2018). Atmospheric mechanisms for MJO decay over the Maritime Continent. Journal of Geophysical Research: Atmospheres, 123. https://doi.org/10.1029/2017JD026979.

DeMott, C. A., Klingaman, N. P., Tseng, W.-L., Burt, M. A., Gao, Y., & Randall, D.A. (2019) The convection connection: How ocean feedbacks affect tropical mean moisture and MJO propagation. Journal of Geophysical Research Atmospheres, 124, 11,910–11,931. https://doi.org/10. 1029/2019JD031015.

Klingaman, N. P., & Demott, C. A. (2020). Mean-state biases and interannual variability affect perceived sensitivities of the Madden–Julian oscillation to air–sea coupling. Journal of Advances in Modeling Earth Systems, 12, e2019MS001799. https:// doi.org/10.1029/2019MS001799.

PROJECT PRESENTATIONS/CONFERENCES:

DeMott, C. A., N. P. Klingaman, and H. H. Hendon, 2019: Assessing SST forecast skill in the Warm Pool with the S2S database. Asia-Oceana Geophysical Society Annual Meeting, 29 July – 2 August, 2019, Singapore.

Klingaman, N. P., and C. A. DeMott, 2019: Why do atmosphere-ocean interactions improve predictions of the Madden-Julian oscillation? Asia-Oceana Geophysical Society Annual Meeting, 29 July – 2 August, 2019, Singapore.

DeMott, C. A., and N. P. Klingaman, 2020: Warm Pool SST Forecast Skill in S2S Models: Mean state drift versus anomaly patterns. American Meteorological Society Annual Meeting, 13-16 January, 2020, Boston, MA, USA.

PROJECT TITLE: Enabling Cloud Condensate Cycling for All-Sky Radiance Assimilation in HWRF

PRINCIPAL INVESTIGATORS: Ting-Chi Wu

RESEARCH TEAM: Lewis Grasso: Milija Zupanski

NOAA TECHNICAL CONTACT: Christopher Hedge

NOAA RESEARCH TEAM: Avichal Mehra, Qingfu Liu, Jason Sippel, Henry Winterbottom

PROJECT OBJECTIVE:

One main goal of the proposed research aims to improve hurricane forecasts by creating an improved initial state via enabling cloud condensate cycling in the HWRF system in order to facilitate the assimilation of all-sky satellite radiances.

PROJECT ACCOMPLISHMENTS SUMMARY:

1. User account on NOAA supercomputers (which includes Jet and Hera) for PI Ting-Chi Wu has been de-activated due to the delay in Foreign National paperwork since July 2019. User account access to the project allocation “cloudda” on Jet for Co-PI Milija Zupanski is still active as of today, and user account access to the project allocation “cloudda” on Jet for Co-PI Lewis Grass was approved and has been active since December 2019.
2. A seminar by Dr. Evan Kalina, who is with NOAA/EMC/HWRF and Developmental Testbed Center (DTC), was hosted by PI Ting-Chi Wu. During Dr. Kalina’s visit, a new HWRF branch named *icda_dev_cira* was created, with Dr. Kalina’s assistance, in order to facilitate the planned modifications to the model for enabling cloud condensate cycling.
3. In addition to a new branch of HWRF, a new branch of GSI also named *icda_dev_cira* was also created to facilitate the assimilation of all-sky radiance. Since the creation of a new GSI branch, code developments regarding all-sky radiance assimilation specific to HWRF have been committed to the *icda_dev_cira* branch via the Vlab Git functionalities. Figure 1 summarizes the code modifications to GSI within the *icda_dev_cira* branch for facilitating all-sky radiance assimilation with HWRF. As of today, users with access to NOAA Vlab Git repository can check out the latest *icda_dev_cira* branch to use with HWRF.
4. As a result of NOAA de-activating the PI’s user account on NOAA supercomputers, her time during this reporting period has been devoted to advise both Co-PIs on this project. As Milija already had access to Jet, the HWRF code, and the GSI code, the PI’s time advising Milija was

minimal. In sharp contrast, Lewis did not have neither the HWRF code nor the GSI code. A significant amount of the PI's time was spent on helping Lewis acquire the HWRF and GSI code, install the HWRF system, and monitor the progress of a two-cycled HWRF run on Jet.

5. A case study, Hurricane Irma (2017), was selected to perform two HWRF-GSI experiments: 1) Baseline experiment: run HWRF with default GSI for data assimilation (i.e., clear-sky) and 2) All-Sky experiment: run HWRF with *icda_cira_dev* branch of GSI for data assimilation (i.e., all-sky). For both experiments, only a two-cycled run that begins at 12 UTC August 30 and ends at 18 UTC August 30 were used, as a first step. Results from these two experiments are summarized in Figure 2.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Team members (PI Ting-Chi Wu and Co-PI Lewis Grasso) remotely presented the progress of this project during the 2019 HFIP Annual Review meeting, which was held on November 4-6, 2019, in Miami, Florida. During the meeting, results from the two experiments (Baseline and All-Sky) were presented (Figure 2).

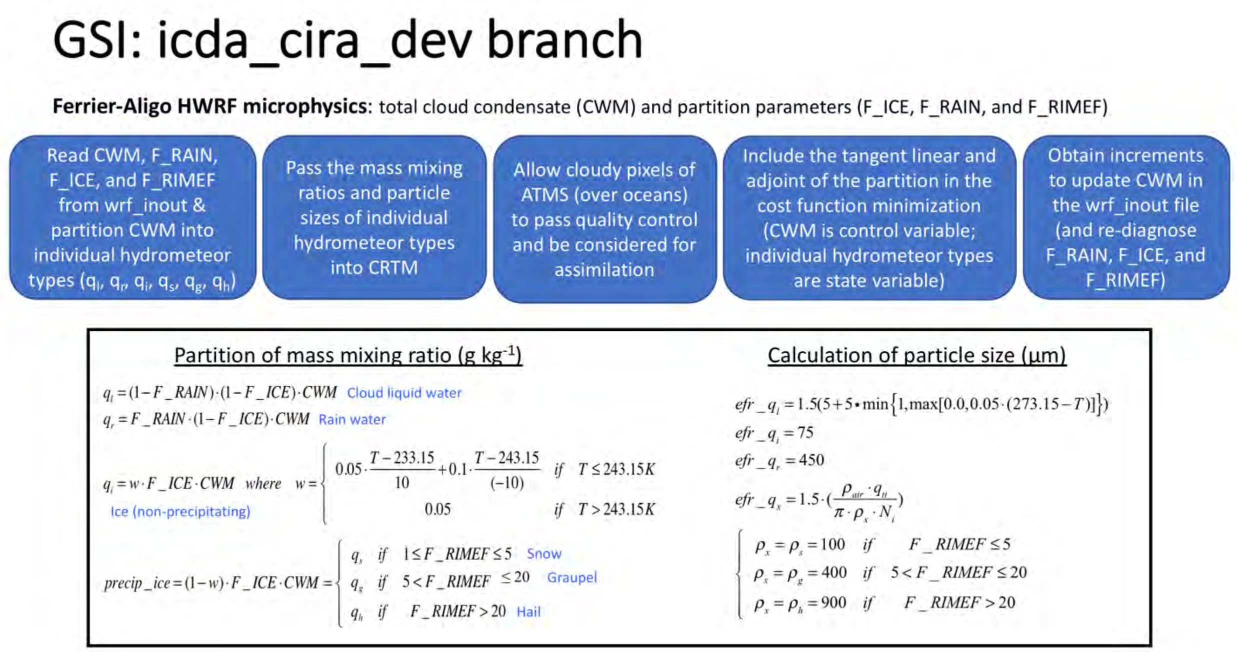


Figure 1. A schematic diagram that describe the relevant code modifications made to the icda_dev_cira branch of GSI in order to facilitate the capability to assimilate all-sky radiances with HWRF.

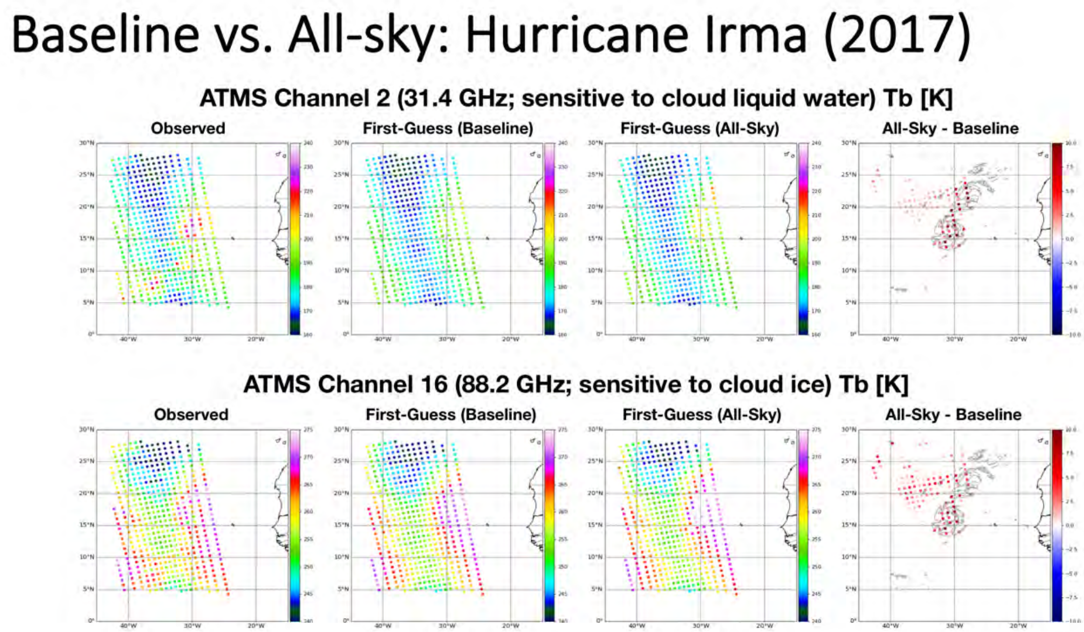


Figure 2. Observed ATMS brightness temperatures (first column), first-guess ATMS brightness temperatures from the Baseline experiment (second column), first-guess ATMS brightness temperatures from the All-Sky experiment (third column) for channel 2 (31.4 GHz) (top) and channel 16 (88.2 GHz) (bottom). The corresponding total column cloud condensate (g/g) (rightmost column) from the Baseline experiment (top) and the All-Sky experiment (bottom).

PROJECT TITLE: Forecasting North Pacific Blocking and Atmospheric River Probabilities: Sensitivity to Model Physics and the MJO

PRINCIPAL INVESTIGATORS: Elizabeth Barnes, Eric Maloney

RESEARCH TEAM: Kai-Chih Tseng, Wei-Ting Hsiao

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

A. Quantification of the predictability and prediction skill of North Pacific blocking and atmospheric river probabilities through knowledge of the MJO.
B. Assessment of the sensitivity of forecast skill to MJO skill and model setup: model physics, model resolution and forecast lead time.
C. Deliver a database of extreme events (i.e. atmospheric rivers and blocking) from the reanalysis and hindcast models
D. Deliver statistical forecast models of extremes (i.e. atmospheric rivers and blocking)

The PIs also have primary goals related to leadership of the MAPP S2S Task Force:

E. provide scientific leadership to the Task Force (PI Barnes is the Lead of the Task Force) by leading scientific papers, reports and special collections, organizing meetings and meeting sessions, leading teleconferences, facilitating collaboration across the Task Force.
F. linking to international efforts on advancing S2S prediction

PROJECT ACCOMPLISHMENTS SUMMARY:

The past fiscal year is year 4 of the project and includes a no-cost extension of the original three-year grant. Below is a list of activities and accomplishments only over the past year, organized by project objective.

- [A, B, D, E, F] Writing and publication of Mariotti et al. (2019) on forecasts of opportunity
- [A] Publication of McGraw et al. (2019) on the response of moisture transport associated with atmospheric rivers to sea ice loss
- [A,B] Publication of Jenney et al. (2019) on a metric for quantifying remote MJO teleconnection sensivity
- [A,B,D] Publication of Stone et al. (2019) on the prediction of Northern Hemisphere temperatures using stratospheric ozone information
- [A,B] Publication of Gonzales et al. (2019) on trends in atmospheric river temperatures along the U.S. West Coast
- [A,B] Manuscript under review on assessing MJO teleconnections under varying QBO states in observations and CESM2-WACCM
    - o Toms, B. A., E. A. Barnes, E. D. Maloney, and S. C. van den Heever: The Global Teleconnection Signature of the Madden-Julian Oscillation and its Modulation by the Quasi-Biennial Oscillation, *Journal of Geophysical Research: Atmospheres, under review*
- [E,F] Completion of the JGR/GRL Special Collection on S2S Prediction, and publication of the collection summary:
    - o Lang, Andrea, Kathleen Pegion and Elizabeth A. Barnes, 2020: Bridging Weather and Climate: Subseasonal-to-Seasonal (S2S) Prediction, Journal of Geophysical Research - Atmospheres, doi: https://doi.org/10.1029/2019JD031833.
- [A,B] Publication of Tseng et al. (2019) on the consistency of MJO teleconnections on interannual timescales.
- [A,B] Publication of Tseng et al. (2019) on the importance of past MJO activity in driving future midlatitude weather variability.
- [A,B,D] Publication of Jenney et al. (2019) on the seasonality and regionality of MJO impacts on North American temperatures.
- [A,B] Submission of Tseng et al. (2019) on MJO teleconnection variability in CMIP5 models
    - o Tseng Kai-Chih, Elizabeth A. Barnes and Eric D. Maloney: The important role of the MJO for extratropical variability in observations and the CMIP5 climate models, JGR-Atmospheres, (under review).
- [A,B] Submission of Mayer et al. (2019) on S2S prediction skill in operational forecast models following active QBO-MJO states
    - o Mayer, Kirsten J. and Elizabeth A. Barnes: Subseasonal Midlatitude Prediction Skill Following QBO-MJO Activity, Weather and Climate Dynamics, under review as interactive public discussion at https://www.weather-clim-dynam-discuss.net/wcd-2019-13/
- [A,B,D] Submission of Nardi et al. (2019) on statistical forecast models for predicting rainfall at S2S leads using the MJO and QBO
    - o Nardi, Kyle M., Cory F. Baggett, Elizabeth A. Barnes, Eric D. Maloney, Daniel S. Harnos, and Laura M. Ciasto: Skillful all-season S2S prediction of U.S. precipitation using the MJO and QBO, Weather and Forecasting, (under review).
- [F] Publication of Anderson et al. (2019) on the future of climate epidemiology and how skillful S2S forecasts could play a role.

- [E,F] PI Barnes is part of the organizing committee for the NCAR ASP S2S Summer School to be held in July 2020.
- [E,F] PI Barnes and the other Task Force leads continue to organize and facilitate monthly telecons across the Task Force. These telecons have focused on science results across the Task Force, and average 25 participants per call.

[D] Web Application:
We developed a web application for visualizing predictions of weather anomalies at S2S leads using our empirical model based on the MJO, QBO, and ENSO. Weather variables include: precipitation, atmospheric rivers, integrated water vapor transport and surface temperature. The we application can be accessed here: http://barnes.atmos.colostate.edu/S2SPredictionModel/

PROJECT PUBLICATIONS:

This list of publications is over the entirety of the project.

Mariotti, Annarita, Elizabeth A. Barnes, Edmund Kar-Man Chang, Andrea Lang, Paul A. Dirmeyer, Kathy Pegion, Daniel Barrie, and Cory Baggett, 2019: Bridging the Weather-to-Climate Prediction Gap. EOS, https://doi.org/10.1029/2019EO115819.

Baggett, Cory F. , Kyle M. Nardi, Samuel J. Childs, Samantha N. Zito, Elizabeth A. Barnes, Eric D. Maloney, 2018: Skillful 5 Week Forecasts of Tornado and Hail Activity. Journal of Geophysical Research: Atmospheres.

Tseng, Kai-Chih, Eric Maloney and Elizabeth Barnes, 2018: The consistency of MJO teleconnection patterns: an explanation using linear Rossby wave theory. Journal of Climate, https://doi.org/10.1175/JCLI-D-18-0211.1.

Baggett, C. F., E. A. Barnes, E. D. Maloney, and B. D. Mundhenk, 2017: Advancing atmospheric river forecasts into subseasonal-to-seasonal time scales. Geophys. Res. Lett., 44, 2017GL074434.

Henderson, S. A., and E. D. Maloney, 2018: The impact of the Madden-Julian Oscillation on high-latitude winter blocking during El Niño-Southern oscillation events. J. Climate, 31, 5293–5318.

Mundhenk, B. D., E. A. Barnes, E. D. Maloney, and C. F. Baggett, 2018: Skillful empirical subseasonal prediction of landfalling atmospheric river activity using the Madden–Julian oscillation and quasi-biennial oscillation. npj Climate and Atmospheric Science, 1, 7.

Tseng, K.-C., E. A. Barnes, and E. D. Maloney, 2018: Prediction of the Midlatitude Response to Strong Madden-Julian Oscillation Events on S2S Time Scales. Geophys. Res. Lett., 45, 2017GL075734.

Mariotti, Annarita; Cory Baggett; Elizabeth Barnes; Emily Becker; Amy Butler; Dan C Collins; Paul A Dirmeyer; Laura Ferranti; Nathaniel C. Johnson; Jeanine Jones; Ben P. Kirtman; Andrea L. Lang; Andrea Molod; Matt Newman; Andrew W. Robertson; Siegfried Schubert; Duane E. Waliser, 2019: Windows of Opportunity for Skillful Forecasts S2S and Beyond, BAMS.

Lang, Andrea, Kathleen Pegion and Elizabeth A. Barnes, 2020: Bridging Weather and Climate: Subseasonal-to-Seasonal (S2S) Prediction, Journal of Geophysical Research - Atmospheres, doi: https://doi.org/10.1029/2019JD031833.

Tseng, Kai-Chih, Elizabeth. A. Barnes and Eric D. Maloney, 2019: The importance of past MJO activity in determining the future state of the midlatitude circulation, Journal of Climate, https://doi.org/10.1175/JCLI-D-19-0512.1

Jenney, Andrea, Kyle Nardi, Elizabeth Barnes, and David Randall, 2019: The Seasonality and Regionality of MJO Impacts on North American Temperature, Geophysical Research Letters, https://doi.org/10.1029/2019GL083950.

Gonzales, K., D. Swain, K. Nardi, E. A. Barnes, and N. Diffenbaugh, 2019: Recent warming of landfalling atmospheric rivers along the west coast of the United States, Journal of Geophysical Research: Atmospheres, 10.1029/2018JD029860

Anderson, G. Brooke, Elizabeth A. Barnes, Francesca Dominici, and Michelle Bell, 2019: The future of climate epidemiology: Examples of key opportunities for advancing research on climate and health in the context of climate change, American Journal of Epidemiology, https://doi.org/10.1093/aje/kwz034.

Jenney, Andrea., D. Randall, E. Barnes: Quantifying regional sensitivities to periodic events, 2019: Application to the MJO. Journal of Geophysical Research: Atmospheres, https://doi.org/10.1029/2018JD029457.

Stone, Kane, S. Solomon, D. Kinnison, C. Baggett and E. Barnes, 2019: Prediction of Northern Hemisphere regional surface temperatures using stratospheric ozone information, https://doi.org/10.1029/2018JD029626.

Tseng, Kai-Chih, Eric D. Maloney and Elizabeth. A. Barnes, 2020: The consistency of MJO teleconnection patterns on interannual timescales, Journal of Climate.

McGraw, M.C., C. F. Baggett, C. Liu, and B.D. Mundhenk, 2019: Changes in Arctic moisture transport over the North Pacific associated with sea ice loss, Climate Dynamics, https://doi.org/10.1007/s00382-019-05011-9.

Nardi, Kyle M., Cory F. Baggett, Elizabeth A. Barnes, Eric D. Maloney, Daniel S. Harnos, and Laura M. Ciasto: Skillful all-season S2S prediction of U.S. precipitation using the MJO and QBO, Weather and Forecasting, (under review).

Toms, B. A., E. A. Barnes, E. D. Maloney, and S. C. van den Heever: The Global Teleconnection Signature of the Madden-Julian Oscillation and its Modulation by the Quasi-Biennial Oscillation, Journal of Geophysical Research: Atmospheres, (under review).

Tseng Kai-Chih, Elizabeth A. Barnes and Eric D. Maloney: The important role of the MJO for extratropical variability in observations and the CMIP5 climate models, JGR-Atmospheres, (under review).

Mayer, Kirsten J. and Elizabeth A. Barnes: Subseasonal Midlatitude Prediction Skill Following QBO-MJO Activity, Weather and Climate Dynamics, under review as interactive public discussion at https://www.weather-clim-dynam-discuss.net/wcd-2019-13/

PROJECT PRESENTATIONS/CONFERENCES:

Barnes, et al. Viewing Climate Signals through an AI Lens, Department of Atmospheric and Oceanic Sciences Seminar, UCLA [invited]. February 12, 2020.

Barnes, et al. Viewing Climate Signals through an AI Lens, invited speaker for 19th Conference for Artificial Intelligence for Environmental Science, AMS 2020, Boston, MA [invited]. January 14, 2020.

Barnes, et al. Viewing Forced Climate Patterns through an AI Lens, invited speaker and panel member at AGU Union Session Data Analytics and Machine Learning Innovation for Climate and Earth Surface Processes [invited]. December 11, 2019.

Barnes, et al. Viewing climate signals through an AI lens, invited visitor and speaker, Max Plank Institute [invited]. November 7, 2019.

Barnes, et al. Viewing climate signals through an AI lens, Distinguished Women of Environmental Systems Science invited speaker, ETH Zurich [invited]. November 4, 2019.

PROJECT TITLE: Identifying Drought-related Triggers and Impacts on Decision Calendars for the Ski Industry

PRINCIPAL INVESTIGATOR: Rebecca Bolinger

RESEARCH TEAM: Trevor Even, Natalie Ooi, Russ Schumacher

NOAA TECHNICAL CONTACT: Nancy Beller-Simms

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

1. Collection of information from ski areas
2. Identifying gaps where added information can be useful and usable
3. Delivery of information to decision makers

PROJECT ACCOMPLISHMENTS SUMMARY:

At the project start, the team met to discuss first steps and hiring a student. We hired Trevor who is in his final year of his PhD and has experience with interviewing farmers about drought impacts. With beginning questions drafted by Becky and Russ, Trevor and Natalie worked to develop the initial contact and interview process with ski area managers. Natalie developed a comprehensive list of ski contacts throughout the Intermountain West.

During January – February 2020, Natalie and Trevor conducted phone interviews with ski area managers. These interviews have been recorded and are currently being transcribed, verbatim, for further research and assessment.

During our last team meeting, we discussed some of the interview responses. Interview questions are seeking to gather information about how ski areas currently make decisions based on drought and climate, what climate data and information do they use, and what information do they need to improve decision making with respect to drought and climate. Some responses from ski areas have been that they primarily use weather information to make day-to-day decisions, there is varying amounts of trust in climate outlook products that are available, and they would appreciate if there was a “one-stop-shop” to find everything they need. For smaller resorts, there is a feeling that they don’t have the capacity to alter their decision-making, regardless of the information that is provided to them.

Also discussed at our last team meeting was next steps as we proceed. We will be going over the interview transcriptions, and with that information we will begin drafting a ski-based decision calendar and categorizing and prioritizing existing gaps.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Enhancing NIDIS drought monitoring and early warning in the Intermountain West

PRINCIPAL INVESTIGATOR: Rebecca Bolinger

RESEARCH TEAM: Rebecca Bolinger, Peter Goble, Julian Turner, Noah Newman, Henry Reges, Zach Schwalbe, Russ Schumacher

NOAA TECHNICAL CONTACT: Veva Deheza

NOAA RESEARCH TEAM: Elizabeth Weight, Kathryn Bevington

PROJECT OBJECTIVES:

1. Enhancing Engagement and Interaction: the primary goal of this objective is to increase the gathering of information through new and existing networks and partnerships in the Intermountain West.

2. Communication and Dissemination: with this objective, we are testing new and novel methods of communicating drought information to stakeholders and the public. We want to identify best practices for information delivery and increase the number of users who rely on our information.

3. Value Added Information and Products: In addition to providing climate data to our users, we seek to tailor products to specifically meet the needs of our various groups and stakeholders.

PROJECT ACCOMPLISHMENTS SUMMARY:

[Objective 1] As a result of our engagement with Utah partners during the 2018 drought, a Utah Drought Monitor Working Group formed in 2019. This group's goal is to develop and maintain their own in-state drought monitoring efforts, and we have regularly engaged with them in this effort to ensure success. Information gathered from Utah's meetings have been used to enhance our monitoring efforts, and we've expanded partnerships with various groups in the state.

We continue to promote CoCoRaHS Condition Monitoring as a way to enhance engagement with the user community and get information from local sources on the ground. Henry Reges also traveled throughout the Intermountain West to promote CoCoRaHS and our drought monitoring efforts in the region.

[Objective 2] We continue to provide drought updates and information via website, monthly webinars, through media interviews and on social media. In May 2019, Colorado became completely d-category free for the first time ever on the U.S. Drought Monitor, which we heavily publicized. Not only did it result in increased communication with media, our Facebook post about it was one of our largest ever posts (shared over 300 times and reaching over 30,000 people).

In 2019, we also created a drought products inventory. This inventory is a comprehensive list of all possible products that we are using (or not using) for drought monitoring that may pertain to drought and climate. We also identified possible gaps where information may exist that we are not using and don't know about. This report has been finalized and will be used to modify our current drought monitoring efforts and to provide recommendations to NIDIS and the drought community.

[Objective 3] Peter Goble worked on several agricultural-based products in 2019. These included added soil moisture monitoring on our CoAgMET stations. For 9 stations, we have daily soil moisture plots compared to a long-term average for the growing season. He's also worked on crop-specific drought demand mapping and a high impact evaporative stress map.

PROJECT PUBLICATIONS:

Goble, P. and Russ Schumacher, 2019. 2019: A Snow Year to Remember for Western Colorado. Colorado Water, Newsletter of the Water Center of Colorado State University, vol. 36, 3 (Aug), pp. 35-37.

Newman, N., 2019. The Evolution of Measuring Drought. Colorado Water, Newsletter of the Water Center of Colorado State University, vol. 36, 2 (Mar/Apr), pp. 22-24.

PROJECT PRESENTATIONS/CONFERENCES:

Rangeland Management Workshop – Cheyenne, WY - October 24, 2019
Climate and drought resources you can use - and how to use them
Presented by Becky Bolinger

Drought Amelioration Workshop - Boulder, CO - September 24, 2019
Drought Tools and Monitoring for the Intermountain West
Presented by Becky Bolinger

U.S. Drought Monitor Forum - September 19, 2019
Providing Crop-Specific Flash Drought Information
Presented by Peter Goble

U.S. Drought Monitor Forum - September 18, 2019
The Evolution and Impacts of the 2018 Four Corners Drought
Presented by Becky Bolinger

PROJECT TITLE: Identifying Varying Patterns of Combined Change over the 21st Century with Neural Networks

PRINCIPAL INVESTIGATORS: Elizabeth Barnes, Imme Ebert-Uphoff, Chuck Anderson

RESEARCH TEAM: Jamin Rader, Elizabeth Barnes, Imme Ebert-Uphoff and Chuck Anderson

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

Develop a state-of-the-art neural network architecture to detect forced time-varying combined patterns of change of impact-related earth system quantities.

Identify the combined patterns of change over the 21st Century, determine how they change over time, and quantify when these patterns will emerge from the background of climate noise within CMIP6.

Quantify the extent to which combined patterns of change have already emerged in observations.

PROJECT ACCOMPLISHMENTS SUMMARY:

The project start date was Sept. 1, and so, this report only contains activities since that date (6 months).

The PIs have successfully hired an outstanding postdoc (Zachary Labe) to begin on this project June 2020. Zack is a leading expert on climate variability and change, and he obtained a Data Science certificate from UC-Irvine during his graduate studies.

The PIs successfully hired a graduate student, Jamin Rader, to start on this project Sept. 2019. However, Jamin received a 4-year DOE fellowship and so is now fully funded. Jamin hopes to work on this project for his graduate studies, and has spent the past 6 months cleaning-up the code used for the initial prototype and learning the details of neural networks.

The PIs have successfully developed an ANN architecture that produces the year as a classification problem (rather than regression). This allows for the use of novel ANN visualization methods which convey the time evolving patterns of change. The authors are currently writing up these results for publication.

PROJECT PUBLICATIONS:

No scientific results have been published yet since the project has only been active for 6 months. However, the PIs are currently writing-up a manuscript for submission in spring 2020.

PROJECT PRESENTATIONS/CONFERENCES:

Barnes, et al. Viewing Climate Signals through an AI Lens, Department of Atmospheric and Oceanic Sciences Seminar, UCLA [invited]. February 12, 2020.

Barnes, et al. Viewing Climate Signals through an AI Lens, invited speaker for 19th Conference for Artificial Intelligence for Environmental Science, AMS 2020, Boston, MA [invited]. January 14, 2020.

Barnes, et al. Viewing Forced Climate Patterns through an AI Lens, invited speaker and panel member at AGU Union Session Data Analytics and Machine Learning Innovation for Climate and Earth Surface Processes [invited]. December 11, 2019.

Barnes, et al. Viewing climate signals through an AI lens, invited visitor and speaker, Max Plank Institute [invited]. November 7, 2019.

Barnes, et al. Viewing climate signals through an AI lens, Distinguished Women of Environmental Systems Science invited speaker, ETH Zurich [invited]. November 4, 2019.

PROJECT TITLE: Improving Probabilistic Forecasts of Extreme Rainfall through Intelligent Processing of High-resolution Ensemble Predictions

PRINCIPAL INVESTIGATOR: Russ Schumacher

RESEARCH TEAM: Gregory Herman, Aaron Hill

NOAA TECHNICAL CONTACT: Chandra Kondragunta

NOAA RESEARCH TEAM: Mark Klein, Jim Nelson (NOAA Weather Prediction Center)

PROJECT OBJECTIVES:

As outlined in the original proposal, the specific objectives of this project are as follows:

- Using this forecast system, identify the ensemble membership that optimizes the skill and reliability of probabilistic forecasts of extreme local rainfall. Some of this research has already been conducted and is outlined in greater detail below. This support will allow for continued fine-tuning of this analysis for different models and regions of the US.
- Evaluate a prototype of this forecast system in the Flash Flood and Intense Rainfall (FFaIR) experiment and in an operational environment at the Weather Prediction Center (WPC). FFaIR allows for robust evaluation of a forecast system by forecasters and researchers in a realistic real-time environment. Based on this evaluation, the system will be improved and prepared for evaluation in WPC operations.
- Implement an operational version of this forecast system at WPC. Assuming the evaluations are successful, we will work with WPC to implement an operational version of the forecast system after incorporating relevant feedback and suggestions.

PROJECT ACCOMPLISHMENTS SUMMARY:

The proposed work plan for tasks over the full period of performance is reproduced from the original proposal in the table below, and the final status of these tasks is given in the right-hand column.

Time	**Tasks and milestones**	**Accomplishments/completion**
Months 1-8 (Oct 2016-May 2017)	Prepare the forecast system for formal evaluation in the FFaIR experiment in the summer of 2017; fine-tune the code; work with HMT/WPC staff to provide real-time forecast files	**complete**
Months 9-10 (June-July 2017)	Participate in FFaIR, including evaluation of the forecast data	**complete**
Months 11-16 (August 2017-Jan 2018)	Make use of the feedback from FFaIR to make necessary improvements to the forecast system	**Complete**

Months 17-20 (Feb-May 2018)	Produce improved version of forecast system and provide to HMT/WPC for testing in FFaIR environment	**Complete**
Months 21-22 (June-July 2018)	Near-operational version will be evaluated again during FFaIR in 2018	**Complete**
Months 23-24 (Aug-Sep 2018)	Operational version will be implemented at WPC; manuscripts will be submitted/published	**Complete**

(Note that a one-year no-cost extension was granted to complete these tasks; the proposed timelines therefore do not exactly match the times of actual completion, but all tasks were completed by the completion of the grant.)

In this project, we developed, evaluated, revised, and finally implemented into operational use a probabilistic forecast system for excessive rainfall that is based on machine learning methods. This forecast system, known as Colorado State University-Machine Learning Probabilities (CSU-MLP), uses the global Reforecast-2 dataset (GEFS-R; Hamill et al. 2013), which has ensemble forecasts from a fixed version of the GFS model; and observed indicators of excessive rainfall such as average recurrence interval (ARI) exceedances from multiple gridded precipitation analyses, and flash flood reports. This information from an approximately 10-year historical period was used to train a machine learning model based on the random forest algorithm. Then, real-time GEFS forecasts are used, along with the trained ML model, to generate a probabilistic forecast of excessive rainfall on days 2 and 3. This product was evaluated, and has now been implemented into operations, as a "first guess" product for WPC forecasters when preparing their excessive rainfall outlooks (EROs) for days 2 and 3.

For the three years covered by the project, 2017-2019, our research team participated in the Flash Flood and Intense Rainfall (FFaIR) testbed experiment at WPC/HMT. We have also collaborated closely with many members of the WPC staff, which has yielded a beneficial set of iterations to produce a system that is most useful for operations.

During FFaIR, we provided real-time gridded versions of our forecast output in GRIB2 format, and the FFaIR participants provided quantitative and qualitative feedback on the forecast system, which allowed for upgrades to the system and improvements to the forecasts. In the 2017 FFaIR final report (http://www.wpc.ncep.noaa.gov/hmt/2017_FFaIR_final_report.pdf), the feedback regarding the product was very favorable, with a summary statement of "The **CSU Machine-Learning First Guess field** for the ERO showed great potential and was scored well by participants. It is recommended that the CSU developers work to reduce recurring biases and continue to refine the tool and reintroduce it into the testbed next year for further evaluation."

Based on this feedback, we worked to address several biases in the forecasts by incorporating additional precipitation datasets and by adjusting the thresholds for "excessive rainfall" in a couple of the regions. (This analysis led to an additional study of the precipitation proxies that best correlate to reports of flash flooding.) In the 2018 FFaIR experiment, the CSU-MLP product once again received positive reviews: "Based on positive feedback and the need for a Day 2/3 First Guess Field, WPC-HMT recommends both products be transitioned to operations. Adjustments to the ARI sensitivities are suggested to increase the probabilistic confidence along the Gulf Coast and Southeast United States and decrease the confidence in the upper plains, specifically Montana and the Dakotas." (from the 2018 FFaIR final report, https://www.wpc.ncep.noaa.gov/hmt/2018_FFaIR_final_report.pdf).

With the no-cost extension, we were able to make some further adjustments and transition a further improved final version of the day 2-3 forecast system in 2019. This final version has better-calibrated probabilities and reduced some of the remaining biases. Three different versions of the CSU-MLP system (versions 2017, 2018, and 2019) were installed on WPC operational computer systems and are now running operationally at WPC and are used by forecasters in their forecast process.

We also published multiple journal articles on the work supported by this project. Three of these articles were led by former CSU graduate student Greg Herman, and the fourth was a collaboration led by WPC researcher Mike Erickson. The articles on the CSU-MLP system have received considerable attention in the research and forecast community, considering the interest in applying machine learning techniques to weather prediction. These two articles have received a total of 17 citations in the ~1.5 years since publication, according to Web of Science.

PROJECT PUBLICATIONS:

Erickson, M.J., J.S. Kastman, B. Albright, S. Perfater, J.A. Nelson, R.S. Schumacher, and G.R. Herman, 2019: Verification results from the 2017 HMT-WPC Flash Flood and Intense Rainfall experiment. *Journal of Applied Meteorology and Climatology*, **58**, 2591–2604, https://doi.org/10.1175/JAMC-D-19-0097.1

Herman, G.R., and R.S. Schumacher, 2018: Flash flood verification: Pondering precipitation proxies. *Journal of Hydrometeorology*, **19**, 1753-1776, https://doi.org/10.1175/JHM-D-18-0092.1

Herman, G.R., and R.S. Schumacher, 2018: "Dendrology" in Numerical Weather Prediction: What random forests and logistic regression tell us about forecasting extreme precipitation. *Monthly Weather Review*, **146**, 1785-1812, https://doi.org/10.1175/MWR-D-17-0307.1

Herman, G.R., and R.S. Schumacher, 2018: Money doesn't grow on trees, but forecasts do: Forecasting extreme precipitation with random forests. *Monthly Weather Review*, **146**, 1571-1600, https://doi.org/10.1175/MWR-D-17-0250.1

PROJECT PRESENTATIONS/CONFERENCES:

Russ Schumacher: “Evaluation of a Machine-Learning Model for the Prediction of Heavy and Extreme Rainfall”, 34th Conference on Environmental Information Processing Technologies, American Meteorological Society, Austin, TX, January 2018.

Greg Herman: Advances in Using Random Forests to Forecast Heavy Precipitation and Flash Floods, 34th Conference on Environmental Information Processing Technologies, American Meteorological Society, Austin, TX, January 2018.

Russ Schumacher: “Evaluation of a Machine-Learning Model for the Prediction of Heavy and Extreme Rainfall”, 29th Conference on Weather Analysis and Forecasting, American Meteorological Society, Denver, CO, June 2018.

Greg Herman: “Verifying Flash Floods: Pondering Precipitation Proxies”, 29th Conference on Weather Analysis and Forecasting, American Meteorological Society, Denver, CO, June 2018.

Russ Schumacher: “Evaluation of a Machine-Learning Model for the Prediction of Heavy and Extreme Rainfall”, 2019 Hydrology Days, Colorado State University, Fort Collins, CO, March 2019

Russ Schumacher gave a presentation to Weather Prediction Center staff in July 2019, titled "Development and evaluation of the Colorado State University Machine Learning Probabilities system for excessive rainfall forecasting".

PROJECT TITLE: Investigating the Underlying Mechanisms and Predictability of the MJO - NAM Linkage in the NMME Phase-2 Models

PRINCIPAL INVESTIGATORS: Elizabeth Barnes, Jason Furtado

RESEARCH TEAM: Savini Samarasinghe, Imme Ebert-Uphoff and Elizabeth Barnes

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

- [A] Enhance our knowledge about the dynamical links between the MJO and the NAM by considering the modulating influence of the extratropical stratosphere
- [B] Evaluate these mechanisms of MJO-NH extratropical atmospheric teleconnections in the North American Multi-Model Ensemble Phase-2 (NMME-2) system
- [C] Connect and apply our findings and evaluations to predictions of atmospheric blocking and extreme weather events.

PROJECT ACCOMPLISHMENTS SUMMARY:

- [A,C] Publication of Barnes et al. (2019) in *JGR-Atmospheres* on the causal connections between the MJO and NAO via the stratosphere.
    - Barnes, Elizabeth, Savini Samarasinghe, Imme Ebert-Uphoff, and Jason Furtado, 2019: Tropospheric and stratospheric causal pathways between the MJO and NAO, Journal of Geophysical Research: Atmospheres, 10.1029/2019JD031024.

- [A,C] PI Barnes and her CSU team have continued to investigate the links between the MJO and NAO via the stratosphere in dynamical climate models. They have specifically focused on causal inference methods for this work and are currently writing up the results.

- All three objectives are being investigated by other members of the team while CSU PI Barnes supports these efforts.

PROJECT PUBLICATIONS:

Barnes, Elizabeth, Savini Samarasinghe, Imme Ebert-Uphoff, and Jason Furtado, 2019: Tropospheric and stratospheric causal pathways between the MJO and NAO, Journal of Geophysical Research: Atmospheres, 10.1029/2019JD031024.

PROJECT PRESENTATIONS/CONFERENCES:

Barnes, et al. Viewing Climate Signals through an AI Lens, Department of Atmospheric and Oceanic Sciences Seminar, UCLA [invited]. February 12, 2020.

Barnes, et al. Viewing Climate Signals through an AI Lens, invited speaker for 19th Conference for Artificial Intelligence for Environmental Science, AMS 2020, Boston, MA [invited]. January 14, 2020.

Barnes, et al. Viewing Forced Climate Patterns through an AI Lens, invited speaker and panel member at AGU Union Session Data Analytics and Machine Learning Innovation for Climate and Earth Surface Processes [invited]. December 11, 2019.

Barnes, et al. Viewing climate signals through an AI lens, invited visitor and speaker, Max Plank Institute [invited]. November 7, 2019.

Barnes, et al. Viewing climate signals through an AI lens, Distinguished Women of Environmental Systems Science invited speaker, ETH Zurich [invited]. November 4, 2019.

PROJECT TITLE: MJO and QBO Contributions to U.S. Precipitation Skill at S2S Leads

PRINCIPAL INVESTIGATORS: Elizabeth Barnes, Eric Maloney

RESEARCH TEAM: Eric Maloney, Elizabeth Barnes

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

- [A] Understand the role of the MJO and QBO in driving skillful precipitation forecasts.
- [B] Diagnose processes that drive biases within FV3 that lead to low precipitation skill.
- [C] Improve precipitation forecasts at S2S leads using information from UFS and empirically-derived relationships between the MJO and QBO.

PROJECT ACCOMPLISHMENTS SUMMARY:

The project start date was Sept. 1, and so, this report only contains activities since that date (6 months).

- [A,B,C] The CSU PIs have successfully hired an outstanding postdoc (Zane Martin) to begin on this project Spring 2020. Zane's doctoral dissertation is on the MJO-QBO connection in observations and models, and thus, his background is ideal for this project. Due to Zane's defense timing, CSU's main efforts on this project will not begin until Spring 2020.
- [A,B,C] The CSU PIs have successfully hired an outstanding master's student (Wei-Ting Hsiao) to begin on this project Summer 2020.
- [A,B] The NOAA/CIRES team have completed Experiments D1 & D2. The entire team had a telecon in February 2020 to discuss next steps, useful diagnostics, data transfer and possible next experiments to run.
- [A,C] Analysis of warming scenarios from the CMIP5 archive indicate that MJO circulations weaken per unit precipitation in a warmer climate, associated with increases of tropical static stability with warming. These results are detectable relative to the historical records as soon as the coming decade. These results inform generation of empirical MJO precipitation forecasts for the coming decades as the reliance of precipitation skill on the MJO is likely nonstationary. These results are published in *Geophysical Research Letters*.

PROJECT PUBLICATIONS:

Bui, H. X., and E. D. Maloney, 2019: Transient response of MJO precipitation and circulation to greenhouse gas forcing. *Geophys. Res. Lett.*, 46, 13546-13555.

Toms, B. A., E. A. Barnes, E. D. Maloney, and S. C. van den Heever: The Global Teleconnection Signature of the Madden-Julian Oscillation and its Modulation by the Quasi-Biennial Oscillation, *Journal of Geophysical Research: Atmospheres,* under review.

Nardi, Kyle M., Cory F. Baggett, Elizabeth A. Barnes, Eric D. Maloney, Daniel S. Harnos, and Laura M. Ciasto: Skillful all-season S2S prediction of U.S. precipitation using the MJO and QBO, *Weather and Forecasting*, under review.

PROJECT PRESENTATIONS/CONFERENCES:

2020 AMS Annual Meeting: Assessing the Influence of Tropical Forecast Errors on Higher-Latitude Predictions Using Nudging Experiments. Authors: Juliana Dias, S. N. Tulich, M. Gehne, and G. Kiladis

PROJECT TITLE: Near-field Characterization of Biomass Burning Plumes

PRINCIPAL INVESTIGATOR: Delphine K. Farmer

RESEARCH TEAM: Sonia Kreidenweis, Chris Kummerow

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

This project is focused on investigating the near-field chemistry of biomass burning plumes as part of a larger aircraft-based measurement campaign, including sampling the source for extended periods and characterizing the evolution of emissions within the first few hours of aging. The proposed work includes these four specific objectives:

(1) To characterize the composition of biomass burning aerosol sources, and, in particular, emission ratios and their variability,

(2) To investigate the physical evolution of emissions in the near field, with emphasis on dilution effects,

(3) To characterize the emission ratios of black carbon, and

(4) To determine the contributions and variability in organic nitrate components of biomass burning aerosol in the near-field.

PROJECT ACCOMPLISHMENTS SUMMARY:

(1) Characterization of biomass burning sources and evaluation of dilution effects in near-field of plume

We published the emissions ratios of organic aerosol from >20 wildfires from the WE-CAN field campaign in a publication (Garofalo et al. ACS Earth and Space Chemistry. 2019)

This paper reported the following key points:

- We reported the organic aerosol (OA) emission ratios from aircraft observations near the fire source for the 20 wildfires sampled during the Western Wildfire Experiment: Cloud Chemistry, Aerosol Absorption, and Nitrogen (WE-CAN) study of summer 2018.
- We observed no changes in submicron nonrefractory OA mass concentration, relative to CO, which accounts for simple dilution, between 0.5 and up to 8 h of aging. However, static OA excess mixing ratios hide shifts in the aerosol chemical composition that suggest near-balanced, simultaneous oxidation-driven condensation and dilution-driven evaporation.
- We observed significant increases in the extent of oxidation, evident by an increase in oxidation marker f_{44} and loss of the biomass burning marker f_{60}, as the smoke ages through chemistry and dilution. We discuss the competing effects of oxidative chemistry and dilution-driven evaporation on the evolution of the chemical composition of aerosols in wildfire smoke over time.

- We highlighted the variation in organic aerosol and the extent of oxidation through plume cross-sections

(2) Organic nitrogen in wildfire plumes

We are investigating organic nitrogen in wildfire plumes. Lindaas et al. (Submitted, 2020) reported the budget of emitted nitrogen from the WE-CAN fire plumes, and in that paper we reported the substantial role of particulate ammonium and nitrate to the total nitrogen budget. However, two questions are open from that paper. (1) We found a large discrepancy between PILS and AMS measurements, which prompted extensive aerosol intercomparisons and confirmation that the AMS made the most robust measurement of sub-micron aerosol during the WE-Can project. (2) The extent to which organic nitrogen contributed to both the particulate nitrate and ammonium. Briefly, the NO^+ and NO_2^+ ions in the AMS are the result of both inorganic nitrate with organic nitrates and other oxidized nitrogen species. The ratio observed during WE-CAN is not consistent with organic nitrates(R-O-N-O_2), but instead nitro-organics (R-N-O_2). To further investigate that chemistry, we participated in a chamber study to understand the source of these nitro-organics, and find that oxygenated aromatics such as catechol and guaiacol can form a substantial amount of nitrogenated species. These species account for an impressive amount of light absorption in biomass burning plumes (~5% of the organic aerosol accounts for ~30% of the light absorption) – but more impressively, these components behave uniquely in terms of aerosol uptake and secondary organic aerosol formation. We find that these nitro-organics partition preferentially to particles that already have coatings, creating an inhomogeneous mixture as evidence by bimodal size distributions.

This organic nitrogen story, and linkages between lab measurements and field observations, are the core of our next manuscript, in progress. Further, the extent to which reduced organic nitrogen contributes to organic aerosol in wildfire plumes is of future interest, as is the presence of other heteroatoms and links to aerosol coatings on black carbon particles.

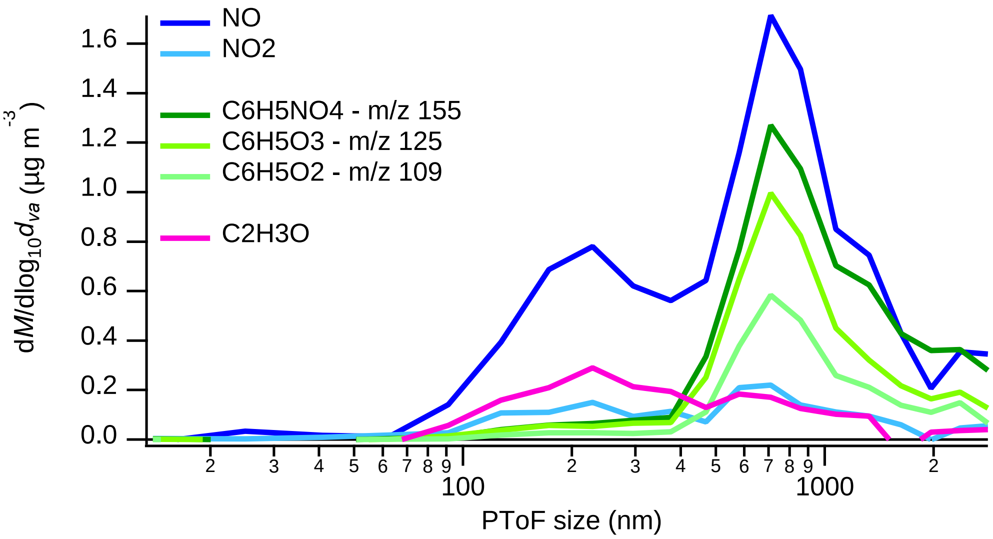


Figure 1. The bimodal size distributions observed in a high NOx catechol + O3 experiment. The bulk of secondary organic aerosol is captured in the smaller mode (e.g. the $C_2H_3O^+$ peak from the AMS) including some nitro-oxygenated organics, but nitrocatechol accumulated exclusively in a separate larger mode.

(3) Intercomparisons with other datasets

We spent part of Fall 2019 conducting intercomparisons with other aerosol research groups from the WE-CAN team. Key outcomes included: identifying saturation in the UHSAS, PCASP and other aerosol size distribution measurements; identifying an as-yet-not-understood loss in the Particle-Into-Liquid-Sampler off-line measurements; and cohesion that our High Resolution Aerosol Mass Spectrometer provided the most robust measure of sub-micron aerosol mass.

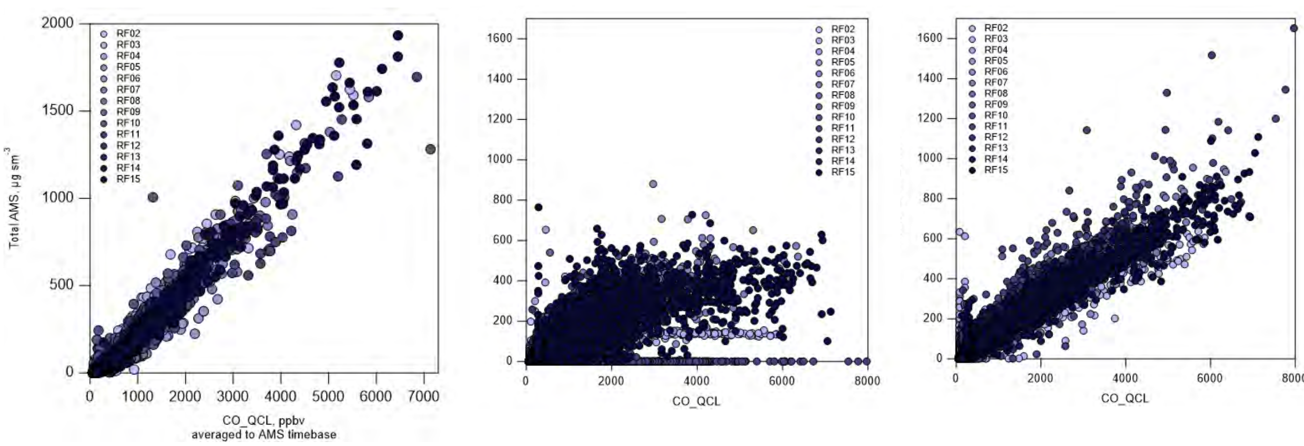


Figure 2. Correlations between total AMS (left), UHSAS (middle) and PCASP (right) with observed CO during WE-CAN show evidence of saturation at high particle loadings in both optical techniques, but not in the AMS.

PROJECT PUBLICATIONS:

L. Garofalo, M. Pothier, E. Levin, T. Campos, S. Kreidenweis, D.K. Farmer. Emission and Evolution of Submicron Organic Aerosol in Smoke from Wildfires in the Western United States. ACS Earth and Space Chemistry. 2019, 3(7), 1237-1247, doi:10.1021/acsearthspacechem.9b00125

J. Lindaas, I. B. Pollack, L.A. Garofalo, M.A. Pothier, D.K. Farmer, S.M. Kreidenweis, T.L. Campos, F. Flocke, A.J. Weinheimer, D.D. Montzka, G.S. Tyndall, B.B. Palm, Q. Peng, J.A. Thornton, W. Permar, C. Wielgasz, L. Hu, R.D. Ottmar, J.C. Restaino, A.T.Hudack, I.-T. Ku, A.Sullivan, J.L., Collett, E.V. Fischer. Emissions of Reactive Nitrogen from Western U.S. Wildfires during Summer 2018. Submitted to Journal of Geophysics Research Atmospheres, February 2020.

PROJECT PRESENTATIONS/CONFERENCES:

Characterizing Aerosol Emissions from Wildfires in the Western US. EZRA LEVIN, Kevin Barry, Kathryn Moore, John Ortega, Lauren Garofalo, Matson A. Pothier, Darin Toohey, Mike Reeves, Jakob Lindaas, Ethan Emerson, Delphine K. Farmer, Sonia Kreidenweis, Paul DeMott, Emily Fischer, *October 2019, AAAR Meeting, Portland OR*

Emission and Evolution of Submicron Aerosol Composition in Wildfire Smoke in the Western United States. LAUREN GAROFALO, Ezra Levin, Matson A. Pothier, Sonia Kreidenweis, Delphine K. Farmer, *October 2019, AAAR Meeting, Portland OR*

Investigation into Airborne-Based Smoke Marker Ratios and Brown Carbon from Wildfires in the Western U.S. during the WE-CAN Study. AMY P. SULLIVAN, Jakob Lindaas, Emily Fischer, Lauren Garofalo, Delphine K. Farmer, Sonia Kreidenweis, Teresa Campos, Jeffrey Collett, *October 2019, AAAR Meeting, Portland OR*

A21C-01 - WRF-Chem Aerosol Predictions over the US during WE-CAN with the GOES-16 Fire Product, A.Kumar, R.B. Pierce et al. December 2019, AGU Fall Meeting, San Francisco CA

A11D-08 - Investigating Gas-Particle Partitioning of Reduced Nitrogen in Western Wildfire Smoke, J. Lindaas, I. Pollack et al. December 2019, AGU Fall Meeting, San Francisco CA

A21C-07Phenolic Compounds in Wildfire Plumes: Gas-Phase Emissions, Chemistry, and Contributions to Secondary Organic Aerosol Formation , B. Palm, Q. Peng et al. December 2019, AGU Fall Meeting, San Francisco CA

PROJECT TITLE: S2S Forecasting of North American Precipitation Anomalies: Using Empirical Forecasts to Challenge Dynamical Forecasts

PRINCIPAL INVESTIGATOR: David Randall

RESEARCH TEAM: David Randall, Elizabeth Barnes, Donald Dazlich, Andrea Jenney

NOAA TECHNICAL CONTACT: Wanqui Wang, Stefan Tulich

NOAA RESEARCH TEAM: Wanqui Wang, Stefan Tulich

PROJECT OBJECTIVES:

Our objectives and overall research strategy are as follows:

- We will evaluate the S2S teleconnections simulated by enhanced versions of the UFS, already developed under prior NOAA support, with an emphasis on the influence of the MJO. The modified models are the UP-UFS, which uses the resolution-independent cumulus parameterization developed by Arakawa and Wu, and SP-UFS, which uses a super-parameterization based on the cloud-permitting model SAM, which was developed by Marat Khairoutdinov. These two enhanced versions of the UFS are specifically designed to give better representations of precipitation processes. We will compare the results of simulations with UP-UFS and SP-UFS to the corresponding results from the current operational version of the model.

- Our analysis of the dynamical forecasts will be guided by results obtained with the empirical STRIPES index developed by Jenney et al. (2019). The STRIPES index quantifies the strength and consistency of a region's response to periodic remote events, such as the MJO. Because the index can be computed for a single point, it can be plotted on a map to show regional variations. Further explanation STRIPES index is given below. We hypothesize that a dynamical forecast system, such as the UFS, should produce skillful S2S precipitation forecasts where and when the observationally based STRIPES index indicates that good predictability exists. Our analysis will look for improved S2S forecast skill in those particular places and times.

The results of our analysis will document the S2S skill of the two enhanced versions of the UFS, as well as the operational version of the model. This information can be used by NOAA management as they make decisions about the future evolution of the operational model.

PROJECT ACCOMPLISHMENTS SUMMARY:

We are currently performing AMIP simulations with the three models. The results of the simulations are being analyzed with particular attention to the ability of the three models (unmodified UFS, UP-UFS, and SP-UFS) to simulate We are also in the process of setting up the STRIPES codes for use with both the model output and observations.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Understanding the Role of the Diurnal Cycle and the Mean State On the Propagation of the Intraseasonal Variability Over the Maritime Continent

PRINCIPAL INVESTIGATOR: Eric D. Maloney

RESEARCH TEAM: Justin Hudson, Michael Natoli, Emily Riley Dellaripa

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

[A] Use in-situ observations from the YMC and PISTON field campaigns and satellite observations to evaluate the representation of the Maritime Continent (MC) diurnal cycle in global and regional models

[B] Conduct numerical experiments using the global model and regional models to test whether 1) The diurnal cycle of convection in the MC islands and over the adjacent water destructively interferes with convection of the MJO and BSISO and 2) The diurnal cycle over the MC plays a key role in determining/shaping the seasonal mean basic state that affects realistic propagation of intraseasonal variability over the broader MC area)

[C] Characterize biases in the latest NCEP hindcast datasets in terms of the MJO/BSISO propagation, the basic state, and the diurnal cycle over the MC region, and examine possible connections among the biases.

PROJECT ACCOMPLISHMENTS SUMMARY:

[B] *The MJO and changes in basic state due to climate change:* Recent studies have shown that Madden-Julian oscillation (MJO) precipitation anomaly amplitude tends to increase while associated circulations weaken at the end of 21st century in Coupled Model Intercomparison Project phase 5 models under Representative Concentration Pathway 8.5. Transient changes of MJO characteristics earlier in the 21st century have received less attention. In this study, changes of MJO precipitation and circulation amplitude during these interim time periods under Representative Concentration Pathway 8.5 are examined in Coupled Model Intercomparison Project phase 5 models. Multimodel mean changes in MJO precipitation and circulation amplitude are not individually detectable in the early and middle 21st century relative to the historical period (1986–2005). However, robust multimodel mean decreases in the ratio of MJO wind to precipitation anomalies occur even early in the 21st century. This decreased ratio is explained by increasingly large tropical static stability as the climate warms, which under weak temperature gradient balance mandates that a diabatic heating anomaly is balanced by an increasingly weaker circulation anomaly. These results suggest the robustness of weak temperature gradient theory for explaining MJO dynamics, not only in an equilibrium climate but also in the transient response. Bui and Maloney (2019 a,b).

[B] *Convective Transition Statistics over Tropical Oceans for Climate Model Diagnostics: GCM Evaluation* To assess deep convective parameterizations in a variety of GCMs and examine the fast-time-scale convective transition, a set of statistics characterizing the pickup of precipitation as a function of column water vapor (CWV), PDFs and joint PDFs of CWV and precipitation, and the dependence of the moisture–precipitation relation on tropospheric temperature is evaluated using the hourly output of two versions of the GFDL Atmospheric Model, version 4 (AM4), NCAR CAM5 and superparameterized CAM (SPCAM). The 6-hourly output from the MJO Task Force (MJOTF)/GEWEX Atmospheric System Study (GASS) project is also analyzed. Contrasting statistics produced from individual models that primarily differ in representations of moist convection suggest that convective transition statistics can substantially distinguish differences in convective representation and its interaction with the large-scale flow, while models that differ only in spatial–temporal resolution, microphysics, or ocean–atmosphere coupling result in similar statistics. Most of the models simulate some version of the observed sharp increase in precipitation as CWV exceeds a critical value, as well as that convective onset occurs at higher CWV but at lower column RH as temperature increases. While some models quantitatively capture these observed features and associated probability distributions, considerable intermodel spread and departures from observations in various aspects of the precipitation–CWV relationship are noted. For instance, in many of the models, the transition from the low-CWV, nonprecipitating regime to the moist regime for CWV around and above critical is less abrupt than in observations. Additionally, some models overproduce drizzle at low CWV, and some require CWV higher than observed for strong precipitation. For many of the models, it is particularly challenging to simulate the probability distributions of CWV at high temperature. Kuo et al. (2020)

[A], [B] *Intraseasonal variability of the diurnal cycle of precipitation in the Philippines.* Precipitation in the region surrounding the South China Sea over land and coastal waters exhibits a strong diurnal cycle associated with a land–sea temperature contrast that drives a sea-breeze circulation (**Figure 1**). The boreal summer intraseasonal oscillation (BSISO) is an important modulator of diurnal precipitation patterns, an understanding of which is a primary goal of the field campaign Propagation of Intraseasonal Tropical Oscillations (PISTON). Using 21 years of CMORPH precipitation for Luzon Island in the northern Philippines, it is shown that the diurnal cycle amplitude is generally maximized over land roughly 1 week before the arrival of the broader oceanic convective envelope associated with the BSISO. A strong diurnal cycle in coastal waters is observed in the transition from the inactive to active phase, associated with offshore propagation of the diurnal cycle. The diurnal cycle amplitude is in phase with daily mean precipitation over Mindanao but is nearly out of phase over Luzon. The BSISO influence on the diurnal cycle on the eastern side of topography is nearly opposite to that on the western side. Using wind, moisture, and radiation products from the ERA5 reanalysis, it is proposed that the enhanced diurnal cycle west of the mountains during BSISO suppressed phases is related to increased insolation and weaker prevailing onshore winds that promote a stronger sea-breeze circulation when compared with the May–October mean state. Offshore propagation is suppressed until ambient midlevel moisture increases over the surrounding oceans during the transition to the active BSISO phase. In BSISO enhanced phases, strong low-level winds and increased cloudiness suppress the sea-breeze circulation. Natoli and Maloney (2019)

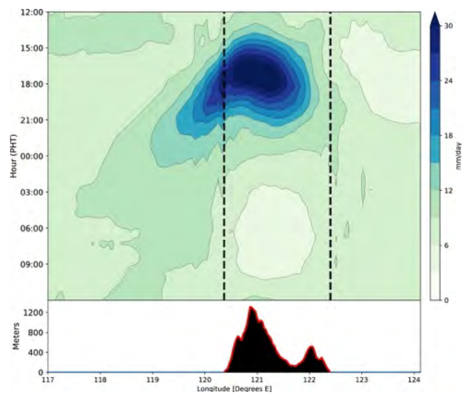


Figure 1. Composite diurnal cycle based on CMORPH precipitation in boreal summer averaged latitudinally across Luzon, with average topography from NOAA ETOPO2 in the same cross section shown below the plot. The average longitudes of the shoreline are denoted as dotted black vertical lines.

[A], [B], *Topographic Effects on the Luzon Diurnal Cycle During the BSISO.* Cloud-resolving simulations are used to evaluate the importance of topography to the diurnal cycle (DC) of precipitation (DCP) over Luzon, Philippines, and surrounding ocean during the July–August 2016 boreal summer intraseasonal oscillation (BSISO) event. Composites of surface precipitation for each 30-min time increment during the day are made to determine the mean DCP. The mean DCP is computed separately for suppressed and active BSISO conditions and compared across three simulations with varying topography—flat, true, and doubled topographic height. The magnitude of the topographic height helps to dictate the timing, intensity, and location of diurnal precipitation over and near Luzon. For example, the mean DCP in the true topography run peaks 1.5 h later, is broader by 1 h, and has a 9% larger amplitude during active conditions relative to suppressed conditions. By contrast, the flat run mean DCP is earlier and narrower by 0.5 h with a 5% smaller amplitude during active conditions versus suppressed conditions. Within the suppressed or active BSISO conditions, the mean DCP peak and amplitude increase as the topographic height increases. The presence of elevated topography focuses precipitation over the coastal mountains during suppressed conditions, while dictating which side of the domain (i.e., east Luzon and the Philippine Sea vs west Luzon and the South China Sea) more precipitation occurs in during active conditions. These topographic-induced changes are discussed in terms of mechanical and thermodynamic forcing differences between the two large-scale BSISO regimes for the three runs. Riley Dellaripa et al. (2019).

[B] *MJO teleconnections over the PNA region in climate models. Part I: Performance- and process-based skill metrics.* We propose a set of MJO teleconnection diagnostics that enables an objective evaluation of model simulations, a fair model-to-model comparison, and a consistent tracking of model improvement. Various skill metrics are derived from teleconnection diagnostics including five performance-based metrics that characterize the pattern, amplitude, east–west position, persistence, and consistency of MJO teleconnections and additional two process-oriented metrics that are designed to characterize the location and intensity of the anomalous Rossby wave source (RWS). The proposed teleconnection skill metrics are used to compare the characteristics of boreal winter MJO teleconnections (500-hPa geopotential height anomaly) over the Pacific–North America (PNA) region in 29 global climate models (GCMs). The results show that current GCMs generally produce MJO teleconnections that are stronger, more persistent, and extend too far to the east when compared to those observed in reanalysis. In general, models simulate more realistic teleconnection patterns when the MJO is in phases 2–3 or phases 7–8, which are characterized by a dipole convection pattern over the Indian Ocean and western to central Pacific. The higher model skill for phases 2, 7, and 8 may be due to these phases producing more consistent teleconnection patterns between individual MJO events than other phases, although the consistency is lower in most models than observed. Models that simulate realistic RWS patterns better reproduce MJO teleconnection patterns. Wang et al. (2020)

[B] *The consistency of MJO teleconnection patterns on interannual timescales* The Madden-Julian Oscillation (MJO) excites strong variations in extratropical geopotential heights which modulate extratropical weather, making the MJO an important predictability source on subseasonal to seasonal timescales (S2S). Previous research demonstrates a strong similarity of teleconnection patterns across MJO events for certain MJO phases (i.e. pattern consistency) and increased model ensemble agreement during these phases that is beneficial for extended numerical weather forecasts. However, the MJO's ability to modulate extratropical weather varies greatly on interannual timescales, which brings extra uncertainty in leveraging the MJO for S2S prediction. Few studies have investigated the mechanisms responsible for variations in the consistency of MJO tropical-extratropical teleconnections on interannual timescales. This study uses reanalysis data, ensemble simulations of a linear baroclinic model, and a Rossby wave ray tracing algorithm to demonstrate that two mechanisms largely determine the interannual variability of MJO teleconnection consistency. First, the meridional shift of stationary Rossby wave ray paths indicate increases (decreases) in the MJO's extratropical modulation during La Niña (El Niño) years. Second, a previous study proposed that the constructive interference of Rossby wave signals caused by a dipole Rossby wave source pattern across the subtropical jet during certain MJO phases produces a consistent MJO teleconnection. However, this dipole feature is less clear in both El Niño and La Niña years due to the extension and contraction of MJO convection, respectively, which would decrease the MJO's influence in the extratropics. Hence, considering the joint influence of the basic state and MJO forcing, this study suggests a diminished potential to leverage the MJO for S2S prediction in El Niño years. Tseng et al. (2020)

PROJECT PUBLICATIONS:

Bui, H. X., and E. D. Maloney, 2019a: Transient response of MJO precipitation and circulation to greenhouse gas forcing. *Geophys. Res. Lett.*, **46**, 13546-13555.

Bui, H. X., and E. D. Maloney, 2019b: Mechanisms for global warming impacts on Madden-Julian Oscillation precipitation amplitude. *J. Climate*, **32**, 6961-6975.

Kuo, Y.-H., J. D. Neelin, C.-C. Chen, W.-T. Chen, L. Donner, A. Gettelman, X. Jiang, K.-T. Kuo, E. Maloney, C. Mechoso, Y. Ming, K. Schiro, C. Seman, C.-M. Wu, and M. Zhao, 2020: Convective transition statistics over tropical oceans for climate model diagnostics: GCM evaluation. *J. Atmos. Sci.*, **77**, 379-403.

Natoli, M. B., and E. D. Maloney, 2019: Intraseasonal variability of the diurnal cycle of precipitation in the Philippines. *J. Atmos. Sci.*, **76**, 3633–3654.

Riley Dellaripa, E. M., E. D. Maloney, B. A. Toms, S. M. Saleeby, and S. C. van den Heever, 2020: Topographic Effects on the Luzon Diurnal Cycle During the BSISO. *J. Atmos. Sci.*, **77**, 3-30.

Tseng, K.-C., E. Maloney, and E. A. Barnes, 2020: The consistency of MJO teleconnection patterns on interannual timescales. *J. Climate*, in press.

Wang, J., H. Kim, D. Kim, S. A. Henderson, C. Stan, and E. D. Maloney, 2020: MJO teleconnections over the PNA region in climate models. Part I: Performance- and process-based skill metrics. *J. Climate*, **33**, 1051–1067.

PROJECT PRESENTATIONS/CONFERENCES:

Natoli, M. B., and E. D. Maloney, 2018: Intraseasonal Variability in the diurnal cycle of precipitation in the Philippines. Abstract A43O-3338 presented at *2018 AGU Fall Meeting*, 10-14 December, 2018, Washington, D.C.

Maloney, E. D., E. Riley Dellaripa, S. M. Saleeby, B. A. Toms, and S. C. van den Heever, 2018: The Importance of Topography to the Luzon Diurnal Cycle During a BSISO Event. Abstract A43O-3350 presented at *2018 AGU Fall Meeting*, 10-14 December, 2018, Washington, D.C.

Maloney, E. D., 2019: Propagation mechanisms of monsoon intraseasonal oscillations. *Air-Sea Interaction in the Bay of Bengal- MISOBOB,* International Centre for Theoretical Sciences, Bangalore, India, 22-23 February 2019 (invited).

Maloney, E., A. Adames, and H. Bui, 2019: How Will the Madden-Julian Oscillation Change in a Warmer Climate? Abstract EGU2019-4425 presented at the *2019 EGU General Assembly*, 7-12 April, 2019, Vienna, Austria.

Maloney, E., A. Adames, and H. Bui, 2019: How Will the Madden-Julian Oscillation Change in a Warmer Climate? *U.S. CLIVAR Workshop on Atmospheric Convection and Air-Sea Interactions over the Tropical Oceans*, 7-9 May 2019, Boulder, CO.

Maloney, E., A. Adames, and H. Bui, 2019: How Will the Madden-Julian Oscillation Change in a Warmer Climate? *AMOS Annual Meeting 2019 and the International Conference on Tropical Meteorology and Oceanography*, 11-14 June 2019, Darwin Convention Centre, Australia.

Riley Dellaripa, E., E. D. Maloney, B. A. Toms, S. M. Saleeby, and S. C. van den Heever, 2019: Topographic Effects on the Luzon Diurnal Cycle During the BSISO. Abstract A43I-3049 presented at *2019 AGU Fall Meeting*, 9-13 December, 2019, San Francisco, CA.

Tseng, K.-C., E. D. Maloney, and E. A. Barnes, 2020: The Consistency of MJO Teleconnection Patterns on Interannual Time Scales. *2020 AMS Annual Meeting*, 12-16 January, 2020, Boston, Massachusetts.

Air-Sea Interactions in the Bay of Bengal From Monsoons to Mixing – MISOBOB, ICTS-TIFR, Bangalore, India, 18 - 23 Feb, 2019. Tutorial on Boreal Summer Intraseasonal Variability (invited).

14th NOAA Climate and Global Change Postdoctoral Fellowship Summer Institute, Steamboat Springs, CO, July 14 - 18, 2019, “Recent Progress on Tropical-Extratropical Interactions: Current and Future Climate” (invited).

ESMEI REU research seminar, Department of Atmospheric Science, Colorado State University, July 23, 2019, Title: A survey of the tropics and recent field programs.

WMO MJO Task Force Meeting, July 31, Singapore. Talk: “Recent CSU work on MJO teleconnections and S2S prediction” (remote presentation)

PROJECT TITLE: Diagnostics of Poor-skill events in FV3GFS and FV3-GEFS, Hurricane Supplemental, 4b-1-1b

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Haidao Lin, Amanda Back, and Liao-Fan Lin

NOAA TECHNICAL CONTACT: Stephen Weygandt OAR/ESRL/GSD/ADB

PROJECT OBJECTIVE:

The hurricane supplementary project aims to explore the physical scheme parameters and data impact in the forecast dropouts of the NCEP Global Forecast System (GFS).

PROJECT ACCOMPLISHMENTS:

Since September 2019, work focused on (1) exploring historic dropouts in the previous GFS in terms of the anomaly correlation coefficient in 500-mb geopotential height; (2) testing the sensitivity of GFS forecasts to the mountain drag related parameters in three forecast dropouts; and (3) preparing the data denial experiments for a dropout case related to atmospheric river in the east Pacific Ocean.

The project team has been working with NCEP Environmental Modeling Center (EMC) to diagnose and characterize the forecast dropouts in the five- or six-day 500-mb height forecasts of GFS in the past years. Via the empirical orthogonal function (EOF) analysis, four types of distinct composite over the North America are identified. Among these four groups, it was determined that group 2 could be related to mountain drag coefficients due to trough passage over the Rockies Areas. To further understand the effect of mountain drag coefficients on the forecast dropouts, staff performed GFS cold-start forecast runs over three dropout events by modifying the efficiency of mountain blocking and orographic gravity wave momentum deposition. We varied the mountain blocking parameter, cdmbgwd(1), between 4.0 (default in C768) and 0.23 (default in C192) and the orographic gravity wave momentum parameter, cdmbgwd(2), between 0.15 (default in C768) and 1.5 (default in C192). The experiments, performed at C768, were initialized on 2018.11.10 00UTC, 2019.08.27 00UTC, and 2019.09.09 00UTC and used initial conditions from GFS analyses. The 500-mb forecasts over North America were verified against the GFS analyses. Figure 1 shows the domain average RMSE of there three dropout events. This figure shows that the forecasts are more sensitive to the mountain blocking than orographic gravity wave momentum. From these three cases, it appears that the mountain blocking parameter in default (i.e., cdmbgwd(1)=4.0) leads to poorer forecast skills than using cdmbgwd(2)=0.23.

In addition, the group-4 composite from the EOF analysis indicates that the dropouts related to this group is potentially relevant to atmospheric rivers over the eastern Pacific Ocean. A recent five-day forecast dropout valid at 00UTC 21 January 2020 was characterized as this group. We are preparing data denial experiments with an initialization time at 2020.01.13 00UTC and three-day cycling runs, in order to evaluate forecasts starting at 2020.01.16 00UTC.

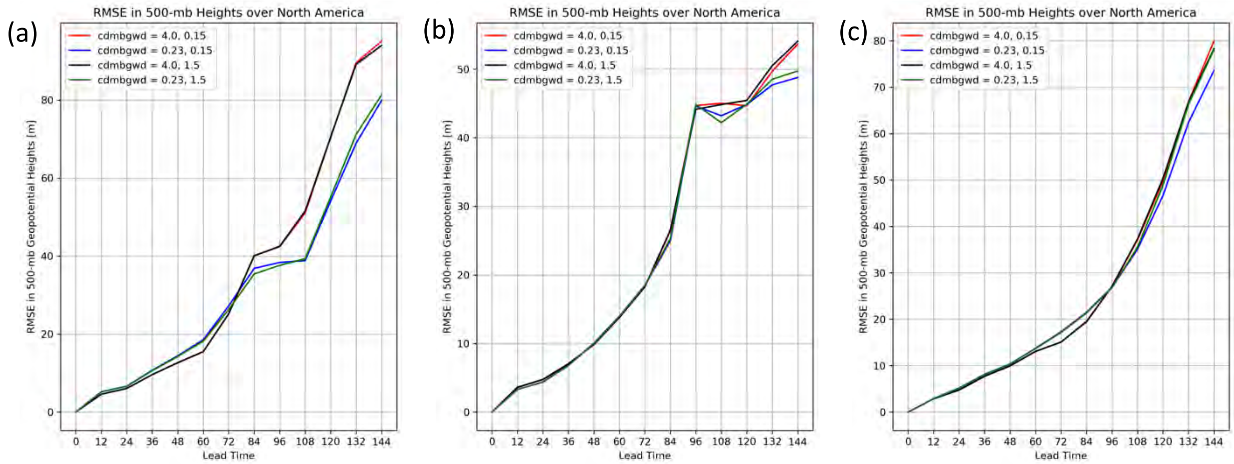


Figure 1. The RMSE in GFS 500-mb height forecasts averaged over North America. These three cases are initialized at (a) 2018.11.10 00UTC, (b) 2019.08.27 00UTC, and (c) 2019.09.09 00UTC.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: PROJECT TITLE: Implementation and Testing of Lognormal Humidity and Cloud-related Control Variables for the NCEP GSI Hybrid EnVar Assimilation Scheme

PRINCIPAL INVESTIGATORS: Steven Fletcher

RESEARCH TEAM: Steven Fletcher

NOAA TECHNICAL CONTACT: Daryl Kleist

NOAA RESEARCH TEAM: Global Data Assimilation

PROJECT OBJECTIVES:

1) To investigate and implement the mixed Gaussian-lognormal data assimilation for hydrometeors in the GSI system

2) Subaward to University of Maryland, to look at the stochastic physics in the ensemble component to improve ensemble spread.

PROJECT ACCOMPLISHMENTS SUMMARY:

1) At Colorado State University (CSU) Dr. Fletcher has been working on deriving the lognormal framework into the GSI formulation to be able to introduce this new formulation into the codes to enable a more consistent, from a probabilistic sense, for the errors associated with the moisture and hydrometeor variables. There have been two approaches that have been derived; the first is through deriving a first order relationship between the current additive increment and the multiplicative increment for the geometric lognormal approach, or alternatively through using the preconditioning approach from the operational version of the static 3DVAR at the time of the start of the project.

The first approach mentioned above is derived through the linearization between the model increments and the logarithmic transformed increment as follows: The first increment is $\delta q \equiv q^t - q_b$,while the second increment is given by $\delta Q \equiv \ln q^t - \ln q_b$, where the superscript t represents the truth and the subscript b represents the background. Therefore

$$q^t \equiv q_b + (q^t - q_b) \equiv q_b + \delta q,$$
$$\frac{q^t}{q_b} = \frac{q_b}{q_b} + \frac{(q^t - q_b)}{q_b} \equiv 1 + \frac{\delta q}{q_b},$$
$$\Rightarrow \ln q^t - \ln q_b \equiv \ln\left(1 + \frac{\delta q}{q_b}\right),$$
$$\Rightarrow \delta Q \equiv \ln\left(1 + \frac{\delta q}{q_b}\right).$$

While the relationship between the two increments is nonlinear, if a Taylor series approximation is applied to the right hand side then the approximate linear relationship between the two increments is given by

$$\delta Q \approx \frac{\delta q}{q_b}.$$

This increment along with its adjoint equation have been implemented into the normal_rh_to_q routine

Dr. Fletcher worked with Dr. Daryl Kleist of EMC to introduce a lognormal version of the NMC background error covariance model that is used in the operational static component of the GSI for the specific humidity model. This was done for a coarse resolution in both time and space.

The second approach came about because Dr. Fletcher has been working with Dr. Apodaca (formally at CIRA, now at AOML) on a similar project where we identified changes needed to the preconditioner in the GSI format to enable a lognormally distributed increment to be minimized. However, there are three situations that have arisen in the theoretical stages that would need to be addressed: 1) whether or not to introduce a lognormal formulation for the satellite observation error which could be more Gaussian as this introduces more non-linearity into the cost function, and 2) to go ahead with the lognormal observational error formulation and use a first order approximation to the exponential that is introduced, or 3) keep the exponential component and determine impact of the extra function evaluation.

Evaluation of model ensemble spread in observation space of AMSU-A

Evaluation of model ensemble spread for the representation of the forecast uncertainty, the Desroziers diagnostics (Desroziers et al, 2006) offers a practical approach based on observation-minus-background |*OmB*| ($\mathbf{d}_b^o$) as well as observation-minus-analysis |*OmA*| ($\mathbf{d}_a^o$) and analysis-minus-background in observation space ($\mathbf{d}_b^a$). To assess the consistency between the background ensemble spread in observation space ($\mathbf{HBH}^{\mathrm{T}}$) and observation error covariance in the GSI , we developed the ensemble spread representativeness (ESR) ratio:

$$ESR = log_{10}\left(\frac{\sqrt{\frac{1}{\mathrm{M}-1}\hat{\mathbf{Y}}^{\mathrm{b}}\left(\hat{\mathbf{Y}}^{\mathrm{b}}\right)^{\mathrm{T}}}}{\sqrt{E[\mathbf{d}_b^a(\mathbf{d}_b^o)^{\mathrm{T}}]}}\right)$$

Figure 1 shows that for all channels of AMSU-A channels. where M is the size of the ensemble which is 80 in our simulation, and $\hat{\mathbf{Y}}^{\mathrm{b}}$ is the difference between each ensemble member and the ensemble mean of the background states in the observation space. Thus, $\sqrt{\frac{1}{\mathrm{M}-1}\hat{\mathbf{Y}}^{\mathrm{b}}\left(\hat{\mathbf{Y}}^{\mathrm{b}}\right)^{\mathrm{T}}}$ represents model ensemble spread. The ensemble spread is close to the model error when ESR is close to zero. The ensemble spread is smaller/larger compared to the model error when ESR is negative/positive. The regional and global ESR averaged over a week for individual assimilated channels of AMSUA Metop A are shown in Figure 2.

2.2. Impact of Stochastically Perturbed Physical Tendencies (SPPT) parameter tuning

The SPPT scheme used in the GSI follow Buizza et al. (1999). It adds perturbation in the parameterized tendency term (**P**) from the original forecast model to represent the model uncertainties in the parameterized physical process. At each grid (λ, ϕ, σ) (where λ is latitude, ϕ is longitude, and σ is vertical hybrid coordinate) and time *t,* the tendency of zonal wind (*U*), meridional wind (*V*), specific humidity (*Q*) and temperature (*T*) of the ensemble member *j* represented by $\mathbf{e}_j$ becomes:

$$\frac{\partial \mathbf{e}_j}{\partial t} = \mathbf{G}(\mathbf{e}_j; t) + \left(1 + \mu(\sigma)\langle r_j(\lambda, \phi; t)\rangle_{A,D,S}\right)\mathbf{P}(\mathbf{e}_j; t)$$

where **G** represents grid-scale term, μ is a vertical weight that is 1 from surface to 100 hPa, and is decreased to 0 at 25 hPa; *r* is a random number following Gaussian distribution with a standard deviation *A* which is used for all grid points inside a *D*×*D* km box and over time period *S*. The default SPPT parameter set is (*A*, *D*, *S*) = (0.8, 500km, 6-hour) in GDAS/GFS (Wang et al., 2019). To study the impact of the SPPT parameter tuning, the four experiments have been carried out (Table 1).

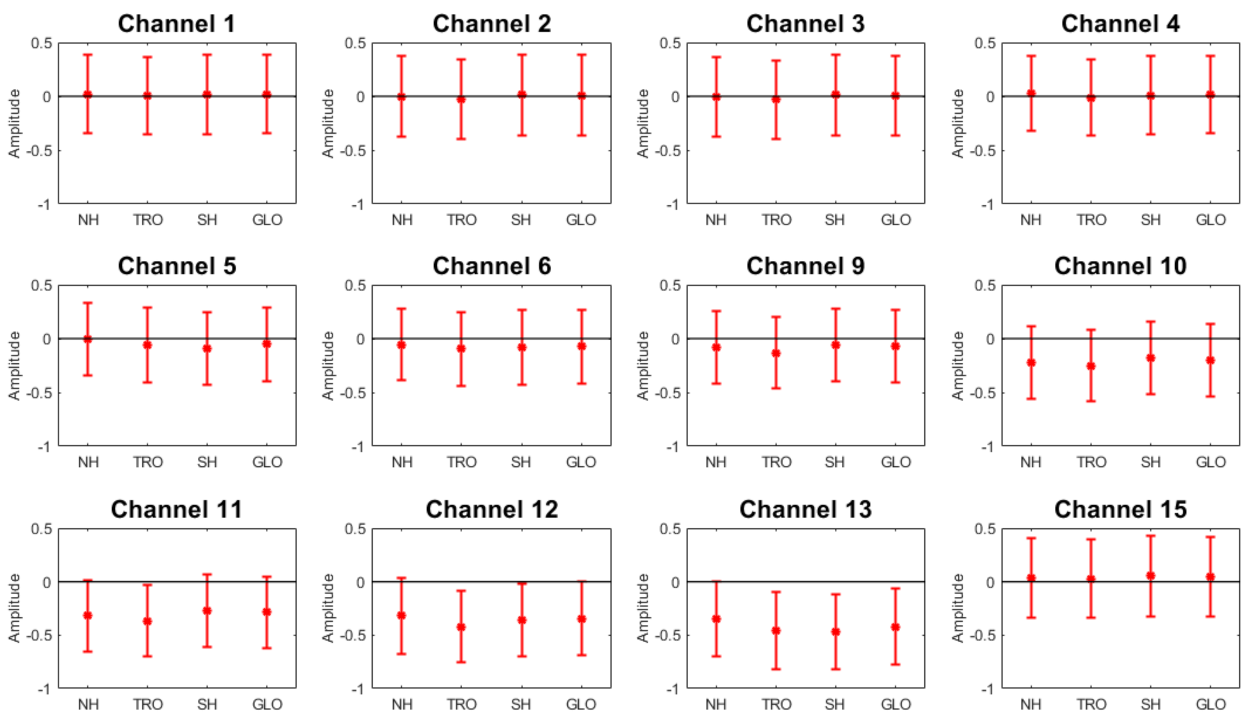


Figure 1. ESR for AMSUA-Metop A channels 1, 2, 3, 4, 5, 6, 9, 10, 11, 12, and 15 in the northern hemisphere, tropical region, southern hemisphere and globally. Standard deviation is shown by the bars for statistical significance.

	A	D	S
Control	0.8	500	6
SPPT Exp A_{down}	**0.5**	500	6
SPPT Exp A_{up}	**1.0**	500	6
SPPT Exp D_{down}	0.8	**250**	6
SPPT Exp T_{up}	0.8	500	**9**

Table 1. The SPPT parameter values for the Control and each SPPT sensitivity experiment

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Skillfully Predicting Atmospheric Rivers and Their Impacts in Weeks 2-5 Based on the State of the MJO and QBO

PRINCIPAL INVESTIGATOR(S): Elizabeth Barnes (CSU PI); Eric Maloney (CSU Co-PI)

RESEARCH TEAM: Cory Baggett (former Research Scientist), Kyle Nardi (former Masters Student), Eric Maloney and Elizabeth Barnes

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

- [A] Successfully transition the anomalous AR frequency forecast tool to operations.
- [B] Refine and extend the methodology of Mundhenk et al. (2018) to maximize skill of AR activity and AR-related variables.
- [C] Leverage additional predictors, including dynamical model MJO forecasts, to extend the skillful forecasts beyond Week 5.

PROJECT ACCOMPLISHMENTS SUMMARY:

- [A,B,C] The CSU PIs have successfully hired an outstanding postdoc (Zane Martin) to begin on this project Spring 2020. Zane's doctoral dissertation is on the MJO-QBO connection in observations and models, and thus, his background is ideal for this project. Due to Zane's defense timing, CSU's main efforts on this project will not begin until Spring 2020 – thus we will be requesting an NCE for this project as there is work to be done. We believe this is justified given large changeover in personell last Spring due to Cory Baggett leaving for INNOVM/CPC and Kyle Nardi leaving to pursue a PhD at Penn State.
- [B,C] Submitted Nardi et al. (2019) on using the MJO and QBO to identify forecasts of opportunity of precipitation over all seasons and across the U.S.
- [B,C] Produced a web application for visualizing the predictions and hindcast skill of 5 variables over the U.S. using an empirical model based on the MJO, QBO and ENSO: http://barnes.atmos.colostate.edu/S2SPredictionModel/
- [A] CPC has the anomalous AR probability routine running in real-time, with an internal webpage to host the graphics. CPC continues to work on getting validation up and running.
- [C] Although Cory Baggett has moved to INNOVM/CPC, he has been working on adding the QBO to CPC's existing statistical model. While his efforts are no longer officially under this CTB project, the code he is using was developed as part of this CTB project, and he continues to work on a paper (joint with our team) on assessing the skill of a hybrid prediction model that takes dynamical forecasts of the MJO and then utilizes our empirical model based off of these MJO predictions.

PROJECT PRODUCTS:

[D] Web Application:
We developed a web application for visualizing predictions of weather anomalies at S2S leads using our empirical model based on the MJO, QBO, and ENSO. Weather variables include: precipitation, atmospheric rivers, integrated water vapor transport and surface temperature. The application can be accessed here: http://barnes.atmos.colostate.edu/S2SPredictionModel/

PROJECT PUBLICATIONS:

Nardi, Kyle M., Cory F. Baggett, Elizabeth A. Barnes, Eric D. Maloney, Daniel S. Harnos, and Laura M. Ciasto: Skillful all-season S2S prediction of U.S. precipitation using the MJO and QBO, *Weather and Forecasting*, submitted 11/2019, *under review.*

PROJECT TITLE: Accounting for Non-Gaussianity in the Background Error Distributions Associated with Cloud-related Variables (Microwave-radiances and Hydrometeors) in Hybrid Data Assimilation for Convective-scale Prediction

PRINCIPAL INVESTIGATORS: Karina Apodaca, Steven J. Fletcher

RESEARCH TEAM: Karina Apodaca, Steven J. Fletcher

NOAA TECHNICAL CONTACT: Emily Liu, Andrew Collard, and Daryl T. Kleist NOAA/NWS/NCEP/EMC

NOAA RESEARCH TEAM: Stephen Weygandt NOAA/ESRL/GSD/ADB, Haidao Lin

PROJECT OBJECTIVES:

The overarching objective is to advance data assimilation and forecasting. In particular, this project seeks to further develop the operationally used Gridpoint Statistical Interpolation (GSI) data assimilation (DA) software by incorporating a new non-Gaussian solver in the static (3DVar) component of the hybrid system

The benefit is for the assimilation of observations for which their associated background state variables exhibit error distributions that are non-Gaussian (NG).

A clear example of this scenario happens when dealing with humidity and cloud hydrometeor control variables, which represents a challenge for the assimilation several observation types. Specifically, this application can be beneficial to the assimilation of microwave radiances of current operational and experimental microwave sensors at NOAA/NWS

As a way to address the NG behavior of cloud variables we proposed to implement the “Lognormal and Mixed-Distribution” formulation (Fletcher and Zupanski, 2006, 2007, Fletcher and Jones, 2014, Fletcher, 2017).

PROJECT ACCOMPLISHMENTS SUMMARY:

The first steps at implementing non-Gaussian-based data assimilation (NGDA) in an operationally used data assimilation software have been pursued

A non-Gaussian mathematical methodology was developed for all the components of the GSI system by constructing a new Bayesian problem for a multivariate lognormal distribution for its three dimensional variational (3DVar) static solver

The goal of this new NGDA variational solver is to produce a non-Gaussian deterministic analysis suitable for observations capable of updating model fields whose associated background error Probability Density Function (PDF) distributions follow a lognormal distribution

Through this new solver, it may be possible to avoid some standard procedures in the data assimilation process, such as rejecting “lognormal” observations to later assimilate them separately (quality control) or to transform lognormal variables into a Gaussian to correct unphysical values for the analysis state

In Figure 1, we show all the current routines in GSI that require development, along with the mathematical formulation that corresponds to the algorithmic components. In addition, new routines are incorporated to complete the new NGDA implementation

The source code development for the NGDA implementation in GSI requires a pre-computed background error covariance matrix lookup table. Thus, we obtained retrospective ensemble forecasts HRRR-E system (size-36, CONUS domain) for a full year

The initial application is intended for microwave radiance assimilation from the Advanced Technology Microwave Sounder (ATMS) data from NOAA-20

The algorithmic framework represents a baseline that could be extended to other non-Gaussian-type observations in the future and it is model agnostic, but other developers
need to generate B-matrix statistics for their desired model

Initial application is meant for the testing and assessment of impacts at convection allowing scales with High-Resolution Rapid Refresh (HRRR)/Alaska analyses, which are to be obtained

Additionally, the initial code review process and sinking of developments to the GSI master were initiated

The PI on this project gave a presentation at the GSI community of developers meeting, on March 5, 2020. This was to introduce upcoming changes to the GSI master, and it was and a prerequisite before consideration for the code review process by the GSI Committee. These meetings are organized by Dr. Daryl T. Kleist (EMC).

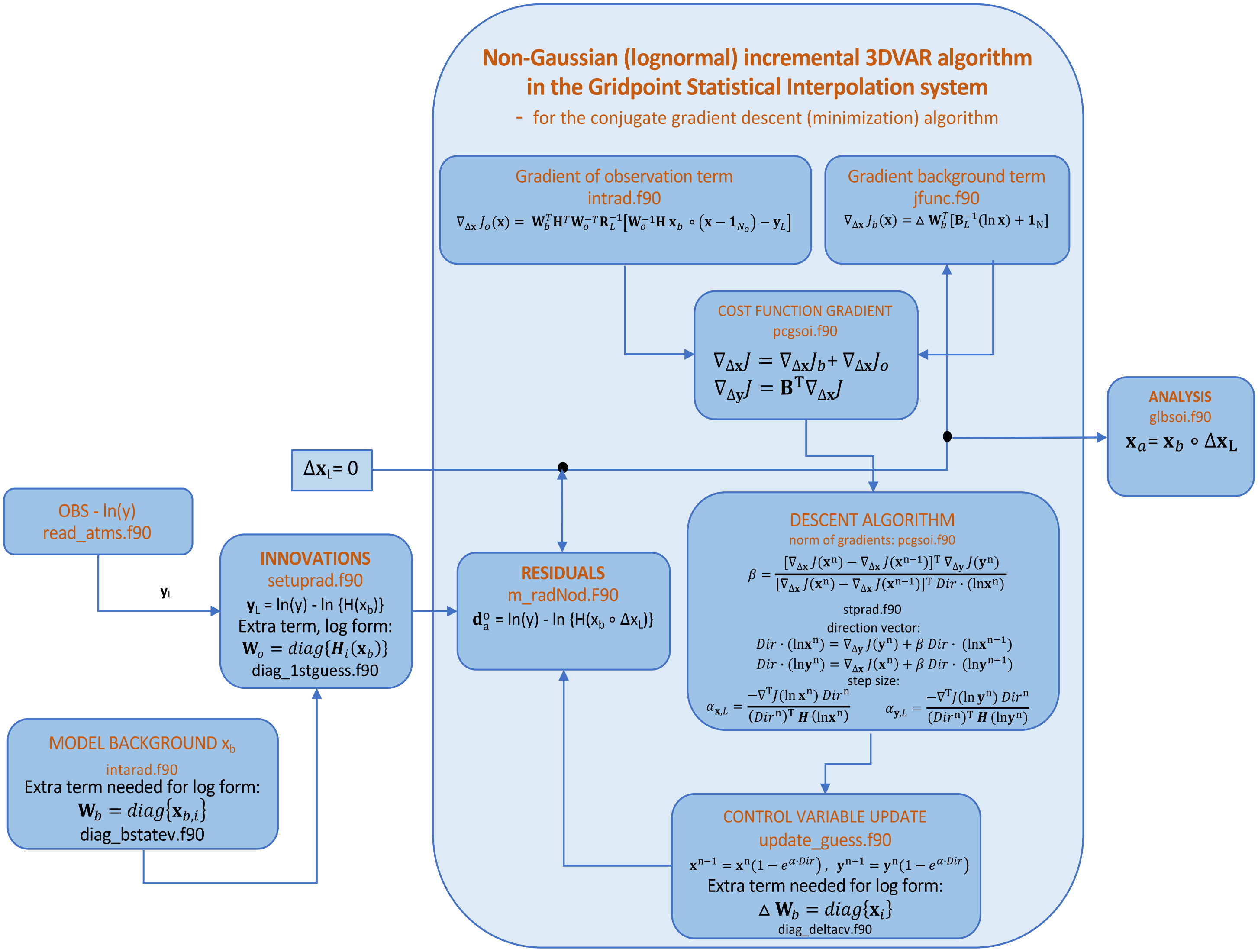


Figure 1. Flow chart of the new non-Gaussian (lognormal) solver for GSI along all the source code programs and routines

PROJECT PUBLICATIONS:

Apodaca K., S. J. Fletcher, Stephen Weygandt, and Haidao Lin: "Incorporation of a new non-Gaussian solver in the static component of the hybrid GSI system" Data Assimilation: New Developments in Methodology Part I, 24th Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS), 100th Annual Meeting of the American Meteorological Society, Boston, MA January 17, 2020

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Research Collaborations with the National Weather Service Meteorological Development Lab

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Kenneth Sperow, John Crockett, Michael Giebler, Jason Burks, David Miller, Michael Coulman, Adam Schnapp, Geoff Wagner, Emily Schlie, Andy Kochenash, Paul Roebber, Kevin McGrath, Greg Stumpf

NOAA TECHNICAL CONTACT: Stephan Smith NOAA/NWS/OSTI/MDL

NOAA RESEARCH TEAM: Mamoudou Ba, Lingyan Xin, Matthew Davis, John Schattel, Michael Churma, Tom Filiaggi, David Ruth, Steve Olson, Jung-Sun Im, Dan Plumb, Dana Strom, Kenneth Howard, Steven Silberberg

PROJECT OBJECTIVES:

Virtual Lab (VLab) https://vlab.ncep.noaa.gov
The National Weather Service (NWS) has created a service and IT framework that enables NOAA, in particular the NWS, and its partners to share ideas, collaborate, engage in software development, and conduct applied research from anywhere. The project's objectives are the following:

1--Reduce the transition time and cost of NWS field innovations to enterprise operations;
2--Minimize redundancy and leverage complementary, yet physically separated, skill sets;
3--Forge scientific and technical solutions based on a broad, diverse consensus; and
4--Promote a NOAA/NWS culture based on collaboration and trust.

AWIPS
AWIPS is an open source, service oriented architecture (SOA) used by the National Weather Service for interrogation/display, forecast preparation and dissemination of weather data and products.

MDL and CIRA provide technical leadership to the AWIPS Program Office. Additionally, we develop new AWIPS applications and enhance existing applications. AWIPS uses many technologies (JAVA, Camel, Hibernate, Python, JMS, JMX, etc.) that are new to the MDL and the NWS. In order for the MDL to be in a position to add value, they need people who have a working understanding of these technologies. Also MDL needs to provide technical assistance in the form of software development expertise to assist in the shaping of the evolving AWIPS architecture. MDL and CIRA are helping the AWIPS program utilize cloud services to improve their development life cycle and reduce risk.

AutoNowCaster (ANC)
Originally developed by the Research Applications Laboratory at the National Center for Atmospheric Research, ANC produces 60-minute nowcasts of convective likelihood and radar reflectivity. The project's objectives are the following:

1--Provide third-tier support for ANC in operations.
2--Contribute to experiments designed to improve, better understand, or showcase ANC, and contribute to any associated publications or presentations.
3--Where necessary or possible, correct or optimize ANC's software and streamline its configuration.
4--Develop a more complete understanding of ANC's architecture and configuration, and document that understanding.

CAP Handler
The CAP Handler will combine and replace the HazCollect (Legacy) and HazCollect-Extended applications. The project's objectives are the following:

1--Provide leadership and technical expertise.
2--Contribute to the engineering of the CAP Handler's software.
3--Transition CAP Handler to operations.

Impacts Catalog / IRIS / iNWS
The National Weather Service's Weather-Ready Nation Roadmap calls out the creation of a national Impacts Catalog, a system whereby the NWS can improve its Impact-based Decision Support Services to its core partners by providing those partners with information regarding the impacts that relevant meteorological variables will have on those partners' operations. The project's objectives are the following:

1--Provide leadership and technical expertise.
2--Contribute to the engineering of the Impacts Catalog's software, including that of its framework system, IRIS, and its corollary system, iNWS.

Community Atmospheric Model Post-Processing System (CAMPS)
CAMPS (previously Weather Information Statistical Post-Processing System -- WISPS) is a software infrastructure, currently under development at MDL, supporting Statistical Post-Processing (StatPP) of atmospheric data, and is maintained as community code. CAMPS Version 1.0 is currently hosted on NOAA's Virtual Laboratory (VLab) as well as on GitHub (https://github.com/NOAA-MDL/CAMPS). It is available as an installable Python package that can simulate a limited MOS-2000 development for a set of temperature variables (Temperature, Dewpoint, Day Max Temp, and Night Min Temp). CAMPS aims to both modernize the current NWP post-processing infrastructure and make it readily accessible to outside users. We work towards these goals by utilizing an established open-source programming language (Python), adopting a self-describing data format (NetCDF), setting metadata ontology standards, and making source code available on public sites such as GitHub. A detailed 2-year project plan has been mapped out along with a 5-year vision of CAMPS reaching Technical Readiness Level 9 (i.e., operational implementation on NOAA's Weather and Climate Operational Supercomputing System, WCOSS), running alongside (and eventually replacing) the current MOS-2000 system, and supporting blended MOS and the National Blend of Models. The project's objectives are the following:
1--Co-lead a team of experts, provided by MDL, on the continued development of the CAMPS software infrastructure, with a goal of releasing a Version 2.0 of the software in 2021 with numerous minor releases in the interim.
2--Establish a streamlined and thorough process for reviewing and incorporating outside user contributions to the CAMPS software through GitHub and subsequently VLab.
3--Continue to expand resources available for the CAMPS project. This could include growing the team and/or working to advance the existing team's skills to meet the needs of the project as it evolves.
4--Conduct outreach efforts to collaborate and engage with the broader weather and StatPP community as a whole (inside or outside of NOAA). Topics could range from data/metadata storage techniques to software development.

Statistical Post-processing of output from Numerical Weather Prediction (NWP) systems
It is difficult to overestimate the importance of StatPP guidance created by MDL. This includes output from MDL's signature Model Output Statistics (MOS) technique as well as the National Blend of Models (NBM). Together, they provide a set of next-generation foundational guidance products based on NWS

and non-NWS model information. The techniques developed are intended to create an enduring process for the generation of guidance products for lead times extending from hours to two weeks. The project's objectives are the following:

1--Work collaboratively and independently with MDL scientists to investigate and develop statistical post-processing and blending techniques for NBM.
2--Develop software and leverage existing algorithms that can derive variables needed to support the StatPP needs of the weather enterprise.
3--Develop, test, and document computer programs (primarily in Fortran and Python) and scripts necessary for data processing.
4--Work collaboratively with MDL scientists as they write documentation, create displays and maps, and prepare presentations.
5--Work collaboratively with MDL scientists who are implementing operational software on NOAA's various supercomputing platforms.

MDL Geospatial Data Services/Interactive Map Viewer

The Meteorological Development Laboratory (MDL) develops and implements techniques that generate products and services that enhance the value of NWS forecast products. Techniques emphasize information on forecast uncertainty that enhance decision making throughout the weather enterprise. Techniques also include data modeling, metadata, and web services that support NOAA's dissemination needs. Prototyping of promising techniques is done to identify those best for implementation. One area of focus includes geospatial data services that provide maximum flexibility for use by public customers and partners. Once developed and vigorously tested, these techniques are implemented in software on NWS "preview" and operational platforms. This project is being developed, tested, and previewed in the AWS cloud environment. The project objects are:

1--Collaborate with MDL's staff to develop and visualize new products for the National Digital Forecast Database (NDFD), the National Digital Guidance Database (NDGD), and other NWS datasets as required by MDL's customers.
2--Collaborate with MDL staff to develop and maintain systems to access quality operational and experimental NWS forecasts under two project areas: Modernized Product Generation and Delivery/Information Dissemination Program (IDP) and interactive Map Viewer.
3--Coordinate with NWS and non-NWS agencies on forecast guidance issues.

Local Climate Analysis Tool (LCAT)

LCAT is an online, interactive tool that will enable NWS forecasters and other registered users to conduct regional and local climate studies using station and reanalysis gridded data and various statistical techniques for climate analysis. LCAT will provide users with "best practice" climatological analysis techniques, saving time for the user and guaranteeing scientifically sound output.   The analysis results could be used for Decision Support Services activities, to guide local decision makers in weather and climate-sensitive actions. LCAT augments current climate reference materials with information pertinent to the local/regional level as they apply to diverse variables appropriate to each locality. The LCAT studies allow users to supplement NOAA NWS climate forecasts with value-added information and increase expertise in impact of climate variability and change at local level. The LCAT outcomes will be also useful for guidance of governmental, economic, and business planning. Project objectives include:

1--Provide direction and expertise to develop the existing LCAT program.
a----Maintain a Science Advisory team to develop environmental intelligence for a range of applications, grid reanalysis capabilities and web interfaces.

2--Develop tools and services for LCAT.
a----Deploy ‘sea ice’ expansion to LCAT.
3--Develop LCAT v.2.
a----RESTful API to expand the reach & utility LCAT provides.
b----Modern web interface for LCAT using RESTful API.

Localized Aviation MOS Product (LAMP)

LAMP is a statistical forecast guidance system which produces frequently updated weather forecast guidance at over 2000 stations and gridded guidance covering the NDFD CONUS domain. LAMP incorporates observational data, numerical weather prediction output, and simple advective models to produce guidance with added value over the inputs. LAMP provides hourly forecast guidance for weather elements most relevant to aviation including ceiling height, sky cover, visibility, obstruction to vision, precipitation occurrence and type, and thunderstorms. LAMP guidance is leveraged by NWS for near term forecast operations such as Terminal Aerodrome Forecast (TAF) generation and is incorporated into the National Blend of Models.

PHI in FACETS

FACETs is an evolutionary paradigm change to the nation’s hazardous weather forecast and warning system, moving from a product-centric to an information-centric system with continuously-updating high spatiotemporal probabilistic hazard grids.

The project objectives are the following:

1--To work with scientists at multiple agencies (MDL, NSSL, GSD, WDTD, U. Akron) in research and development of Probabilistic Hazard Information (PHI) in support of the Forecasting a Continuum of Environmental Threats (FACETs) initiative to improve the nation’s severe convective weather warning and forecast services.
2--To facilitate the transfer of PHI to operations.
3--To collaborate with the NOAA Hazardous Weather Testbed - Experimental Warning Program at the National Weather Center in Norman.

PROJECT ACCOMPLISHMENTS SUMMARY:

VLab

Ken Sperow continues as the VLab technical lead, as well as the technical lead of the Virtual Lab Support Team (VLST). This team currently consists of 10 members to whom Ken provides support and training. Ken is not only the technical lead but also the deployment manager for VLab, overseeing and conducting all upgrades, security and feature updates within VLab. Under Ken Sperow and Stephan Smith’s (the NOAA PI) leadership, the VLab continued to grow in importance and visibility within the NWS and NOAA again this year. The VLab is an essential and required component in the transition of research to operations for the NWS AWIPS. All AWIPS development organizations must use VLab to check in, review, and verify AWIPS II code before it is included in the operational baseline.

VLDS provides web-based services to help manage projects via issue tracking, source control sharing, code review, and continuous integration

Ken Sperow is the VLab expert, which includes providing guidance not only on Gerrit, Jenkins, Liferay, and Redmine, but also git expertise. Multiple demos and consultations were made to development (e.g., NCAR, MDL Managers and staff) and operations groups (NCEP OPC) covering VLab's capabilities and how they can be leveraged to address the group's needs.

Ken managed and actively helped with the development and implementation of ICAM (NOAA's SSO solution) into VLab's 6 components with significant development efforts by Jason Burks and Michael Giebler.

Ken also supervised the successful buildout and launch of the NWS Heritage site within VLab Collaboration Services (VLCS), a public facing website celebrating the NWS 150 year anniversary.

At the request of NWS leadership (David Michaud, Ming Ji, and Stephan Smith) Ken Sperow continues to lead the use of the "Cloud" for NWS prototyping efforts associated with MDL's MDLNet on premise network. Ken created and presented a summary report to OSTI, MDL, and AWIPS management on his findings. His recommendations include:

1--Cloud environments DO provide a flexible infrastructure to quickly develop and test applications.
2--Cloud environments DO provide a stable 24x7 environment in which MDL applications can be previewed by the general weather community.
3--Cloud environments DO provide a potential path for moving the MDLNet FISMA system outside of SSMC2.
4--The team found the cloud to be very effective for development/testing/prototyping of NWS applications. They recommend the NWS expands the use of cloud services, with the understanding that cloud services could be cost prohibitive for high egress network traffic or very computationally extensive projects.

This cloud environment is being used to prototype continuous integration (CI) and continuous delivery (CD) within VLab.

Jason Burks worked to streamline the process of creating new VLab Gerrit projects. Jason developed a program to automate the creation of projects, in the Development section of VLab. Previously, the process of creating projects took approximately 30 minutes per project, and now has been reduced to 10 seconds. The new program improved the response time of the VLab support while also reducing the potential for errors. This project creation is being directly integrated into VLab.

Michael Giebler continues to provide customer support for VLab.

Michael Giebler finished the upgrade to Liferay DXP by upgrading the scheduled ldap import portlet and the NOAA user cleanup portlet to work with DXP.

Michael Giebler also added new functionality to the Collaboration Services (VLCS) portal. This functionality includes the following enhancements:

1-- Document Library – multiple document download
2-- Dynamic Data Lists – give users ability to specify column order and save order as a portlet preference. Added delete if author permission to DDL entries.
3-- Message Boards portlet – interface enhancements plus changed the maximum number of attachments from a fixed number of attachments to a combined sized limit of all attachments. Also increased the size of the subject.
4-- Announcements portlet – Additional information included in email notifications
5-- Knowledge Base Portlet – Give user option to copy a Knowledge Base Folder into another folder.

Various bug fixes to VLCS including:

1--Fixing subscribe by default in the message boards portlet
2--Users can now leave private communities
3--Social activity is now transferred when a staged community is published
4--Ensuring all form fields are displayed in dynamic data list forms (previously limited to 5 columns).

Thao Pham developed and supported the NWS Heritage project. She continued to fine tune the Timeline widget. She added image maps with links to local WFO history sites. Thao also developed a new way to display NWS stories with search and sort capability.

Thao worked on design and implementation of the public MDL web site's migration to VLab. This project involved development of a new Liferay theme which improved the look and feel of the MDL Website. The theme uses a template based on a newer version of Bootstrap (version 4). A CSV viewer template was developed, giving users the ability to display csv files as an html table, with search, sort, and group by capabilities. Users can also display CSV as a geo scatter graph. Thao developed a new Asset Publisher Template (ADT) that incorporates a javascript library for searching and sorting content assets instantly. Thao migrated existing publication entries to web content journal articles and provided a new interface to display the publications within the new MDL site. This work significantly improves methods for displaying, creating, and importing content in VLab. Additionally, she developed table of contents, image grid, and read more capabilities for web content displays within VLab.

Thao assisted Jason Burks in building the AWIPS training course in VLab by designing and implementing a course template and lesson structure, allowing users to view videos and copy code to a clipboard.

Thao added clone commands to VLab Redmine repository interface, enabling Redmine users with syntax on how to clone their repositories, thus reducing user errors.

Thao assisted and promoted the usage of the Knowledge Base portlet in VLab, which was used to develop the VLab user and administrator guides.

Thao continued to provide customer support as part of the VLab Support team and is also a member of the VLab outreach group, promoting VLab services.

The team continued to provide customer support and guidance on the many facets of VLab. This included setting up new communities and projects within VLab, importing legacy data such as project management issues and code repositories, consultations with individuals and groups that provide guidance and assistance.

AWIPS

Ken Sperow and Jason Burks have helped lead an effort to prototype AWIPS cloud activities within the commercial cloud. Ken setup an EC2 instance within Amazon Web Services (AWS) for the APO to prototype developing for AWIPS within the cloud. Accounts, policies, groups, and permissions were all established within AWS to support this effort. Jason Burks has successfully run not only EDEX but also CAVE, with direct rendering, using an EC2 instance with a dedicated GPU. The running of CAVE in the cloud will enable the AWIPS program to be more flexible and responsive in setting up development environments and potentially enabling a new method for using CAVE.

Jason participated in many software design and code reviews for the AWIPS II System.

Jason developed an AWIPS II Developer Training Course and delivered the course to approximately 150 developers. Recordings from the training are available on VLab. Jason is prepared to deliver the course again this year with some updates.

In AWIPS version 20.3 AWIPS will move from Python 2 to Python 3. Currently Ken and Jason are providing support through cloud instances to help with the migration of local applications and GFE python scripts. Jason developed an interface in VLab for users to request an instance to perform the conversion work. That request can be approved and the instance is allocated and the user can turn on and off the instance and get connection information from VLab. These instances reduce the risk of moving to Python 3 for the local offices by allowing them to test and vet their changes on a non-operational system before they get the system installed locally. In that way they can ensure that their software works on the first day of installation providing minimal interruption to their services. This same system will be utilized for development in the future. This system also allows developers to quickly spin-up a development environment without having to perform those steps themselves enabling a significant time savings.

ANC

John Crockett continued to support the day-to-day running of ANC at the MDL, as well as maintaining and updating all of the documentation related to ANC.

Paul Roebber and John Crockett responded to the reviews of the paper that they had submitted in March 2019 to *Monthly Weather Review*; the paper presented further research into Evolutionary Programming using a predator-prey agent-based ecosystem model. After resubmission, the paper was subsequently published in the November 2019 issue of Monthly Weather Review (*Mon. Wea. Rev.*, **147**, 4241-4259).

Paul Roebber continued work on the ANC project with the Central Weather Bureau (CWB) of Taiwan. This work followed the visit that he and Lingyan Xin made to the CWB in March 2019 and was begun in summer 2019 (after the CWB made their data available, as discussed at the March meeting). Paul provided progress report input for a visit that Lingyan and Stephan Smith made to the CWB in November. This report entailed preliminary progress on ANC modifications using Artificial Neural Nets (ANN) to process the ANC and ancillary data for providing convection occurrence nowcasts. Work on this is continuing and Paul is currently exploring Evolutionary Programming applications to the problem.

Along with federal colleagues at the MDL, John Crockett finished a research project to validate ANC in the vicinity of twenty-one aviation hubs considered important by the Aviation Weather Center (AWC). John provided feedback to the author of the corresponding summary report, which was sent to the AWC in September 2019.

John Crockett presented the *Evaluation of NCAR's ANC for Operational Application within the NWS* talk to representatives from the Korean Meteorological Association.

CAP Handler

As Technical Lead of the project, John Crockett directed and managed the work of two project software developers, providing technical assistance and input as needed. As part of these duties, John led biweekly project status teleconferences, managed the associated Redmine project in the VLab, performed code reviews, and created and maintained project documentation.

Through Technical Interchange Meetings and regularly scheduled teleconferences, John interfaced with project-related colleagues from the MDL, the NWS Office of Dissemination, NCEP Central Operations, and FEMA in order to decide upon and document such things as a) the project's Functional Requirements, b) the project's Roles and Responsibilities, c) the project's Software Design, d) the correct mappings to use between NWS text product format and CAP 1.2 format, e) the design of the CAP Handler database, and f) the means by which to replace the HazCollect (Legacy) New York access point.

John contributed substantially to the software development and initial testing of the nascent CAP Handler.

Impacts Catalog / IRIS / iNWS

As Deputy Technical Lead of the project, John Crockett participated in Development Team teleconferences and attended the Development Team Conference in Grand Rapids, MI from October 7-11. Also, as needed, John helped diagnose problems with the operational system.

CAMPS

Emily Schlie is the co-lead for the CAMPS project. She has completed the following for the CAMPS project:

1-- Led an overhaul and update of the CAMPS documentation webpage with improved readability as a main objective.
2-- Led development of CAMPS Version 1.0 both by delegating tasks and contributing to the actual software development.
3-- Successfully released Version 1.0 of the CAMPS software onto Github.
2-- Hosted/co-hosted two workshops (CAMPS and Git) to help launch Version 1.0 of CAMPS and gather interest in the software.
3-- Developed a detailed 2-year project plan through Version 2.0 of CAMPS, with numerous minor patches and releases planned. Additionally, set a 5-year vision for the CAMPS project to be operational on WCOSS, running alongside MOS-2000, and supporting blended MOS and the National Blend of Models.
4-- Established collaborative relationships with several organizations to benefit the CAMPS project (UKMet, EMC, Unitdata).
5-- Gave seminars for CAMPS both at MDL and the NetCDF Standards Working Group session at the OGC Technical Committee meeting.
6-- Main author on a proposal for the UFS Post Processing Working Group for funding to support 2 new contractors for 2 years to work on the CAMPS project.

Geoff Wagner also provided part time software development support for the CAMPS project. His focus was on providing much needed MOS-2000 expertise, as the initial objective for CAMPS is to simulate a MOS-2000 development. This support is likely to continue, as time in his schedule allows.

Statistical Post-processing of output from Numerical Weather Prediction (NWP) systems

Geoff Wagner conducted improvements to the Gridded Model Output Statistics (GMOS) guidance system primarily for the CONUS, with additional work for Hawaii. These improvements focused on Sky Cover and smaller adjustments to Wind Speed, and were primarily to meet the needs of the National Blend of Global models. Work included analysis adjustments, final testing, bug fixes, and quality assurance for an upgrade package handed off in the Spring of 2019, and implemented on the NCEP operational system in December of 2019. Geoff assisted the effort to assess the impact of upstream changes to the Global Forecast System (GFS) model by retrieving data from tape and re-running station MOS forecasts using the new data. Geoff also investigated an issue involving extreme wind gust values in the grids over SW California and made recommendations to remedy the issue.

Based on the promising results from Tropical Cyclone feature matching work done during the previous reporting period, Geoff Wagner was given an expanded role in continuing the development of this technique for implementation in the National Blend of Models version 4.0. Starting in July of 2019, Geoff continued to actively develop and test code for the technique while also conducting weekly status meetings, preparing presentations and assisting with planning activities (such as quad charts). Geoff also provided support for a new contractor on the project, creating spin-up documents, assisting with onboarding tasks (including computing account applications and directing to necessary resources for Python development and APIs), conducting daily check-ins, and directing additional code development.

Geoff Wagner provided additional as-needed support for the National Blend of Models project. Geoff created a process using MDL's objective analysis software to place blended MOS forecasts at METAR stations on a grid at the gridpoint nearest the station. He worked with MDL developers to create a utility script to manipulate the date and lead time section of files in MDL's in-house TDLpack format to enable their use in a new station-based bias correction technique to improve NBM wind speed and gust forecasts. Geoff also provided direction to prepare PRISM climatological normal data for use in NBM and MOS text bulletins.

Geoff Wagner performed general geospatial data support for several MDL projects, including maps and bogus point creation/adjustment to aid Gridded MOS development. He generated gridded terrain and land/water data for Guam and converted it to MDL's TDLpack file format for use with NBM products. Geoff also continued support for the Unified Terrain project, including discovering an issue which caused a downward shift in some land/water fields. Geoff examined all Unified Terrain grids and corrected the few that were impacted by this issue. Geoff continued corresponding with Raytheon to investigate issues with displaying the Unified Terrain grids in AWIPS.

MDL Geospatial Data Services/Interactive Map Viewer

During the previous reporting period, David Miller's prototype web mapping display page for MDL's project to display Global Ensemble Forecast System (GEFS) fields from NCEP was chosen as the basis for the GEFS display page. Recognizing the need for Responsive Web Design, David rebuilt the GUI interface to use the Bootstrap javascript library. In addition, he recognized the need to change the backend GEFS GRIB data processing to use the Geospatial Data Abstraction Library (GDAL) instead of Matplotlib/Basemap python scripts. Basemap ignored key map projection parameters needed for some regions which caused created images to be misaligned in the display.   David expanded the products by adding GEFS spread and QPF threshold probability fields for all regions (CONUS, Alaska, and Pacific). He then successfully deployed the updated web application to the MDLNet system for NOAA/NWS customer use.

David Miller created a similar web mapping display page for Air Quality (AQ) forecast fields. This allows MDL to provide displays of current AQ Forecast products as well as including newly created AQ elements for user evaluation.   He added more sample point value images in the AQ viewer. David deployed this web application page on MDLNet systems and notified MDL's AQ customers.

At the request of NWS field offices, David Miller successfully developed point visualization displays for the GEFS web mapping display for over 1600 locations worldwide and a limited number of GEFS weather elements. He used an open source javascript library called Plotly. These visualizations included: a) 20 member GEFS and Operational GFS plume diagrams, b) Wind rose at 700mb, c) Violin plots of bias-corrected and raw GEFS members where available, d) 6 hour QPF box plots. In addition, David added a slider that updates the violin and wind rose displays with a time step's data when a user moves the slider to another time, the ability for a user to bookmark the page with a particular location data visualizations, and a search capability for locations via name or station identifier.

David Miller redesigned backend processing of GEFS GRIB files to use Cloud native techniques involving AWS Lambda and S3. This approach significantly reduced the time to process files, but was cost prohibitive. However, the lambda invoke methodology could be leveraged in the NDFD AWS project to process individual GRIB files for storage on S3.

After attending the Free and Open Source Software for Geospatial (FOSS4G) conference, David worked on a technique developed by another conference attendee that involved using a lambda function that called MapServer to create images. After learning the basics of the Serverless framework along with gaining adapting the original technique to the GEFS data on AWS, David successfully used this “MapServer-less” lambda function to create images from GRIB files. He has plans to apply this technique to the AWS Cloud project.

David Miller installed the Bootstrap GEFS viewer running on MDLNet onto MDL’s AWS web server area and successfully displayed images of test data. He will use this success in creating a unified viewer capable of displaying other user-designated data sets.

David Miller investigated and corrected security issues associated with graphical.weather.gov and airquality.weather.gov running on the operational NIDS systems at the request of NCO. The NCO Director relayed thanks for resolving the issues so quickly. David also fixed the Alaska and Hawaii maximum ozone graphics by making changes supporting CMAQ 5.1 with NCO’s help.

David Miller provided a demo of the AQ and GEFS web applications to the Air Quality Forecaster Focus Group, which was well received.

David Miller modified code/files on MDL’s NDFD MDLNet server display page to include mouseover value readout as well as point probe retrieval queries.

David Miller assisted MDL’s Dana Strom in preparing a presentation for a VLab seminar highlighting MDL’s latest web data visualizations that were moving towards cloud hosting. David provided technical support during the seminar as well as answered questions from the audience. The seminar was well received and had a record attendance. Dave Ruth, Digital Forecast Service Branch Chief, thanked us for our preparation work.

Kevin McGrath joined CIRA in May 2019 and is the support lead for the National Blend of Models (NBM) data viewer and processing system. Below is a summary of his accomplishments.

1--Viewer:

a----Supported instances of the viewer on both AWS and on-premises. This originally required a fair bit of modification to migrate code from AWS (where it was being developed and tested) to on-prem. Where possible, intelligence was added to the code to identify where it was running (AWS or on-prem) and automatically set location-specific options, greatly reducing the amount of required modifications for migration.
b----Added all missing v3.1 and v3.2 elements. Added support for v4.0.
c----Designed a multipurpose slider, allowing users to view probabilistic elements and forecast trends.
d----Greatly reduced load times by pre-defining expected projections for a given model, element, and cycle rather than blindly requesting imagery for all 100 forecast projections.
e----Developed an “up-to-date” mode so the user is always viewing the latest data.
f----Added an auto-updating widget that tells the user the percentage of expected elements currently available for the selected model cycle.
g----Users are only allowed to request new imagery once the previous images are finished loading. This avoids the viewer getting stuck in a long loading cycle common when users were allowed to select elements in rapid succession.
h----Added image and animated GIF download tools.

i----The calendar widget now displays dates of actual data availability as opposed to a hard-code range of dates.
j----API now captures all options (element, initialization date/time, map center, zoom level, opacity, overlays, etc.) via the URL.
k----Added the ability to quickly change the sample point font size.
l----Implemented mapcache capability, reducing subsequent image load times.
m----Investigated placing multiple instances of the Apache server behind an AWS load balancer. A centralized cache will be required if multiple instances of Apache are used.
n----The number of columns in the forecast grid is now dynamic and based upon browser window width. This change reduces the likelihood of viewer elements wrapping the page.
o----Resolved issues with incorrect color scales and element sample values being displayed.
p----Resolved issue with projection errors resulting in pixels being drawn offset from the true locations.
q----Fixed point layers by translating the supporting GeoJSON latitude and longitudes to meters instead of degrees.
r----Working towards a CI/CD pipeline with the help of Jenkins and Gerrit.

2--Data processing:

a----Real-time data processing of raw NBM data into files used by the viewer has been completely reengineered to increase reliability and reduce processing time. Output files are being actively synced to S3 for use by the AWS NBM viewer.
b----Rather than using an hourly cron-based script to process new data files, an iNotify-based mechanism is now being utilized. This greatly reduces latency by instantly launching instances of the processing script as soon as new data files are available.
c----Kevin was granted a WCOSS account and successfully connected to it from home via VPN. He is now working to migrate real-time NBM processing from shell1 to WCOSS to avoid outages and take advantage of increase in processing speed.

LCAT

Michael Coulman has focused on developing tools and services for LCAT. Specifically, Michael provided direction and expertise to develop the existing LCAT program:

Bug fixes / changes to current LCAT implementation

1--Fixed a critical error (array bounds overrun) in ParseData::get_climo . This error could have been used as an exploit to gain root access to the underlying OS by a knowledgeable hacker.
2--URL change to prevent mixed content error
3--Pre-deployment bug fixes & changes
4--Nomenclature change throughout: NCDC Climate => NCEI
a----CFSR changes
b----Interpretive statements
c----Plot colors
d----Pop-up map fix
e----Pop-up help for CFSR
f----Merge AK climate divisions to CFSR impl
g----Fixed seasonal wrap over year boundary (e.g., Nov - Jan)

Deployment of current LCAT implementation (with Arctic capability)

1--Deployed on AWS

LCAT v.2

1--Moved prototype into active development, replicating legacy impls:
a----Time series plot, including trends and detrended sample
b----Histogram plot
c----Ensemble Plot
d----Enhanced Rate of Change plot
e----Enhanced Summary Statistics tabulation
f----Enhanced tabulation of sample data, trends, ensemble, rate of change (per trend) & detrend

Deployment of LCAT v.2 (with coastal feature impl.)

1--Complete coding of legacy capabilities (including CFSR & CFS2) in LCAT v.2
2--Implement requirements of coastal features
3--Learn how to properly package Node.js code for distribution to web browser
4--Concurrent retirement of legacy LCAT
5--Redirect from existing NIDS 8by5 site to new AWS MDL site

LAMP

Andrew Kochenash is responsible for LAMP convection and lightning product development for Alaska. Andrew has been evaluating the quality of lightning and radar data over Alaska and preparing archives of his data for future LAMP development. From Vaisala (GLD360), Earth Networks (ENI), and the Bureau of Land Management (BLM), he acquired archives of total lightning data beginning in 2013 through the end of 2019. Using MDL software, Andrew gridded these various data into hourly, 6 km grid boxes. He developed new software to merge the GLD360, ENI, and BLM lightning grids into a single climatology using the maximum value in each grid box. Andrew developed the lightning predictand through the end of October, 2019 for LAMP using the merged lightning climatology. In addition, he tabulated 30-minute and 60-minute lightning counts from the Vaisala GLD360 lightning archive, which will be used as predictors for LAMP convection and lightning development in Alaska.

Additionally, Andrew has continued to archive Multi-Radar/Multi-Scan (MRMS) composite reflectivity data for Alaska from the National Severe Storms Laboratory (NSSL). These archives are complete through the end of 2019. Andrew gridded the MRMS composite reflectivity data into 6 km grid boxes, which will be used as predictors for LAMP convection and lighting development. He also gridded simulated composite reflectivity data from the High-Resolution Rapid Refresh (HRRR) and Rapid Refresh (RAP) models. Additional model fields from the HRRR and RAP were gridded and pre-processed. These model fields include accumulated precipitation, accumulated convective precipitation, precipitable water, moisture divergence, wind shear, lifted index, convective available potential energy, lightning threat index, and vertically integrated liquid.

Lastly, Andrew tested, developed, and verified convection equations from the North American Mesoscale (NAM) Model Output Statistics (MOS) and the European Medium Range Forecast Model (ECMWF) MOS. These MOS-derived convection equations are being used as predictors in the ongoing LAMP convection development.

Adam Schnapp worked with the LAMP team to transition existing LAMP ceiling height and visibility (C&V) techniques to Alaska. This involved acquiring and processing predictor data from both the RAP and HRRR models. Adam leveraged RAP model data to develop new LAMP C&V guidance out to 38 hours for Alaska stations using techniques directly analogous to those applied in the CONUS (Glahn et al, 2017). He cross validated the new guidance and found that it outperformed the baseline v2.2 LAMP guidance over the independent sample.

Adam also assisted in the development and evaluation of gridding the observations and LAMP C&V probabilities over Alaska.

In addition, Adam led the effort to incorporate new LAMP stations over Alaska by incorporating them into LAMP-GFS-MOS.

Finally, Adam incorporated new development into the LAMP suite. This included data ingestion, station forecast evaluation, gridded analysis creation, gridded forecast evaluation, and product generation.

PHI in FACETS

Greg Stumpf joined CIRA on October 1, 2019. He remained the liaison between the NOAA Hazardous Weather Testbed's (HWT) Experimental Warning Program (EWP) and NWS-MDL. The EWP is a proving ground for evaluating new applications, technology, and services designed to improve NWS short-fused (0-2 hour) hazardous convective weather warning decisions. He continues to collaborate closely with National Severe Storms Laboratory (NSSL) scientists who are involved in the EWP, including attending scientific and technical meetings.

Prior to joining CIRA, Greg was a co-principal investigator and subject matter expert on a Joint Technology Transfer Initiative (JTTI) grant. The award was granted to several agencies to fund research and development activities for the Forecasting A Continuum of Environmental Threats (FACETs) initiative to change the severe weather forecast and warning paradigm for the NWS. This project, Hazard Services – Probabilistic Hazard Information (HS-PHI), is funded for the three-year period 1 November 2017 - 31 October 2020.

Greg also authored and submitted a proposal for a project entitled "Inter-Office Collaboration Affecting Severe Weather Warning Services" to the FY 2018 Joint Technology Transfer Initiative. The project was awarded a grant from the JTTI, and work began during FY19 and continues for a period of two years.

In support of the above two grants, Greg is the co-team leader, along with a NOAA/ESRL/Global Systems Division (GSD) software engineer, to transfer the technology of the NSSL-developed Probabilistic Hazard Information (PHI) Prototype tool. GSD software developers and meteorologists have been implementing the NSSL PHI Prototype concepts into AWIPS2 Hazard Services, a new application platform from which all NWS watches, warnings, and advisories will be issued in the new future.

Greg also acts as the HS-PHI "product owner" – he is responsible for defining the requirements, developing extensive test procedures, conducting weekly software tests, and working with the ESRL/GSD development team in implementing and prioritizing the development work. He organizes and conducts bi-weekly development team meetings, provides demos of the software to visiting groups, and gives presentations at various scientific conferences.

Greg was also the operations coordinator for a 3-week NOAA HWT experiment for the fourth year in a row, conducted in October 2019, using visiting NWS forecasters to test the Hazard Services – PHI (HS-PHI) application. This included helping guide the GSD software development, selection of archive case scenarios designed to train forecasters on the HS-PHI software and PHI concepts, and test various operational decision making situations including inter-office collaboration. Warning Decision Training Division scientists also collaborated on the experiment, in order to start the process of developing best operational practices. Forecasters used HS-PHI in several archived weather events in displaced real-time scenarios, which included severe pulse storms, hail storms, tornadic supercells, squall lines, bow echoes, and QLCS tornadoes. The evaluation included a human factors component collecting forecaster workload data. This HS-PHI experiment was also the first experiment to employ end users - emergency managers and broadcast meteorologists - a social science component that was funded using other means and led by other scientists. These end users worked with the visiting NWS forecast participants in integrated warning team discussions after each scenario. The data collected in the experiment is being used to refine the software and concepts for eventual operational implementation of PHI.

Over the past three years of development, we have brought the software to over 95% compliance with the 2015 baseline version of the NSSL PHI Prototype. The 2019 HWT experiment exhibited the most stable-version of the software since development began. The focus of recent development included these new features:

- Intermediate "Threats-In-Motion" (TIM) warnings (without PHI) – see more below
- Warning product generation
- Lightning PHI

"Threats-In-Motion" (TIM) is an intermediate solution to smoothly phase the warning paradigm from the current NWS warnings and fully-implemented PHI. The TIM concept comprises deterministic storm-following warning polygons that update at one-minute intervals. TIM has been shown to double location-specific lead times by giving all locations downstream of storms more equitable lead times. TIM also automatically clears out warnings after the events of passed, effectively reducing "departure time" to near zero.

In November 2019, Greg authored and submitted a proposal for a project entitled "Moving Threats-in-Motion (TIM) Toward Operational Readiness" to the FY 2020 Joint Technology Transfer Initiative. The outcome of the proposal decision will be made in April 2020.

Since the 2019 HWT experiment concluded, work has been underway to develop inter-WFO collaboration tools for another HWT experiment to be conducted in February 2020. This work will be reported in the 2020 annual report.

PROJECT PUBLICATIONS: N/A

Charba, J. P., F. G. Samplatsky, A. J. Kochenash, P. E. Shafer, J. E. Ghirardelli, and C. Huang (2019): "LAMP Upgraded Convection and Total Lightning Probability and ''Potential'' Guidance for the Conterminous United States". Wea. Forecasting , 34, 1519-1545

Roebber, P. and J. Crockett, 2019: Using a Coevolutionary Postprocessor to Improve Skill for Both Forecasts of Surface Temperature and Nowcasts of Convection Occurrence. *Mon. Wea. Rev.*, 147, 4241-4259.

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: HAZARD SERVICES: National Center Evolve

PRINCIPAL INVESTIGATOR: Nathan Hardin

RESEARCH TEAM: Nathan Hardin

NOAA TECHNICAL CONTACT: N/A as OWAQ/JTTI funded work

NOAA RESEARCH TEAM: Jim Nelson (NOAA/NWS/NCEP/WPC), Joe Sienkiewicz (NOAA/NWS/NCEP/OPC), and Fran Achorn (NOAA/NWS/NCEP/OPC)

PROJECT OBJECTIVES:

This project's goals are to develop workflows using Hazard Services that allow forecasters at the National Weather Service's (NWS) Weather Prediction Center (WPC) and Ocean Prediction Center (OPC) to produce the following operational products in AWIPS II:

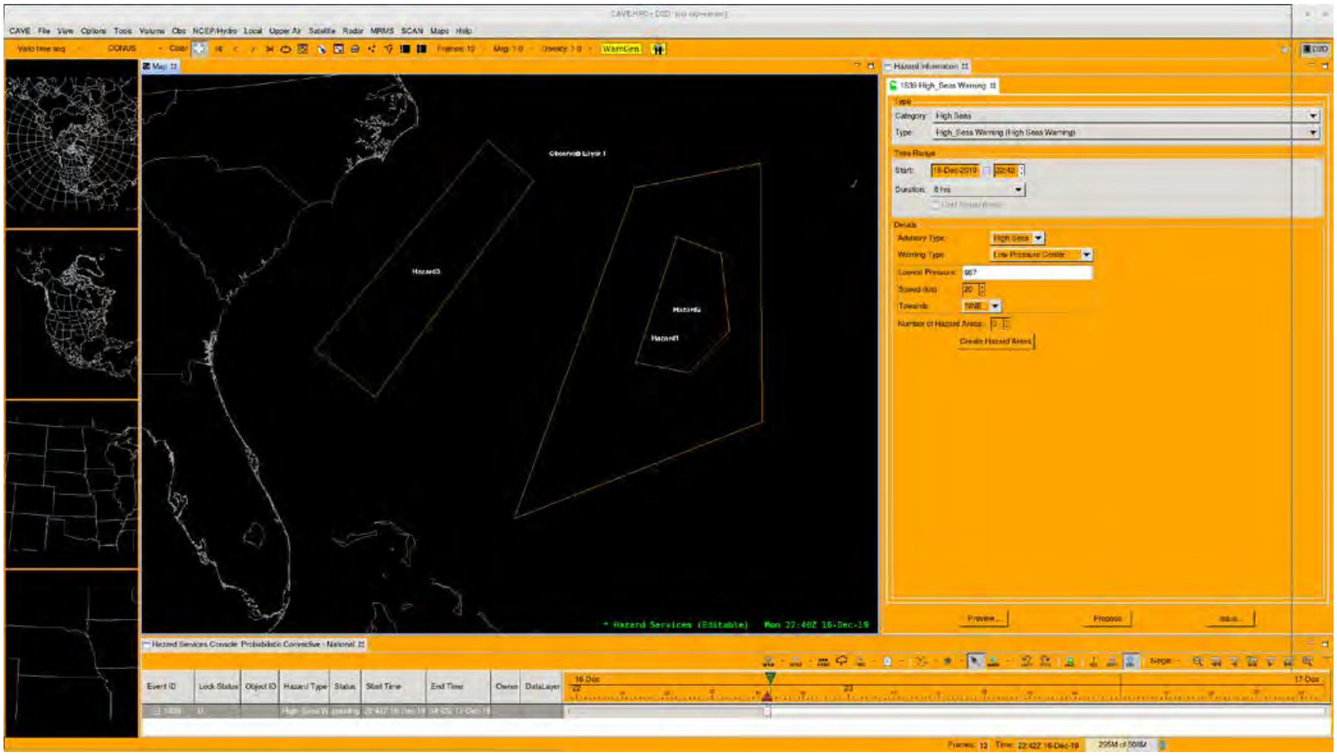
- For WPC:
  - Mesoscale Precipitation Discussion (MPD)
  - Excessive Rainfall Outlook (ERO)
  - Experimental Collaborative Winter Storm Watch
- For OPC:
  - High Seas Product

Updating these workflows into AWIPS II satisfy a requirement at the NWS level to modernize product generation on the AWIPS platform, while also satisfying requirements at the World Meteorological Organization (WMO) level to issue polygon-based hazards over the world's open oceans. Developing these workflows will modernice and improve operational forecasts for extreme precipitation, flooding, and winter precipitation events by infusing ensemble and statistical tools into the forecasting process.

PROJECT ACCOMPLISHMENTS SUMMARY:

This project began in September of 2019 as outlined in the project plan submitted with the grant. Based on the statement of work the only deliverable to this date has been gathering requirements and beginning to write the product design.

As part of the requirements process CIRA/GSD has been facilitating biweekly calls with the NWS Analyze, Forecast, and Support (AFS) Office to ensure robust requirements are being set for the four aforementioned workflows. Due to the collaborative nature of the High Seas Product in particular, it has been imperative that the impacted offices (OPC, National Hurricane Center, and Honolulu Weather Forecast Office) work together to establish desired formats and functionality. CIRA/GSD has also done some preliminary prototyping, which has been demonstrated on these biweekly calls for feedback with regards to design. This prototype was also included as part of a presentation at the National American Meteorological Society conference. An example of this prototype within Hazard Services can be seen in the following image.



At the beginning of February a trip was taken by CIRA/GSD to OPC/WPC in College Park, MD to finalize requirements for the four workflows. These requirements include the general workflow for a forecaster, generation and formatting for any output products (e.g. text, xml), and how those products and graphics will be sent to the web or disseminated for the public. One of the main parts of implementing a design is having a robust set of use cases. Therefore the main task at this point is for WPC and OPC, in conjunction with the National Hurricane Center and Honolulu Weather Forecast Office, to compile an exhaustive list of use cases for the workflows to be developed. These workflows are due to CIRA/GSD in early March. For WPC products the use cases have been gathered and documented.

While use cases are being compiled CIRA/GSD is focused primarily on developing a transition plan for this work, in partnership with the AWIPS Program Office (APO). This transition plan is part of the JTTI grant process and outlines the process for moving this project from testbed evaluation into operations.

The last project accomplishment at this time is the start of developing design documents. These documents will be used during the formal review process with the AWIPS Architectural Review Board (ARB) to ensure the code meets the standard to be included in the AWIPS II baseline code. The design documents highlight the components of each workflow, outline the expected behavior and timeline for generation and issuance, and lay the foundation for successfully integrating the design into the actual code. The designs for the four workflows are due at the end of April, with code reviews scheduled through May of 2020.

Relevant documents to this project can be found here:
JTTI Hazard Services: National Center Evolve Project Plan
High Seas Product Design Document
Excessive Rainfall Outlook Design Document
Mesoscale Precipitation Discussion Design Document
High Seas Requirements for Hazard Services

JTTI Hazard Services: National Center Evolve Transition Plan

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Hardin, N.R., D. Nietfeld, D. Kingfield, J. Sienkiewicz, F. Achorn, J. Nelson, T. Trogdon, J. Rhome: Progress Towards Integrated Tools for NWS National Centers. Abstracts, 36th Conference on Environmental Information Processing Technologies. Boston, MA, January 2020.

PROJECT TITLE: HURRICANE SUPPLEMENTAL 1C Proposal (3A-4)

PRINCIPAL INVESTIGATOR: Nathan Hardin

RESEARCH TEAM: Nathan Hardin

NOAA TECHNICAL CONTACT: Daniel Nietfeld, NOAA/ESRL/GSL

NOAA RESEARCH TEAM: This project is part of a larger effort but completed independently by CIRA personnel and a single PI, Nathan Hardin.

PROJECT OBJECTIVE:

The objective of this project is to implement developmental changes to tools in AWIPS using the Graphical Forecast Editor (GFE) to generate tropical cyclone hazard-specific threat forecasts for wind, inland flooding, coastal flooding, and tornadoes, as well as testing these changes within the AWIPS environment for the National Weather Service (NWS). This development will allow all weather forecast offices to generate and issue hurricane threat impact grids within GFE. Code delivery will be accomplished via code review with the AWIPS Program Office (APO) for baselining.

PROJECT ACCOMPLISHMENTS SUMMARY:

A site visit was conducted in June 2019 to the Honolulu National Weather Forecast Office to gather requirements associated with generating tropical cyclone hazard-specific threats in AWIPS II. The requirements were used to drive new development within the GFE to generate threats for wind, inland flooding, coastal flooding, and tornadoes mainly for the Pacific and Western NWS regions. Improvements to the code were finalized at the end of September 2019, and submitted for code review at the end of October 2019.

Code review was conducted with the AWIPS Program Office (APO), with developers from APO, the Office of Central Processing (CP), the NWS, and Raytheon participating. The code review also updated existing/modified code to version 3 for Python. This ensures operational success when implemented in FY21.

The code review was merged into the AWIPS baseline at the end of December 2019, consistent with the deliverables outlined in the project plan. As such, this project has been completed, although the changes will not show up in the baselined AWIPS code at individual sites until spring of 2021.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Environmental Applications Research - Global and Regional Model Development

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Ning Wang, Jeff Beck, Jacques Middlecoff, Haidao Lin

NOAA TECHNICAL CONTACT: Georg Grell OAR/ESRL/GSD/MDB Chief

NOAA RESEARCH TEAM: Shan Sun, Judy Henderson, CIRES: Mike Toy, Haiqin Li, Reiner Bleck, Yonggang Yu, Gerard Ketefian, and Linlin Pan

PROJECT OBJECTIVES:

1) Developing and improving global and continental scale weather prediction model,
2) Developing and implementing accurate and efficient numerical schemes for these models on massive parallel computer systems, and
3) Designing and developing a data assimilation system for weather forecast.

PROJECT ACCOMPLISHMENTS SUMMARY:

CIRA researchers work with federal and other Cooperative Institutes (CIs) collaborators continuing the effort to upgrade and improve the Finite-Volume Cubed-Sphere (FV3) model.

Based on EMC public release 15 and 16 Beta, CIRA researchers worked with Federal researchers (meteorologists and computer scientists) in the Global Systems Laboratory to create the corresponding versions to compile and run on Hera and Jet. To integrate different physics parameterization schemes into the future Unified Forecast System (UFS), CIRA researchers and researchers from other CIs helped evaluate various physics parameterization packages on FV3 through CCPP coupling interface.

To enable and test different parameterization schemes and to introduce and advect chemistry tracers, CIRA researchers added new software to ingest new initial data sets required by these schemes. In addition, a new statistical orographic data set for cubed sphere grid cells was ingested to FV3 to evaluate its impact on the parameterization of the orography induced gravity wave drag and its interaction with boundary layer physics parameterization.

CIRA researchers at GSL, together with Dr. Yonggang Yu of CIRES, implemented an icosahedral-grid based global atmospheric Shallow Water Model (SWM). SWM implements A-grid (NICAM) staggering and C-grid (MPAS) staggering in one framework. CIRA researchers parallelized the SWM C-grid (A-grid was parallelized last year). The structure of the C-grid presents a parallelization challenge.

The parallelization was done using the Scalable Modeling System (SMS). SMS is a directive based system based on MPI. SMS was developed by CIRA researchers to facilitate parallelization of weather models. Recently CIRA researchers improved SMS by eliminating the copy of data into and out of buffers before sending and receiving the data between processors. For SWM, exchanging data between processors without buffer-copying results in the exchanges taking less than 5% of the computing time and leads to excellent scaling for both the A-grid and the C-grid.

With the transition of the NCEP model suite into the Unified Forecast System (UFS), efforts have begun to move all operational regional forecast systems to the FV3 dynamical core in what will be called the

Rapid-Refresh Forecast System (RRFS). Within this new paradigm, work focused on testing and subsequent development of the new, stand-alone regional (SAR) version of the FV3 model. Primary goals included evaluating pre-processing capabilities (grid generation/initial and boundary condition options) and engineering necessary changes to run a 3-km HRRR-like simulation over the CONUS.

Building on work from the previous year, a new gnomonic grid was developed for the FV3-SAR, in collaboration with EMC, to allow for more uniform grid spacing across the domain than using the original option provided with FV3. This option is now implemented in the community workflow and configured for all pre-defined domains. In addition, through collaborative work with NSSL, a new version of chgres_cube (pre-processing utility) including a grib2 capability was added to the community workflow, providing support to initialize the FV3-SAR off of both RAP and HRRR data. CCPP was also integrated into the community workflow with the capability to run several GFS and GSD physic suite options.

With necessary pre-processing development work complete and the option to run GSD physics in CCPP, a 3-km HRRR-like domain was generated in order set up simulations as closely as possible to the operational HRRR. Next, two GSD real-time systems using the 3-km HRRR-like domain were set up on Hera using the community workflow; one to run with HRRR initial conditions and another to run using FV3GFS initial conditions. Otherwise, these two real-time simulations are identical. Both simulations are cold-started and run at 00Z and 12Z, with NCL graphics sent to the real-time HRRR website (https://rapidrefresh.noaa.gov/hrrr/). Surface, upper-air, and reflectivity verification is also available for both simulations on the MATS website (https://www.esrl.noaa.gov/gsd/mats/). These real-time systems will serve as a benchmark for comparison to the operational HRRR as well as the framework upon which future iterations and implementations of the RRFS will take place.

To support the development of the FV3-SAR model, CIRA researchers have been working on the software that modifies the surface initial condition data, including fractional land-sea-ocean mask. A new program lake_frac_sar has been created by CIRA researchers to produce lake depth and fractional lake mask data for SAR FV3’s spherical grid as model non-time varying initial data. The program and the dataset is currently being tested by EMC for the SAR FV3 model

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

"Comparing Numerical Performance of Icosahedral A-grid and C-grid Schemes for the Shallow Water Model" by Jacques Middlecoff, Yonggang G. Yu, Ning Wang, and Mark Govett, 2019 AGU Fall Meeting.

PROJECT TITLE: Environmental Applications Research - Advanced Computing for Models

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Bryan Flynt, Isidora Jankov, Jacques Middlecoff, Duane Rosenberg, Jebb Stewart

NOAA TECHNICAL CONTACT: Mark Govett NOAA/OAR/ESRL/GSD/ATB

NOAA RESEARCH TEAM: Mark Govett, Lidia Trailovic, Yonggang Yu

PROJECT OBJECTIVES:

This project seeks to advance the state of numerical weather forecasting (NWP) by undertaking research into numerics and exascale-directed performance of dynamical cores and representative dynamical processes, by development of performant data assimilation (DA) elements, and by application of novel techniques, such as machine learning (ML) in development of potential subgrid, regression, or parameterized processes that can leverage exascale capabilities to speed up forecasting workflow. This work is strongly motivated by the need to take advantage of the roughly 1000-fold increase in emerging computing power over current targets that the exascale era will offer. The work will, more broadly, help guide and inform algorithm design and development for future modeling systems, aid in improving more near-term prediction products, and quantitatively assessing existing models and optimization techniques. Since the outcome of nearly all efforts is the creation of production software and software components that are curated throughout their life-cycle, this research strives to be a showcase for scientific software development: all efforts adhere to modern software development practices so as to make engagement with collaborators more efficient and constructive, and to enable faithfulness to research guidelines regarding reproducibility of results, and data provenance. Lastly, since all efforts rely inherently on high-performance computing (HPC), they are often able to be leveraged symbiotically in support of HPC operations. Accomplishments are provided for each topic area in support of these objectives.

PROJECT ACCOMPLISHMENTS SUMMARY:

A. Data assimilation

During the past year CIRA researchers led and participated in several different DA related activities:

- The HPC branch DA team developed an MPI version of the Shallow Water model (SWM) and its tangent linear and adjoint and implemented it within JEDI. One aspect of this work focuses on background error covariance matrix (B matrix). The impact that various versions of B matrix have on the model performance has been evaluated by utilizing the JEDI environment. In addition to model performance in terms of accuracy (the analysis quality) changes in computational cost for a variety of B matrices has also been evaluated.

  An additional focus related to this work was on examining different ways of localizing the B matrix for an ensemble-based DA system. This work resulted in the preparation of a manuscript for submission in a peer-reviewed journal. The localization is often based on a single best estimate of horizontal and vertical localization scales. This manuscript presents a new way of determining horizontal localization scales as a single best estimate as well as dynamically estimated localization scales at each analysis time. The new approach to defining the horizontal localization scales was tested for both observation and model based localizations. The impact of new localization scales was evaluated by examining the changes in analysis and forecast errors. Results showed a notable reduction in analysis error when dynamical estimation of localization scales was employed. The effect of various estimates of the horizontal localization scale parameter on analysis results have been tested by utilizing the Constant Potential Vorticity (PV) f-plane Quasi-Geostrophic turbulence, or simply the Surface Quasi-Geostrophic (SQG) turbulence model with one layer and with its corresponding Square Root EnKF data assimilation system. An example of change in analysis error for different types of localization is presented in Figure 1.

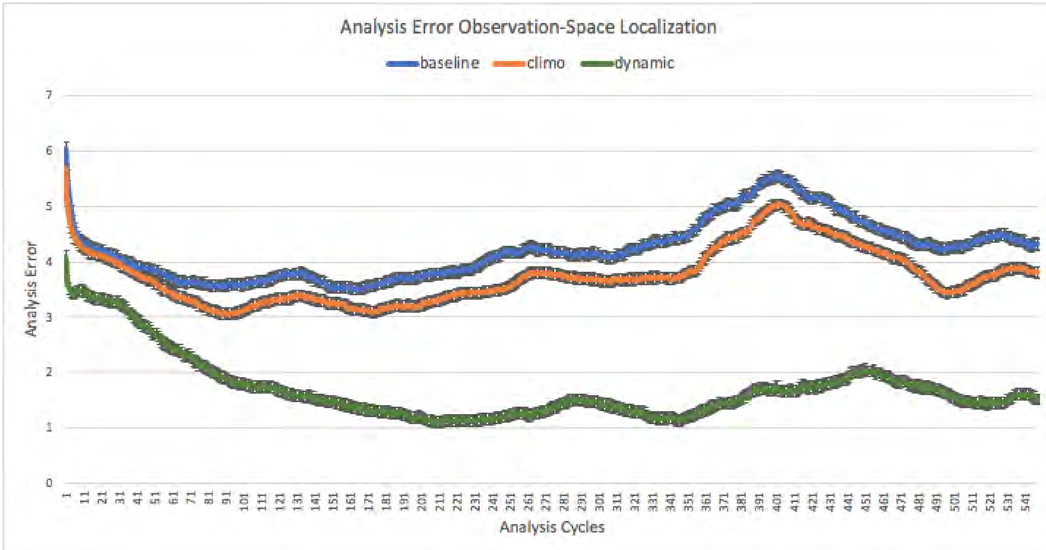


Figure 1. Analysis error as a function of analysis cycles, for the three experiments for observational space localization: empirically determined value of localization scales (baseline), climatological value of localization scales (climo) and dynamically determined localization scale at each analysis time (dynamic). Error bars represent observation error.

- CIRA researchers at GSD in collaboration with CIRA colleagues in Fort Collins prepared and submitted a proposal focusing on using a Machine Learning (ML) algorithm to improve the Rapid Refresh (RAP)/High Resolution Rapid Refresh (HRRR) initial soil state (soil moisture and temperature). The proposal was submitted to NOAA-OWAQ-JTTI. Prior to the proposal submission, preliminary work was performed that included development and testing of several ML algorithms and examination of ABI data to assess their feasibility for this project.

- The CIRA research team implemented and tested stochastically perturbed parameterizations (SPP) approach as a part of HRRR DA system (HRRRDAS). Stochastic perturbations are created by applying random patterns to parameters/variables of interest. These patterns are spatially and temporally correlated. An example of temporal and spatial de-correlation lengths is presented in Figure 2. HRRRDAS including the SPP was implemented into operations at NCEP/EMC as a part of the HRRRv4 operational system.

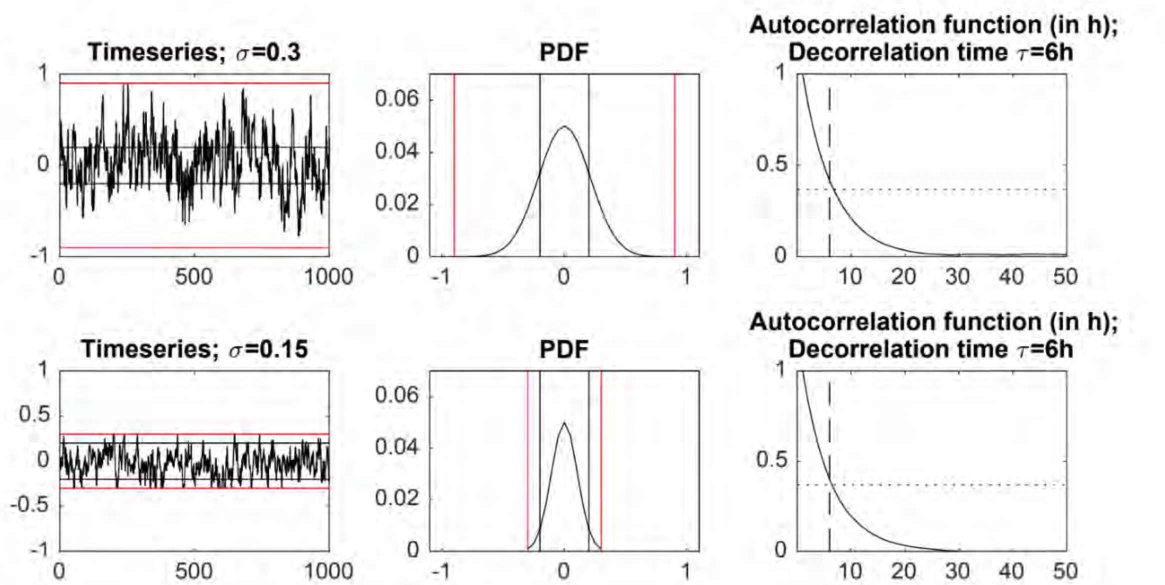


Figure 2. Temporal and spatial de-correlation lengths used for application of random patterns to parameters/variables of interest in SPP.

B. Shallow Water: Examining accuracy and computational efficiency of grid centerings.

CIRA researchers at GSL, together with Dr. Yonggang Yu of CIRES, implemented an icosahedral-grid based global atmospheric Shallow Water Model (SWM). SWM implements A-grid (NICAM) staggering and C-grid (MPAS) staggering in one framework. CIRA researchers parallelized the SWM C-grid (A-grid was parallelized last year). The structure of the C-grid presents a parallelization challenge.

Our original layout of the <*word missing*: grid?>, which is the usual C-grid layout, had two independent variables: NIP and NIE=3*NIPC-grid, where NIP is the Number of Icosahedral Points and NIE is the Number of Icosahedral Edges. The center points were represented by NIP and the edges by NIE. The hexagons have 6 edges, but since the hexagons are adjacent only 3 of the 6 are independent. For parallelization, two independent variables translates to two decomposed dimensions which makes parallelization complicated and requires time consuming transformations between the two independent variables. Many C-grid parallelization schemes maintain the two independent variables but CIRA researchers decided to simplify the parallelization and make it more efficient by first changing the layout so NIP was the only independent variable. This was accomplished by changing the dimension of the side variables from side(NIE) to side(6,NIP). This doubles the memory requirement of the side variables, but these variables are distributed so memory is not a problem. After parallelization was completed the C-grid was optimized by only calculating the three independent sides and copying the result to the corresponding side on the adjacent icosahedral cell.

The parallelization was done using the Scalable Modeling System (SMS). SMS is a directive based system based on MPI. SMS was developed by CIRA researchers to facilitate parallelization of weather models. Recently CIRA researchers improved SMS by eliminating the copy of data into and out of buffers before sending and receiving the data between processors. For SWM, exchanging data between processors without buffer-copying results in the exchanges taking less than 5% of the compute time and leads to excellent scaling for both the A-grid and the

C-grid. Scaling plots for the A and C grids are shown in figure 3 for both scalar, left and bottom axes, and log-log, top and right axes.

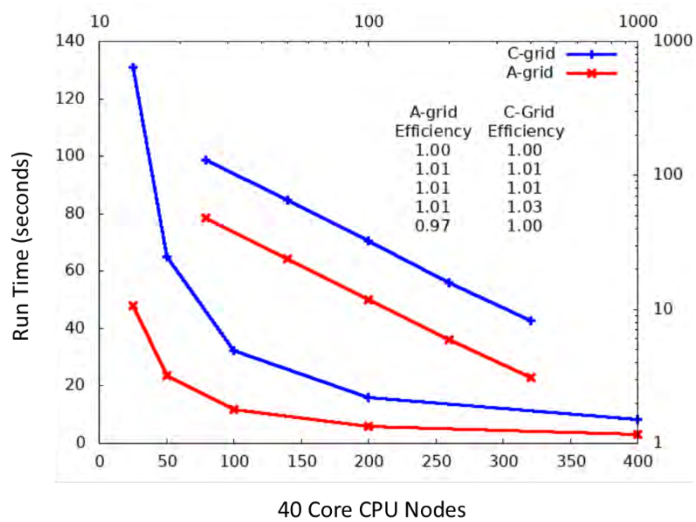


Figure 3. Shallow Water Model data exchange.

In our implementation on Intel Skylake CPUs, the A-grid is 2.7X faster than the C-grid which we attribute mostly to the equations which promote good variable reuse for the A-grid but not for the C-grid. Dr. Yu has shown, at high resolution and plotted against the number of icosahedral cells that the L2 error norm for the A-grid is smaller and is decreasing faster than for the C-grid. We have plotted the L2 error norm against time to completion for fixed resolutions which elucidates the A-grid L2 error norm advantage (Figure 4.).

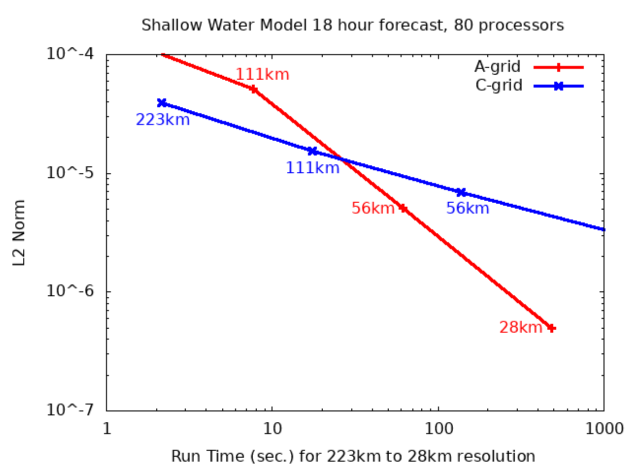


Figure 4. Shallow Water Model error norm.

A poster on this work entitled "Comparing Numerical Performance of Icosahedral A-grid and C-grid Schemes for the Shallow Water Model" by Jacques Middlecoff, Yonggang G. Yu, Ning Wang, and Mark Govett was presented at the 2019 AGU Fall Meeting.

C. GeoFLOW: Dynamics modeling framework

CIRA researchers have developed the GeoFLuid Object Workbench (GeoFLOW) framework as a means to examine computational elements of fluid and fluid-like partial differential equations (PDEs) that not only comprise the essence of dynamical cores used in NWP and climate modeling systems, but that also represent more narrowly-focused problems in the earth sciences. GeoFLOW enables development and testing of such elements from individual serial numerical operators up to entire fully parallelized PDEs, including their time integration as well as IO, and is designed to examine tradeoffs between performance and solution accuracy. The framework uses a common set of high level interfaces (template classes) for all discretization schemes that specify all aspects of time-integrating and monitoring PDE solutions.

During this performance period, a number of significant advancements were made to the GeoFLOW software.

1. Completed all high-order integro-differential operators for fiducial (generalized advection-diffusion) solver.
2. Began detailed testing of fiducial solver (and, therefore, the entire code base), in parallel, using analytic linear advection and nonlinear N-wave solutions in 2d planar and spherical and 3d planar geometries. Found that error scaling is spectral, as expected.
3. Achieved an 82% speed up in initialization of ‘gather-scatter’ geometry-free exchange (GGFX) operator that handles distributed and local communication, by implementing a Quick Sort algorithm in the primary Vector class, and using this to carry out the bin-sorting step during operator initialization.
4. Systematized user initialization of GeoFLOW by creating base classes and ‘factories’ for boundary conditions, boundary condition specification, forcing methods, and state initialization methods. Began the process of providing implementations for each of these features in a way that may be expanded upon by other users, and that are useful (and used) for the runs we are doing with the fiducial solver. This work has provided the architectural design governing how users will interact with the solvers supported in GeoFLOW.
5. Initiated abstraction of (binary) IO methods, by developing a base class interface, an IO method factory, and a new default implementation. The new scheme, GeoFLOW-IO, or GIO, was conceived to subsume and replace the existing POSIX IO capability, and to provide for *both* collective (via MPI-IO) and per-MPI task POSIX IO.
6. Formalized the method by which users may carry out in-situ computation of state-derived (hence, not evolved) quantities and output them at the same cadence as the PDE ‘primitive’ variables. These derived quantities are specified at runtime via the configuration file.
7. Began development of a new solver for moist convection using high-order CG/DG formalism, using the same operators that are used for the fiducial solver.
8. Developed a post-processing tool to read in GeoFLOW data and compute probability distribution functions (PDFs).
9. Developed post-processing tools to convert raw grid and solution data to parallel VTK format for visualization (see Figure 5 for examples); wrote Matlab scripts to read GeoFLOW data, and to visualize solutions for all grids currently supported, mainly for debugging purposes.
10. In a significant effort, we created an easily extensible modern (version 3.x) CMake build system in such a way that it can be maintained on various computer systems and with evolving library versions. The system includes advanced capabilities such as automatically extracting repository information (dates, commit numbers and hash information) during configuration and embedding it within the source code to be displayed at run time for better tracking of model results to code versions (i.e., better handling of data provenance).

11. Implemented algorithms from the shallow water model discussed in Sec. C using GeoFLOW framework and data structures, in a first attempt to include low order schemes into the framework.
12. Took initial steps toward a unified grid interface that allows finite volume and finite/spectral element computation on the same grid; examined use of the Distributed and Unified Numerics Environment (DUNE) interface while allowing for curved geometric shapes spectral element method allows.

In addition, CIRA researchers undertook more fundamental research into single point statistics of multi-dimensional nonlinear-advection-diffusion in different geometries in 1d and 2D to determine whether theoretically-predicted behavior in the tails of PDFs of field derivatives can be confirmed in the original 1d formalism, and in 2D planar and spherical geometries. A key goal is to determine the effect of polynomial expansion order on this behavior, as this determines whether low order schemes can hope to capture these types of scale interactions. This is a compelling test of the numerics' ability to handle fine-scale interactions, and a key step towards being able to quantify trade-offs between accuracy and numerical efficiency using GeoFLOW that will also be used for other PDEs. Figure 5 shows representative initial conditions and evolved small scale structures from which statistics are derived in 2d simulations on the sphere.

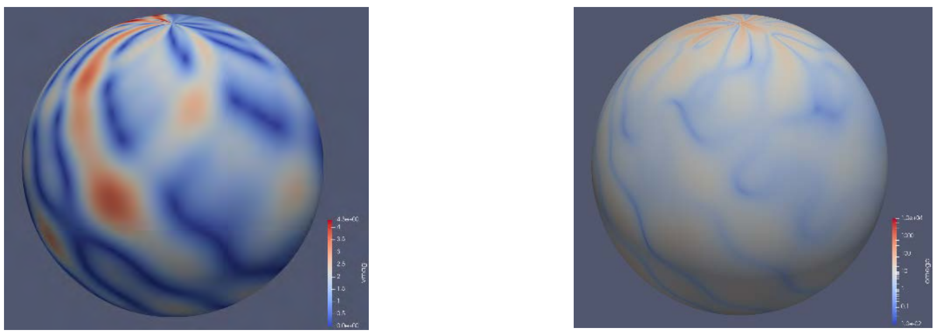


Figure 5. *Left*: Initial conditions for field in high Reynolds number Burgers turbulence run; *Right*: Vorticity field near peak in enstrophy, showing sharp front networks, from which statistical information is extracted. Visualizations were made using the new VTK post-processing utility.

D. Hardware characterization and support

CIRA researchers, using the previously reported code sendRecv.F90, found a bug in MPI_scatterv on the Hera Fine Grain Experimental (FGE) system. Another code called testScatterV.F90 was written by CIRA researchers to demonstrate the bug in MPI_scatterv. A help ticket was submitted including testScatterV.F90 with instructions on how to use it. Later, at the request of FGE systems analysts, the code sendRecv.F90 was used to demonstrate the MPI_scatterv problem still existed. CIRA researchers wrote the code SRscatterv.F90 which replaced MPI_scatterv with MPI_send and MPI_recv to demonstrate that the scatterv problem is not with the system but with MPI_scatterv. CIRA researchers replaced MPI_scatterv in SMS with SRscatterv.F90 because at high processor counts MPI_scatterv was very slow on some systems and caused a segfault on others.

SWM (Sec. B) requires PAPI to interface with the performance counters on Hera. A help ticket was submitted by CIRA researchers to have PAPI installed and SWM was used to verify that PAPI works properly.

Using the SWM build process CIRA researchers found an error on the FGE system with modules. A help ticket facilitated the error's correction.

Using SWM, CIRA researchers determined FGE node tg015 was bad. By way of a help tg015 was removed and later repaired and returned to the system.

E. Software processes and practices

CIRA researchers collaborated with GSD software engineers to enable Travis CI (*continuous integration*) for the GeoFLOW GitHub repository. All Travis CI configuration scripts were extended to build GeoFLOW libraries and a series of regression tests. The regression tests, so far, are largely unit tests that currently encapsulate: BLAS & other tests of fundamental Vector and Matrix objects, tensor products, integration (checks of metric terms), and parallel communication via a "gather-scatter" operator. These tests were configured to run automatically whenever a "pull request" is made to the master GeoFLOW branch. A number of the regression tests were augmented with additional internal tests; more holistic regression testing is likely in subsequent performance periods.

F. Machine Learning and Artificial Intelligence Research

CIRA researchers continued to work with other colleagues at GSD in researching the applications of Machine Learning (ML)/Artificial Intelligence (AI) techniques towards atmospheric science. In a partnership with the Taiwan Central Weather Bureau, CIRA researchers expanded previous work into deep learning for object segmentation to build a Neural Network (NN) to detect areas of likely convection initiation with various lead times using satellite imagery. Part of this research also explored better understanding of what NNs identify in the data to make their determination, increasing our understanding of how NNs work. Other applications of ML/AI included using ML regression models to extract an improved relationship between surface weather conditions and soil moisture state. This improved NN model is currently under evaluation to determine improvements to overall weather forecasting.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

A poster on this work entitled "Introducing GeoFLOW: Single point statistics in decaying multidimensional Burgers turbulence" by D. Rosenberg, B. Flynt, M.Govett, and A. Pouquet was presented at the 2019 AGU Fall Meeting.

PROJECT TITLE: Environmental Applications Research - Unified Post Processor (UPP) Software Support and Community Engagement (DTC Task)

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Ka Yee Wong, Isidora Jankov

NOAA TECHNICAL CONTACT: Georg Grell NOAA/OAR/ESRL/GSD/MDB

PROJECT OBJECTIVES:

The DTC provides a framework for the operational and research communities to collaborate in order to accelerate the transition of new scientific techniques into operational weather forecasting. In this framework, UPP continues to serve as a bridge between the two communities. It provides the capability to process atmospheric model output from WRF and FV3, compute a variety of diagnostic fields, interpolate to pressure levels, de-stagger grids, and interpolate to specified grids. It is a critical component of end-to-end NWP systems for all applications. UPP is currently used in operations for global, regional, and hurricane applications. Its user base continues to expand as capabilities grow. The community UPP repository has been maintained in a manner such that updates and enhancements may be contributed by, and shared between, both the operational and research communities.

PROJECT ACCOMPLISHMENTS SUMMARY:

During this performance period, the repository was ported to a git-based repository and moved to GitHub to be in line with the EMC operational UPP repository and to easily facilitate shared code. A new community release of UPP (V4.0.1) was distributed in August 2019, with a major update of this version including a FV3GFS processing fix, including a modified input format for processing FV3GFS data. Staff also updated logic for selecting a subset of channels from a satellite sensor.

Extensive testing was performed prior to this release, with a set of regression test scripts (UPP Framework For Detecting Anomalies: UFFDA) developed to run the tests automatically. Both NetCDF for WRF model output and NEMSIO for FV3GFS file formats were tested in serial and parallel (using MPI) environments. The full suite of tests was run on computing platforms available to the DTC (including the NCAR supercomputer, Cheyenne, and NCAR computer systems, Puffling, and with extension to the NOAA supercomputer, Hera) during this period of performance using a variety of compilers, to ensure portability to the user community. Updates to documentation were made available to the user community with the release (Users' Guide and webpage).

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: EAR – Verification work to support regional and global modeling

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Randy Pierce, James Frimel, Venita Hagerty, Bonny Strong

NOAA TECHNICAL CONTACT: Dave Turner (OAR/ESRL/GSD/ADB Section Chief)

NOAA RESEARCH TEAM: Dave Turner (OAR/ESRL/GSD/ADB), Jeff Hamilton (CIRES), Molly Smith (CIRES)

PROJECT OBJECTIVES:

The objectives of this project include:

1) Develop and maintain a modern web-based verification toolset to replace existing tools which support weather modeling development within GSD.
2) Support modelers within GSD/ADB and GSD/MDB to use verification tools effectively.
3) In collaboration with NCAR, meet planned deliverables within the Developmental Testbed Center (DTC) Verification Task to enhance the METplus software package

4) Complete deliverables for a funded project within the NWS Next Generation Global Prediction System (NGGPS) to support Unified Verification across Research and Operational centers.
5) Develop a verification system to support the specific needs of the Atmospheric Science Renewable Energy project, including a new database based on NoSQL technology.
6) Plan for the longer-term development of process-oriented verification tools and enhanced use of satellite data in verification, including the use of Machine Learning technology.

PROJECT ACCOMPLISHMENTS:

Objective 1: Verification Tool Suite

The Model Assessment Tool Suite (MATS) was developed by the project team to provide a modern web-based interactive web application for performing verification of real-time and retrospective runs of model forecast systems, based on a legacy MySQL database maintained at GSD. In addition, the web frontend is being used to interface to a MET database that is part of the Developmental Testbed Center community MET verification package. This has been named METexpress and has been installed within Amazon Web Services for use by NCEP/EMC.

During this past year, 3 more METexpress apps were added for Ensembles, Air Quality, and Precipitation. A MET database has also been installed and maintained for use at GSD. As the legacy GSD system does not have any ensemble verification capabilities, METexpress has taken on greater importance for GSD as well. Completing an app for ensemble verification was a significant accomplishment for the year, filling a major need for model developers.

A major focus this past year for the MATS tool suite has been managing development and deployment using containers, which especially support cloud-based deployments. A new build and deploy integration system has been built using Docker, Kubernetes, and Rancher tools.

Objective 2: Support to Modelers

The software development team has interacted with the model developers on an almost daily basis understand their needs clearly and to identify software issues, bugs, and requested new features. Bugs, issues, and feature requests are tracked through NOAA's VLab Development Service. Requests for significant new features are reviewed with the GSD/ADB Leadership Team to assign priorities for team efforts.

Objective 3: DTC Deliverables

CIRA developers at GSD are also part of the Developmental Testbed Center, a joint center between NCAR and NOAA. During this past year, a major focus for that effort has been building a framework for Continuous Integration and Testing using Jenkins tools.

In addition, the team has provided support for METplus scripting, including systems engineering analysis and design, unit and integration testing, and bug fixes, leading to 3 releases during the year:

METplus-3.0 release current
METplus-2.2 release July 25, 2019
METplus-2.1 release May 3, 2019

The team has also helped DTC build a use case template for ensemble verification and helped to debug the MET software for ensembles.

Objective 4: NGGPS Deliverables

During this reporting period, a proposal was successfully submitted to the Next Generation Global Prediction System (NGGPS) for the team to support the development of the Unified Verification System.

Deliverables under the NGGPS funding this year included:

1) Development of 3 new apps for METexpress, including Air Quality, Precip, and Ensembles, and
2) Rewriting the MET database code to load data into the database to be more modular and support multiple database management systems.

For the 3 new apps for METexpress, the team interacted with the NCEP/EMC verification team to understand their needs and produce specifications for each app. The 3 new apps were developed and then installed in the METexpress instance running on Amazon Web Services, where they were reviewed by EMC users. This development has been completed and a final report is in progress.

A screenshot of the new Ensembles interface is shown in figure 1 below.

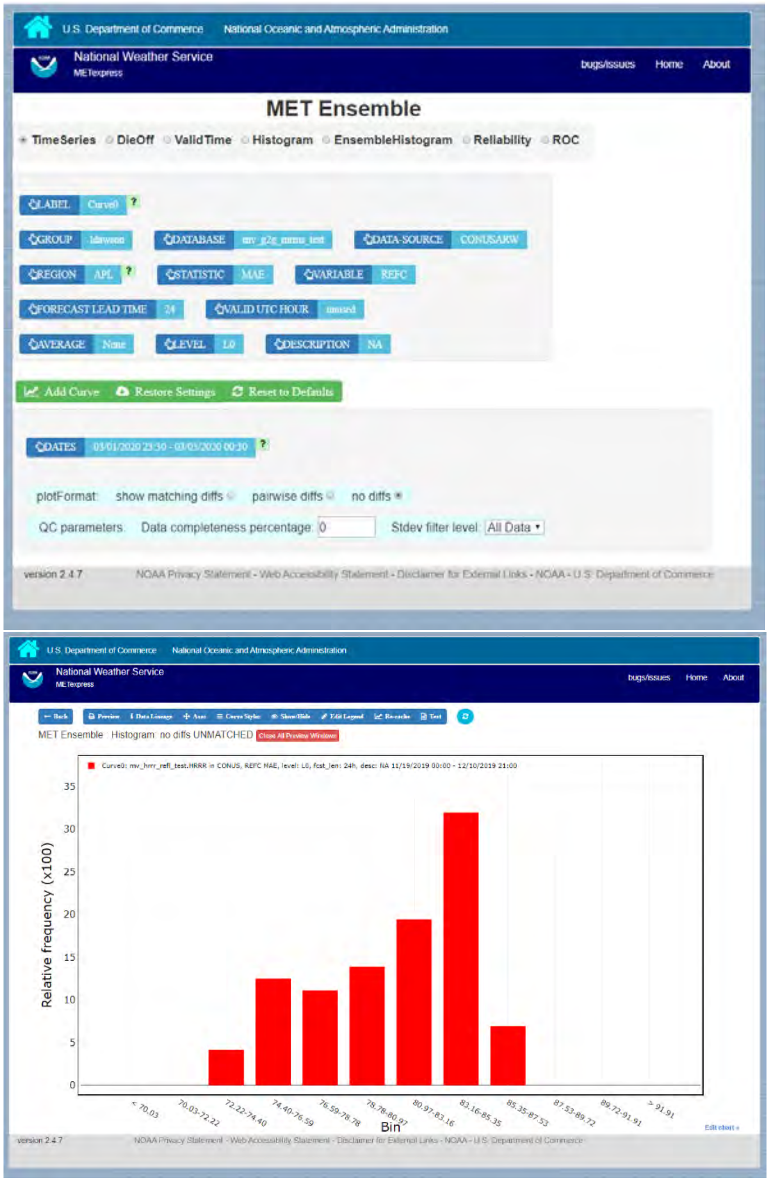


Figure 1. Ensemble App Interface and Plot

Deliverable 2 evolved from work to develop a new database system for METviewer/METexpress. The GSD team has worked to create a backend for MET using newer database technology, specifically Couchbase, a NoSQL or document-based database. The METviewer database code was originally written some years ago to only work with a MySQL database. In addition to wanting to use Couchbase, it has become necessary to support other SQL databases such as AuroraDB, used on Amazon Web Services. In order to make support of multiple backend databases sustainable and manageable an effort was begun to rewrite the code for loading and querying the database more modular, allowing databases to be switched by changing a small number of routines.

During the past year, this work has been mostly completed for the software that loads data into the database. Testing and code reviews have been implemented and used throughout the development process.

Objective 5: Renewable Energy Deliverables

In order to support model improvements for wind forecasting, the verification team was asked to develop a system to support more detailed analysis of model outputs and to support analysis of model results at individual stations rather than aggregated over a region. In order to do this, an appropriate database was needed which can support much larger sets of data and still remain performance. The MATS system has been working a new database schema using a document-based approach and written in Couchbase.

Over this past year, the team has been closely at the design of the new database. In-depth sessions have been held with database and software experts together with modelers and scientists, in order to gain a clear understanding of the data and use cases for how it will be used. The data model has been completed and an initial prototype implementation is in process. This will lead to an iterative approach between database design and use.

Objective 6: Machine Learning

The verification team began work during this past year under an internally-funded proposal to do new work in Machine Learning. The funded proposal is to use physics-guided machine learning methods to improve radiative transfer in dense neural networks. The team is exploring using physically-based constraints in training a neural network to compute shortwave radiative heating rates and fluxes to provide a significantly faster radiation scheme that has small biases. This work is mostly complete and a report on the results will be forthcoming in April 2020.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Environmental Applications Research – Hurricane Weather Research and Forecasting Model (HWRF) Support (DTC Task)

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Jim Frimel

NOAA TECHNICAL CONTACT: Curtis Alexander NOAA/OAR/ESRL/GSD/ADB Chief

NOAA RESEARCH TEAM: Evan Kalina CIRES

PROJECT OBJECTIVES:

The DTC currently hosts the HWRF code repository, which is composed of a set of scripts plus eight component repositories: WRF atmospheric model, WRF Preprocessing System (WPS), GSI data assimilation, HWRF-utilities (which includes several libraries and a vortex initialization package), ocean-atmosphere coupler, MPIPOM-TC ocean model, UPP postprocessor, and vortex tracker. The DTC and CIRA engineers maintain the HWRF code repository and coordinate the links to all external source code components. This work includes updating the main HWRF development branches with all code enhancements in the trunk of the community repositories, assuring that the main HWRF development and community codes remain synchronized.

CIRA provides software and systems engineering analysis, development, and support to meet the annual scientific and research goals of the HWRF project. Additionally, CIRA engineers support scientists and external partners to advance their required deliverables.

PROJECT ACCOMPLISHMENTS SUMMARY:

CIRA staff implemented changes to the HWRF workflow to support Inter-Cycle Data Assimilation (ICDA). This task is meant to support data assimilation (DA) developers who want to conduct DA in between full forecast cycles. The workflow has been modified so Rocoto can run inter cycles at a user-specified frequency. Modifications to have the ensemble DA Task support hourly cycling, without running relocation were completed and implemented, enabling non-synoptic hourly cycling with only GSI influencing the relocation of the storm. CIRA also provided HWRF testing and support of the transition from the MOAB/TORQUE scheduler to the SLURM scheduler on the NOAA HPC systems. Including making changes needed, and resolving issues found in the HWRF "produtil" code base and a new version of Rocoto. Work also included keeping changes updated in the NCEPLIBS "produtil" software repository. Other work included providing changes, testing and support for compiling, and running HWRF on the new Hera HPC cluster, with the latest Intel 18 compilers. All changes needed to run HWRF on Hera were merged into the HWRF trunk. CIRA also provided code support and changes to GSI with intel 18 compilers and finalized bug fixes and testing of the GSI source code with version 18 of the Intel compiler and version 2.2.6 of CRTM. Regression tests on Jet and Hera were run to verify that the bug fixes did not change the HWRF model results.

CIRA engineers, along with partners at NCEP/EMC and the Developmental Testbed Center (DTC), also continued development on HWRF with ongoing software lifecycle maintenance and support. This work included general software repository maintenance and support with branch/trunk sync-merges, software conflict resolution, and HWRF consistency checks – integration and results testing.

Overall, staff provide ongoing and continued support to project scientists and users, related to the HWRF codebase, troubleshooting, the HWRF-Help user support RT Ticketing system, the HWRF database, and GitHub.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Environmental Applications Research – UFS-CAM Software Support and Community Engagement (DTC Task)

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Jeff Beck

NOAA TECHNICAL CONTACT: Georg Grell NOAA/OAR/ESRL/GSD/MDB

NOAA RESEARCH TEAM: Gerard Ketefian, Linlin Pan

PROJECT OBJECTIVES:

The Unified Forecast System (UFS)-Convective-Allowing Model (CAM) capability has undergone rapid development in an effort to establish a stand-alone regional (SAR) version of the FV3. A number of operational and research partners have been collaborating on this quickly-changing code base to advance the system, emphasizing the need for robust governance of repositories and extensive regression testing. Therefore, one goal is to create a GitHub repository for the SAR-FV3 workflow in order to facilitate community interaction. Code management regulations regarding software development practices and how community contributions can make their way into the workflow repository will be clearly defined in a code management plan and implemented based on protocols being put together by EMC management. A code review committee will be established with representation from the DTC, EMC, GSD, and other NOAA laboratories to assess potential commits to the master workflow repository. While it is understood that each community has specific needs, it will remain a goal to avoid unnecessary divergence between the operational agencies and the research community, with the operational configuration remaining a subset of the larger community workflow repository capabilities. Therefore, another goal is to assist community developers with the governance protocol when contributing scripts and utilities to the workflow repository. To this end, regression tests will be created to ensure code remains in a working state after each commit. In addition, portability of the code to all NOAA and NCAR HPC platforms will facilitate accessibility for the majority of the weather enterprise. Finally, updates to the community workflow will serve to incorporate the latest capabilities of the FV3-SAR system as they are developed by operational and research partners.

PROJECT ACCOMPLISHMENTS SUMMARY:

During the past year, the FV3-SAR workflow repository was successfully transitioned to GitHub, with a code review committee established between scientists at NOAA/GSD, NCAR, NSSL, and NOAA/EMC to review pull requests. Work began on initial regression testing, including the development of end-to-end comparison scripts ensuring code changes result in identical model output. Throughout the year, changes were incorporated into the FV3-SAR community workflow, including options for new pre-defined domains, the uniform JPgrid, new CCPP suites, and modifications to output variables/UPP. Work also began on porting the community workflow to multiple NOAA HPC machines (Jet and Hera) and Cheyenne (NCAR's HPC machine). As work progressed, documentation was developed in parallel for each component of the workflow. User support for the community workflow was also provided to a number of collaborators in both the research and operational communities.

A code sprint was held during the summer of 2019 to merge the operational EMC FV3-SAR workflow with the community workflow being developed by DTC. An outline to merge the codes was developed with a number of milestones defined, culminating with a final, merged community workflow in January 2020.

Members of the team also contributed their time on global UFS Medium-Range Weather App focus teams, helping to organize documentation, pre-processing/workflow code, and user support for the first global release.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Environmental Applications Research – Verification Work to Support Regional and Global Modeling (DTC Task)

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Jim Frimel

NOAA TECHNICAL CONTACT: Curtis Alexander NOAA/OAR/ESRL/GSD/ADB

NOAA RESEARCH TEAM: Melinda Marquis, Dave Turner

PROJECT OBJECTIVES:

CIRA has been working closely with the DTC verification team at NCAR to build a unified verification system based on the MET verification software package. For the past year, objectives centered on the continued development of METplus wrappers (consisting of a suite of Python code) and ancillary scripts to enhance a user's ability to run MET. A description of METplus can be found on GitHub: https://ncar.github.io/METplus

PROJECT ACCOMPLISHMENTS SUMMARY:

CIRA engineers worked closely with NCAR scientists and engineers to provide software and systems engineering analysis, development, and support to meet the annual goals of the METplus project.

CIRA engineers ported METplus wrappers and the EMC "pyprodutil" package subset used by the METplus scripts from Python 2 to Python 3 and coordinated the integration with the NCEPLIBS-pyprodutil GitHub repository. Progress continued for implementing a continuous integration and testing environment for METplus, utilizing Travis CI and to automate building of the METplus documentation using the Sphinx documentation generator deployed on GitHub Pages. Another major area of work over the past year involved support, testing, and development of the python scripts for METplus use cases and work on the upcoming major METplus 3.0 release. Three minor releases of METplus were also delivered over the past year.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Environmental Applications Research - WRF-Chem Model Development

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Ka Yee Wong

NOAA TECHNICAL CONTACT: Georg Grell NOAA/OAR/ESRL/GSD/MDB

NOAA RESEARCH TEAM: Ravan Ahmadov CIRES

PROJECT OBJECTIVES:

Objectives include continued development of WRF-Chem to simulate the emission, transport, turbulent mixing, and chemical transformation of trace gases and aerosols simultaneously with meteorological forcing. Other goals include the improvement of regional-scale air quality forecasting, to conduct field program analysis, and assess cloud-scale interactions between clouds and chemistry. Finally, diagnosing and resolving atmospheric chemical phenomena using WRF-Chem is the ultimate goal of this work.

PROJECT ACCOMPLISHMENTS SUMMARY:

WRF-Chem has major code updates annually, contributed by NOAA/GSD, NCAR, and the global research communities. This year, the code had one release (version 4.1) in March 2019. In addition, GSD has been contributing to RAP/HRRR-Smoke modeling by developing shell scripts and helping with post-processing of the output. Other work included setting up MET successfully for HRRR-Smoke

verification and processing PM2.5 observation data to input into MET. Continuous user support was provided including answering user questions and official WRF-Chem website content was updated regularly.
PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

Data Assimilation:

PROJECT TITLE: Environmental Applications Research–Data Assimilation: Improving Short-range Forecasts of Severe Weather and Aviation Weather from the Assimilation of Satellite Data

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Haidao Lin, Amanda Back, Liaofan Lin, Ning Wang

NOAA TECHNICAL CONTACT: Stephen Weygandt NOAA/OAR/ESRL/GSD/ADB

PROJECT OBJECTIVES:

Investigate the impact from satellite data in the Rapid Refresh, HRRR, and global models and report on the increase in accuracy of short-range model forecasts from the assimilation of satellite data into the Rapid Refresh and global models

PROJECT ACCOMPLISHMENTS SUMMARY:

1. Satellite radiance
Over the past year, work has been focused on 1) preparing for and finalizing the radiance upgrade package for RAPv5 and HRRR-AK, including the RAPv5/HRRRv4 code handoff to EMC in June of 2019 and building/testing of RAPv5/HRRRv4 parallel runs at WCOSS as well as the implementation of the radiance upgrade into the experimental RAPx/HRRRx-AK; 2) evaluating individually and combined data impact from the new data sets planned for RAPv5; 3) evaluating the N20 CrIS-FSR DB data coverage; and 4) starting GOES-17 ABI radiance assimilation work.

With the implementation of radiance upgrade into the experimental RAPx/HRRRx-AK, completion of the RAPv5/HRRRv4 parallel runs on WCOSS, and the science approval for implementation of RAPv5/HRRRv4, the RAPv5/HRRRv4 codes have been fully delivered to NCO for the planned operational implementation in June 2020. Thus, the work on radiance updates for RAPv5/HRRRv4 is complete. The radiance upgrade package for RAPv5/HRRRv4 includes new radiance data from N20 CrIS-FSR/ATMS (including DB data sets) and GOES-16 ABI as well as radiance assimilation for 3-km HRRR-AK. In order to evaluate and identify the total and individual data impact from the new data sets planned for RAP5, we've conducted a series of RAP retrospective experiments. The control retrospective run (Sep 09-Sep 15 2018) assimilated all operational conventional and satellite radiance data in RAPv4. The CrIS-FSR experiment run added 72 CrIS-FSR channels from N20. The ATMS experiment run added 18 ATMS channels from N20. The GOES-16 ABI experiment run added 3 water vapor channels from GOES-16 and the all data experiment run added N20 72 CrIS-FSR channels, N20 18 ATMS channels, and 3 water vapor channels from GOES-16 ABI. Figure 1 shows 12-h forecast RMS normalized impact (%) against rawinsonde observations over the RAP domain from different data sets (N20 CrIS-FSR, N20 ATMS, GOES-16, and all above three) for (a) temperature, (b) relative humidity, (c) vector wind compared with the control run (RAPv4) averaged from this 7-day retro period. Figure 1d shows the time series of 12-h relative humidity forecast RMS errors against rawinsonde observations for the control run (blue) and the all data run (adding N20 CrIS-FSR/ATMS and GOES-16 ABI). It is noted from Fig. 1 that N20 CrIS-

FSR has small or neutral positive impact for temperature and wind. All data sets have small positive impact with statistical significance for relative humidity forecast. For 12-h relative humidity forecast, N20 CrIS-FSR has the largest normalized positive impact (around 1%) and N20 ATMS and GOES-16 ABI have similar positive impact (around 0.5%). The combination of all three data sets yields about 1.5% positive impact with statistical significance for relative humidity forecast. Figure 1d also shows the consistent positive impact for 12h relative humidity forecast during this 7-day retro run period from all data run (red) compared with the control run (blue). We further examine the 1-12h relative humidity forecast impacts for these data sets (individually and combined together), which are shown on Fig. 2. It can be seen from Fig. 2 that N20 CrIS-FSR has the largest normalized impact for 1-12h relative humidity forecast with statistical significance and N20 ATMS and GOES-16 ABI have smaller impact than CrIS-FSR. The positive impact for water vapor from CrIS-FSR data is probably partly due to the 8 water vapor channels. The largest positive impact for relative humidity from N20 ATMS is seen at the 12-h forecast.

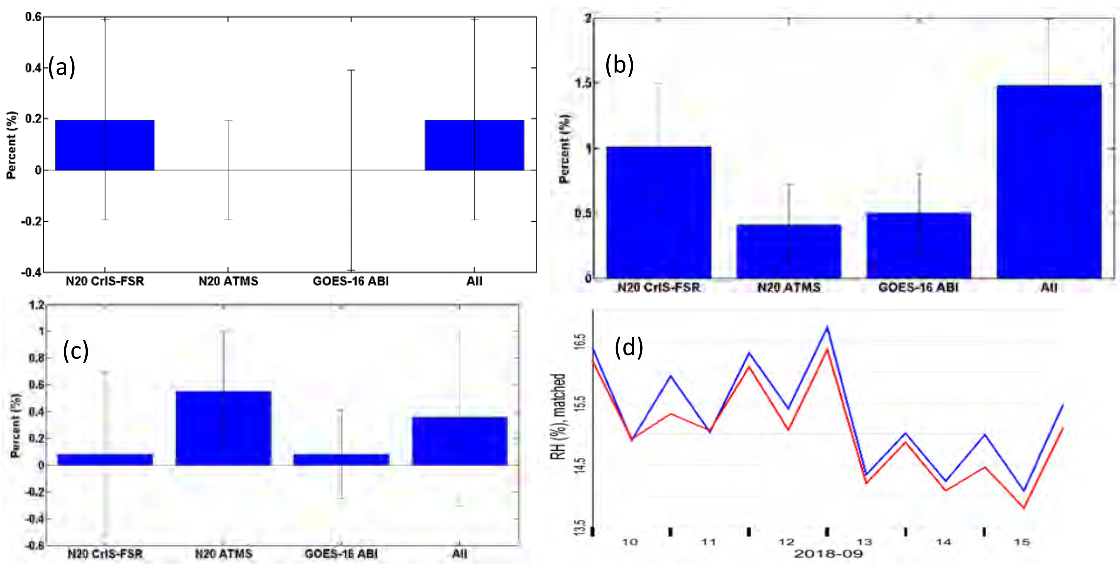
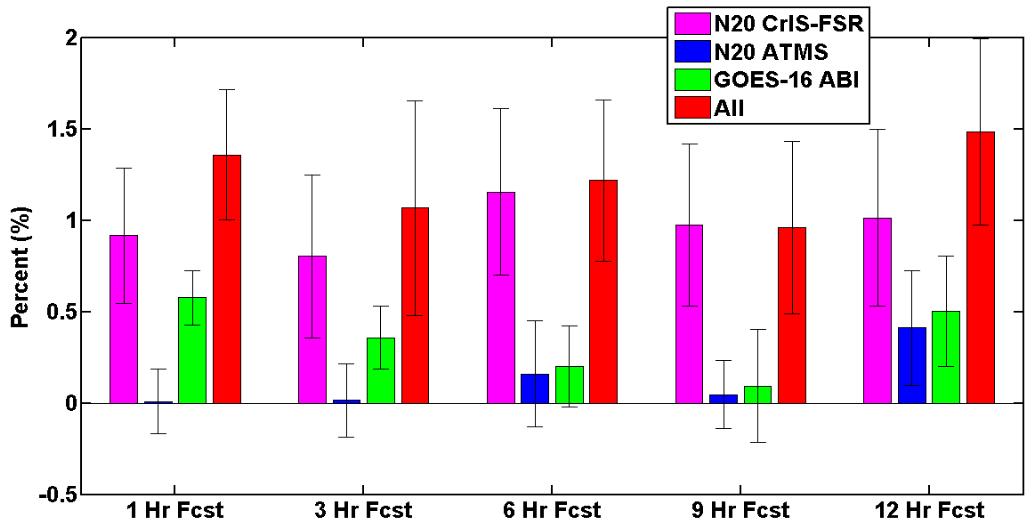


Figure 1: 12-h forecast RMS normalized impact (%) against rawinsonde observations over the RAP domain from different data sets (N20 CrIS-FSR, N20 ATMS, GOES-16, and all above three) for (a) temperature, (b) relative humidity, (c) vector wind compared with the control run (RAPv4). (d) Time series of 12-h relative humidity forecast RMS errors against rawinsonde observations for the control run (blue) and the all data run (red, adding N20 CrIS-FSR/ATMS and GOES-16 ABI).



(b)

Figure 2: 1-12 relative humidity forecast RMS normalized impact (%) against rawinsonde observations over the RAP domain from N20 CrIS-FSR (maga), N20 ATMS (blue), GOES-16 (green), and all above three data sets (red) compared with the control run (RAPv4).

2. Geostationary Lightning Mapper (GLM) instruments and cloud-top cooling rate (CTCR)

In the current operational High Resolution Rapid Refresh (HRRR) analysis and forecast system, convection is spun up during a “pre-forecast” hour of model integration, during which the temperature tendency field is modified based on latent heating rates empirically derived from radar reflectivity and ground-based lightning observations. A hybrid-ensemble-based assimilation of conventional observations is then performed, followed by the free forecast. During this reporting period, we continued to study the ingest, via the latent heating adjustment procedure, of novel convective indicators derived from GOES-R satellite. The two products under study are lightning detections from the Geostationary Lightning Mapper (GLM) instruments and cloud-top cooling rate (CTCR) calculated as part of the SATCAST nowcasting product from University of Alabama, Huntsville (UAH).

The GLM instruments onboard the GOES-16 and GOES-17 satellites provide continuous detection of total lightning throughout the HRRR domain and surrounding areas at about a 10-km resolution. The satellite data complement reflectivity and ground-based lightning detections for storms over data sparse regions (primarily oceanic regions adjacent to North America for the RAP/HRRR systems), offering improved capability to determine the extent and intensity of storms in these areas. In an experimental HRRR configuration, we tested the assimilation of GLM data both in place of, and in addition to, ground-based lightning data. When the datasets are merged prior to ingest, we follow the methods described by Philip Bitzer and his collaborators at UAH, who have applied merging techniques to ground-based datasets and the Lightning Imaging Sensor. In addition to testing the various dataset combinations, we also test a technique to broaden the impact of lightning observations by dilating them onto neighboring HRRR grid columns.

The lightning ingest configurations were tested over the more convectively-active hours in a 3-day period, July 19-22, 2019, with new forecasts initiating between the hours 15Z and 0Z. It was expected that replacing the ground-based lightning data with GLM would degrade storm representation due to the coarse resolution of GLM and very high detection efficiency of the ground-based product. The results of experiments support this hypothesis. However, the augmentation of the ground-based data with GLM is indicated to enhance skill in forecasting reflectivity over the first few hours of forecasts. The greatest impact of the GLM ingest may be outside radar range, where forecasts cannot be assessed, so the positive effects of merging these datasets may be even greater than the skill scores indicate. For lower reflectivity thresholds, where the model tended to be low-biased, both the merging and dilating strategies appear beneficial. At higher thresholds where the bias tended to already be high, the merging was beneficial but the dilating was not. The dilation procedure is being refined and further tested.

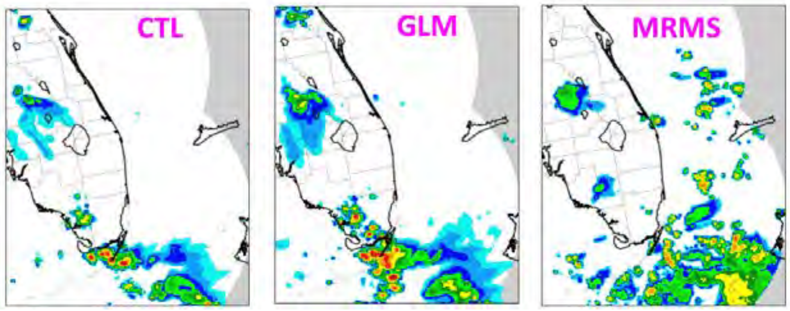


Figure 3: Observations and four-hour forecasts of composite reflectivity valid at 3Z on July 21st, 2019, around Florida. Left: control run; center: run using the merged lightning product, dilated into neighboring HRRR grid columns; right: composite reflectivity observations from MRMS.

Figure three shows two, four-hour forecasts of reflectivity valid at 3Z on July 21st: a control run, into which ground-based lightning detections were ingested along with radar reflectivity, and an experiment in which the ground-based data set was replaced with the merged lightning data and also dilated (still ingested along with the reflectivity observations). In this instance, the merging and dilating procedures improved representation of two storms: one, east of Florida, was mostly outside radar range and was underforecast without the added GLM observations and dilation. The second, over central Florida, was weak at analysis time and only the runs including GLM captured its strength over the following hours (by the hour depicted it is again diminishing).

The second novel satellite-based source of information regarding the onset of convective weather is the SATCAST product, using cloud object tracking and cloud-top cooling rates (CTCR) derived from GOES-R ABI products; high rate of cooling indicates rapid cloud top rise and developing convection. These data are able to identify nascent storms earlier than high radar reflectivity or dense lightning can be observed. In addition to the cloud-top cooling rate, SATCAST includes an index of convective initiation (CI) probability. In one experimental configuration, the magnitude of CI probability is used to filter the CTCR; heating is only applied where the CI probability exceeds a certain threshold. The CTCR data were assimilated experimentally into HRRR in a subset of the hours in which GLM was tested—22 hours total--using the same latent-heating scheme that is used to assimilate radar and lightning. While the greatest benefit of GLM seems to be in areas of low radar coverage, the CTCR's greatest strength seems to be in capturing convective initiation earlier than either radar or lightning do. The CTCR product was recently upgraded to make use of the GOES GLM's high cadence, which appears to have reduced the risk for it producing false detections due to object-tracking errors. The filtering by CI probability was less beneficial than other studies have suggested, perhaps because of the recent upgrade.

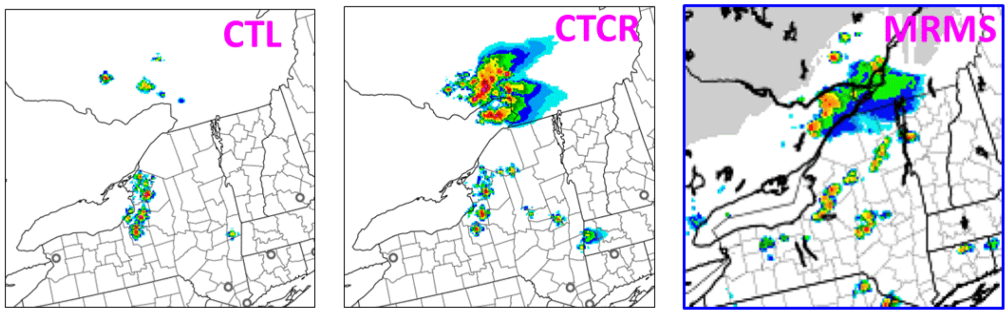


Figure 4: Observations and three-hour forecasts valid at 21Z on July 20th, 2019, along the Canadian border north of New York.. Left: control run; center: run including cloud-top cooling rate ingest from GOES-16; right: composite reflectivity observations from MRMS.

Figure 4 shows two three-hour reflectivity forecasts valid at 21Z on July 20th: one run ingesting the CTCR without filtering, and a control run. In both cases the radar and ground-based lightning detections are ingested as in the operational HRRR. In this case the storm initiated around analysis time and had only weak reflectivity and low lightning density at that time; however, a strong signal in cloud-top cooling occurred 45 minutes before the analysis time and was ingested as latent heating in the pre-forecast hour.

GOES-17 data for both GLM and UAH cloud-top cooling rate were also ingested for the tested time period. However, the results were ambiguous for these data because of low activity in the western portion of the HRRR domain throughout the testing time period. Results for the UAH cloud-top cooling rate and GLM ingest experiments were communicated through presentations at the 2019 Joint Satellite Meeting in October 2019 and the AGU Fall Meeting in December 2019.

Work with the GOES-16 AMV data was also completed during the reporting period, enabling these data (along with additional AMVs from EUMETSAT and JMA) to be included in the upcoming RAPv5/HRRRv4 operational implementation. This work included cataloging the new data types, identifying types most likely to benefit forecast skill, and performing data impact tests.

Lastly, an effort was initiated during this time period to ingest aerosol optical depth (AOD) measurements from JPSS to correct cycled smoke forecasts in RAP and HRRR. A proof-of-concept trial was performed in late 2019 using the AOD data as a guide to clear smoke from HRRR columns where overall measured AOD was very low. The test yielded lower error in temperature against radiosonde verification; however, a variational approach is preferred and will be tested in the next reporting period. This work is ongoing.

PROJECT PUBLICATIONS:

Lin, H., S. S. Weygandt, M. Hu, J. Brown, A. Back, C. R. Alexander, and S. G. Benjamin, 2019: Quantification of short-range regional forecast impacts from satellite radiance data assimilation for the upcoming RAP version 5, *2019 Joint Satellite Conference*, Boston, MA, Amer. Meteor. Soc., 11B.2, https://ams.confex.com/ams/JOINTSATMET/meetingapp.cgi/Paper/359467.

Lin, H.: Optimizing the Assimilation of AIRS SFOV Retrievals and Radiances within the Rapid Refresh. CIRA Seminar as part of the 2012 CIRA Research Initiative Award, 26 September 2012, Fort Collins, CO.

Lin, H., S. S. Weygandt, M. Hu, J. Brown, A. Back, C. R. Alexander, and S. G. Benjamin, 2019: Satellite Radiance Assimilation Enhancements for the Upcoming NCEP Operational Rapid Refresh Upgrade, *JCSDA 17th Workshop on Satellite Data Assimilation*, Washington, DC, 29-31 May 2019.

Back, A. and Kingfield, D. M. "Assimilation of Total Lightning from the GOES-16 Geostationary Lightning Mapper in the Rapid Refresh." GSD DDRF Report-Out, 17 Apr. 2019.

Back, A.: "Convective Indicators Assimilated into the High Resolution Rapid Refresh." CIRA Fellows Gathering, 23 May 2019.

PROJECT PRESENTATIONS/CONFERENCES:

Back, A., Weygandt, S.S., et al. "Impact of GLM Lightning and GOES Cloud-Top Cooling Rate Data Assimilation on HRRR Short-Range Forecast Guidance." Joint Satellite Conference, 2 Oct. 2019. Conference Presentation.

Back, A., Kingfield, D.M., et al. "Assimilation of GLM Data Together with Ground Based Lightning Observations for Improved Storm Spin-Up in the High Resolution Rapid Refresh." American Geophysical Union Fall Meeting, 10 Dec. 2019. Conference Presentation.

Transferred technology to operations: The radiance upgrade package for RAPv5/HRRRv4-AK, along with the additional AMVs, is planned to be included in operational RAPv5/HRRRv4 on June 2020.

DATA DISTRIBUTION:

PROJECT TITLE: Environmental Applications Research - Data Distribution and Visualization for Global Models

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Brian Jamison

NOAA TECHNICAL CONTACT: Stanley Benjamin NOAA/OAR/ESRL/GSD

NOAA RESEARCH TEAM: Jian-Wen Bao OAR/ESRL/PSD, Mark Govett OAR/ESRL/GSD/ATB

PROJECT OBJECTIVES:

1) Generate graphics of output fields, creation, and management of web sites for display of those graphics.
2) Create and manage graphics for public displays, including software for automatic real-time updates.

PROJECT ACCOMPLISHMENTS SUMMARY:

A website for the display of FIM model output https://fim.noaa.gov/FIM/ currently has up to 65 products available in 24 regions for perusal, with 6-hourly forecasts going out to 14 days. Many regions use direct interpolation from the native icosahedral grid to a 0.125-degree global grid (approximately 14 km grid spacing).

New versions of EMC's FV3 model were set up at GSD including an experimental 128-level version and a Stand-Alone Regional Convective-Allowing Model (SAR-CAM) version, the latter matching the 3km

HRRR domain. Graphics are available at https://fim.noaa.gov/FV3/ and https://rapidrefresh.noaa.gov/ as well as difference plots. New radiation graphics products were also developed.

A dual-monitor hallway display and a large touchscreen kiosk monitor, both on the second floor of the David Skaggs Research Center (DSRC) displays FV3 model graphics for public viewing. Currently, a montage loop of four output fields is displayed and updated regularly on the dual-monitor display, and selectable FV3 products are automatically updated on the kiosk.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Forecast Impact and Quality Assessment

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Ken Fenton, Paul Hamer, Dana Mueller, Tanya Peevey, Xue Wei

NOAA TECHNICAL CONTACT: Michael Kraus OAR/ESRL/GSD/EDS

NOAA RESEARCH TEAM: CIRES: Matt Wandishin, Geary Layne, Joan Hart, Michael Rabellino, Laura Melling

PROJECT OBJECTIVES:

The objectives of this project are to provide program management, scientific, and engineering support for the NOAA/OAR/ESRL/GSD/EDS/Forecast Impact and Quality Assessment Section (FIQAS), the primary activities of which are:

1) Scientific research and formal, impact-based product evaluations;

2) Technology development supporting product evaluation and decision support.

PROJECT ACCOMPLISHMENTS SUMMARY:

1. Scientific Research and Product Evaluation

The primary sponsor for evaluation activities in 2019/20 was the Federal Aviation Administration (FAA) Aviation Weather Research Program (AWRP), for whom FIQAS serves as the Quality Assessment Product Development Team (QA PDT). The role of the QA PDT is to conduct independent evaluations of AWRP products as part of the formal AWRP Research to Operations process. In addition to evaluations performed for the FAA, the FIQAS also received funding in 2019/20 from GSD's Atmospheric Science for Renewable Energy (ASRE) Program to partner with Idaho National Laboratory (INL) and investigate the use of weather forecast information for more effective transmission of electricity. Finally, the FIQAS received funding from GSD to investigate the use of probabilistic forecasts of snowfall by airports.

Accomplishments for evaluation activities included:

A. Offshore Precipitation Capability (OPC) Assessment:

Massachusetts Institute of Technology Lincoln Laboratory (MIT/LL) developed the OPC product to provide radar-like data to the aviation industry in regions that do not have radar coverage, such as over the Atlantic Ocean off the east coast of the United States. FIQAS performed an assessment of the OPC product by comparing it to observations from the Global Precipitation Mission (GPM) satellite, the Global Lightning Mapper (GLM) on GOES-East, aviation routine reports (METARs), and radar data. The 2019/20 activities supporting the evaluation of OPC included completion of assessment implementation, data collection and processing, analysis of results, and reporting of findings. The evaluation found differences in in the performance of OPC that depended on the regional differences in the efficiency of the ground-based lightning detection network. In particular, the algorithm's performance decreased farther east over the Atlantic Ocean as the detection efficiency of the ground-based lightning detection network waned. Overall, however, the OPC output was relatively unbiased and produced a radar-like product in regions where radar coverage was not available. Results were presented to the AWRP, MIT/LL, and the FAA Convection Program Manager.

B. Icing Product Alaska – Forecast (IPA-F) Implementation Assessment:

IPA-F is scheduled to become an operational product in FY20 and will run on a NOAA National Centers for Environmental Prediction (NCEP) Central Operations (NCO) platform. Minor changes to the IPA-F algorithm were implemented since the last assessment by FIQAS in 2016. In addition, NCO platforms have different configurations than the research platform that was running IPA-F in experimental status. FIQAS conducted an assessment to ensure that the NCO version of IPA-F is comparable to the research version. The 2019/20 activities supporting this assessment included a verification plan, data collection and processing, analysis of results, and reporting of findings. The evaluation found that the version of IPA-F transitioned to NCO was nearly identical to the research version. Results were presented to the AWRP, NCAR, the Alaska Aviation Weather Unit, and the Aviation Weather Center (AWC).

C. Rapid Refresh (RAP) Model Version 5 (v5) Assessment:

RAPv5 was delivered to NCEP in 2019 with a goal of operational implementation in FY20. The RAP is an input to both the Forecast Icing Potential (FIP) and Graphical Turbulence Product 3 (GTG-3), which provide forecasts of aviation hazards over the contiguous United States (CONUS). Upgrades to the RAP have the potential to effect downstream products such as the FIP and GTG-3. Parallel runs of the FIP and GTG-3 were collected using inputs from RAPv4 and RAPv5, with the output used to access the effects of the RAP model upgrade. The 2019/20 activities supporting this assessment included a verification plan, data collection and processing, analysis of results, and reporting of findings. The evaluation found the largest differences in icing probability in the low-level stratus off the west coast of the United States in the parallel runs of the FIP. Over the CONUS, there was little difference in the FIP output as a result of the upgrade. In addition, the RAPv5 GTG-3 produced weaker turbulence near the surface, especially over the water. At higher levels, the newer version of the RAP produced stronger turbulence, except over the mountains. In general, the differences were small in magnitude. The initial results were provided to the NCEP Director's Briefing and supported the decision to upgrade to RAPv5/HRRRv4. Complete results in the form of a presentation and a report were provided to the AWRP, GSD, AWC, and NCAR.

D. High-Resolution Rapid Refresh (HRRR) Model Version 4 (v4) Impact Assessment:

HRRRv4 was deliver to NCEP in 2019 with a goal of implementation in FY20. The HRRR is a convection-allowing model that makes it suited towards thunderstorm forecasting critical to aviation flight planning. The HRRR is an input to the Traffic Flow Management (TFM) Convective Forecast (TCF). The TCF is used by FAA air traffic management to determine weather-related impacts. FIQAS conducted an impact assessment of the upgrade from HRRRv3 to HRRRv4 by using the Flow Constraint Index (FCI) tool. The FCI tool combines weather and air traffic information to derive constraint information using an airway-based geometry. The tool was developed by the FIQAS team to perform impact-based verification on convective models to quantify their impact to the National Airspace System. The 2019/20 activities supporting this assessment included a verification plan, data collection and processing, analysis of results, and reporting of findings. Two time periods were evaluated during the assessment from retrospective runs of the HRRR, July/August 2018 and May 2019. The assessment found that HRRRv4 provided forecasts of convection that more closely aligned with the observed constraint than the forecasts from HRRRv3. The observed constraint was calculated from the vertically integrated liquid (VIL) and echo top fields of the Corridor Integrated Weather System (CIWS), which is used by the FAA for decision making. In particular, the upgraded model version showed more substantial improvement over its predecessor in the May 2019 time period, which corresponds to strongly forced convection, and during the early forecast hours of the model. These improvements correspond to the HRRRv4 improvements to boundary layer conditions and data assimilation. The initial results were provided to the NCEP Director's Briefing and supported the decision to upgrade to RAPv5/HRRRv4. Complete results in the form of a presentation and a report were provided to the AWRP, GSD, and AWC.

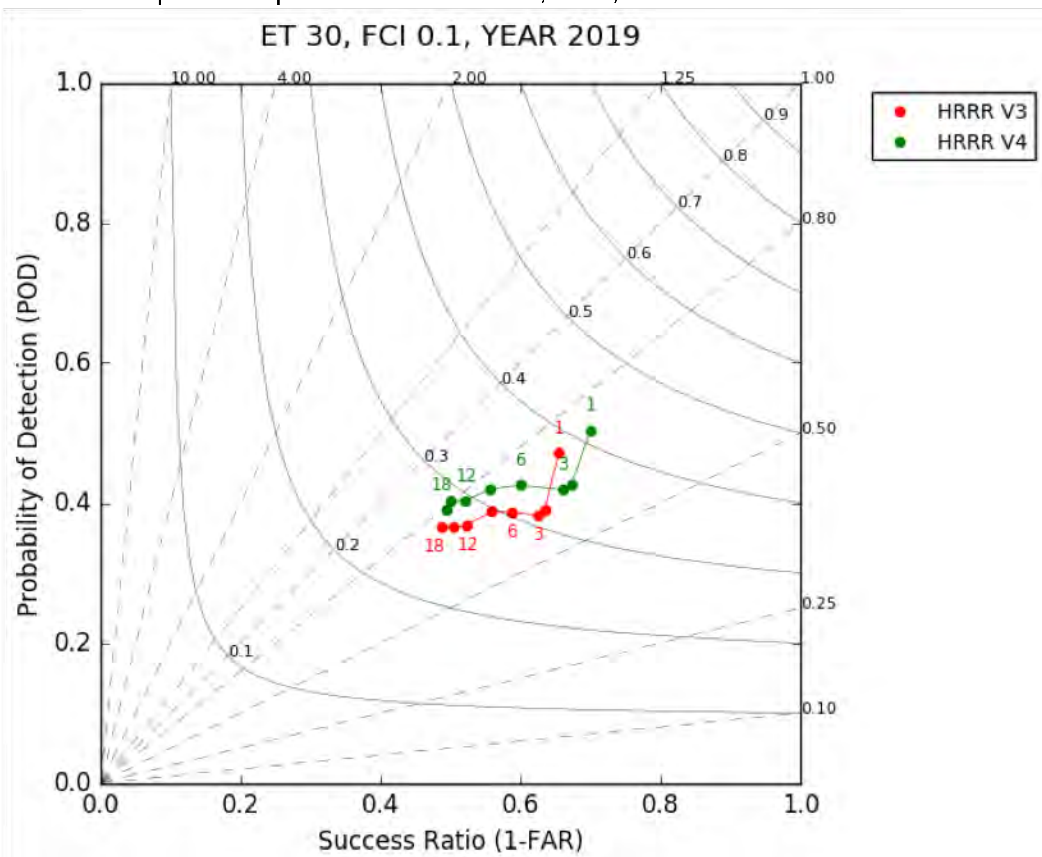


Figure 1. Performance diagram comparing the HRRRv3 (red) to the HRRRv4 (green) as verified against CIWS VIL and echo top observations. The different points and their labels refer to various forecast lead times from the model (1, 3, 6, 12, 18-hour forecasts).

E. Core Research and Development:

The FIQAS team engaged in a number of core research and development projects funded by the AWRP. First, the team investigated the differences between GOES GLM data and ground-based lightning detection from Earth Networks. The goal of this project was to determine whether one network was sufficient for lightning detection or if both networks were necessary for the group's verification needs. The first finding of the research was that the group data from GLM was most comparable to Earth Networks data. The second finding was the both networks are necessary for storm-scale verification. While the two data sources did offer a high level of agreement in placement of lightning, there were enough cases when only one source detected the lightning to deem it necessary to require data from each for proper verification. In particular, two grids were evaluated, the HRRR 3-km grid and a coarser 0.5 degree grid. Especially at the 3-km grid spacing, but also at the 0.5 degree grid spacing, there were grid cells that were identified as detection by one data set but not the other. Overall, the GLM was more likely to detect lightning than the ground-based network, but the ground-based network is a necessary supplement, especially in areas were the optical detection from GLM may be more challenging, such as areas with dense cloud coverage.

The second area of core research was to determine whether or not satellite detection of gravity waves could be used to infer the presence of turbulence to aircraft. An algorithm that performs image processing on geostationary satellite imagery was selected for evaluation. The algorithm, developed by the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), looks for differences in brightness temperature between water vapor and infrared imagery to identify possible gravity waves. The output is processed into a clear air turbulence (CAT) score, with the intent to identify areas of likely clear air turbulence. The CAT score was matched up against eddy dissipation ratio (EDR) measurements from aircraft. FIQAS found that there was no relationship between the CAT score and the EDR measurements, and no predictive skill of the CAT score.

Third, FIQAS investigated the utility of the United States Air Force's World-Wide Merged Cloud Analysis (WWMCA) to be a definitive verification source for clouds. The WWMCA is produced operationally every 30 minutes and is a global gridded data set with cloud amounts and heights at each grid point. The product is produced by stitching together the most recent geostationary and polar orbiting satellite data that is available in real time. The output from the WWMCA was compared against cloud reports from METARs and the cloud identification from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite. While the WWMCA did show some agreement with METAR and CALIPSO cloud detections, the correlations were not deemed strong enough to warrant WWMCA as a stand-alone verification true set for cloud presence.

The results of the core research and development work were provided to the AWRP in a series written reports.

F. Evaluation of the High-Resolution Rapid Refresh (HRRR) for Dynamic Transmission Line Ratings:
The power transmission community uses line ratings to determine the amount of current that can safely be passed through transmission lines. At present, line ratings are based on seasonal extreme weather values. FIQAS partnered with Idaho National Laboratory (INL) to investigate the gains in transmission line capacity that could be realized with dynamic line rating based on forecasts from the High-Resolution Rapid Refresh (HRRR) weather model. Activities included a quantification of the errors of the HRRR model over the western interconnect as compared against METAR observations. The evaluation found several biases in the HRRR temperature and wind forecasts based on time of day and surface roughness. Results were presented to the Atmospheric Science for Renewable Energy program members and at the Annual Meeting of the American Meteorological Society.

G. Improved Presentation and Use of Probabilistic Forecast Products:
Probabilistic forecasts are being issued by NWS forecast offices, but little work has been done on the verification of these forecasts and how they are used in the decision-making process. The goal of this project was to understand and improve how NWS forecasters and decision makers access, interpret, and use weather risk information. Both model and NWS-generated probabilistic snowfall forecasts for Denver International Airport (DIA) and selected airports in the intermountain west were verified against METAR observations. The project found the SREF 50^{th} percentile for snow amount and start time forecasts were more accurate than forecasts from the HRRRE, largely due to the under dispersive nature of the HRRRE at that time in its development. The results were presented to stakeholders from the GSD, the NWS

Boulder Forecast Office, and DIA operations leadership.

2. Technologies for Product Evaluation and Decision Support
Technology Development:
CIRA was responsible for application development in support of FIQAS activities, including FIQAS assessments as well as the development of technologies for external users. The primary sponsor for these activities in 2019/20 was the FAA AWRP. The NWS Aviation and Space Weather Services Branch (ASWSB) and the NWS Office of Science and Technology Integration (OSTI) were also partners in these endeavors.

Accomplishments include:
A. Verification and Requirements Monitoring Capability (VRMC):
The VRMC is a web-based application developed and maintained by FIQAS for AWRP. It provides ongoing verification metrics for operational AWRP turbulence and icing products as well as verification capabilities to support FIQAS assessments performed as part of the operational transition process. Activities for 2019/20 included a hardware upgrade and optimization of the database configurations. The results of these enhancements were an increased the ability to perform additional data analysis and better response time to queries. In addition, FIQAS added monitoring for GTG-Global and ceiling and visibility analyses from the Gridded Local Aviation Model Output Statistics Program (GLMP) algorithm (see Figure below). Finally, an enhancement was made to the VRMC to incorporate grid-to-grid techniques developed from the neighborhood core research.

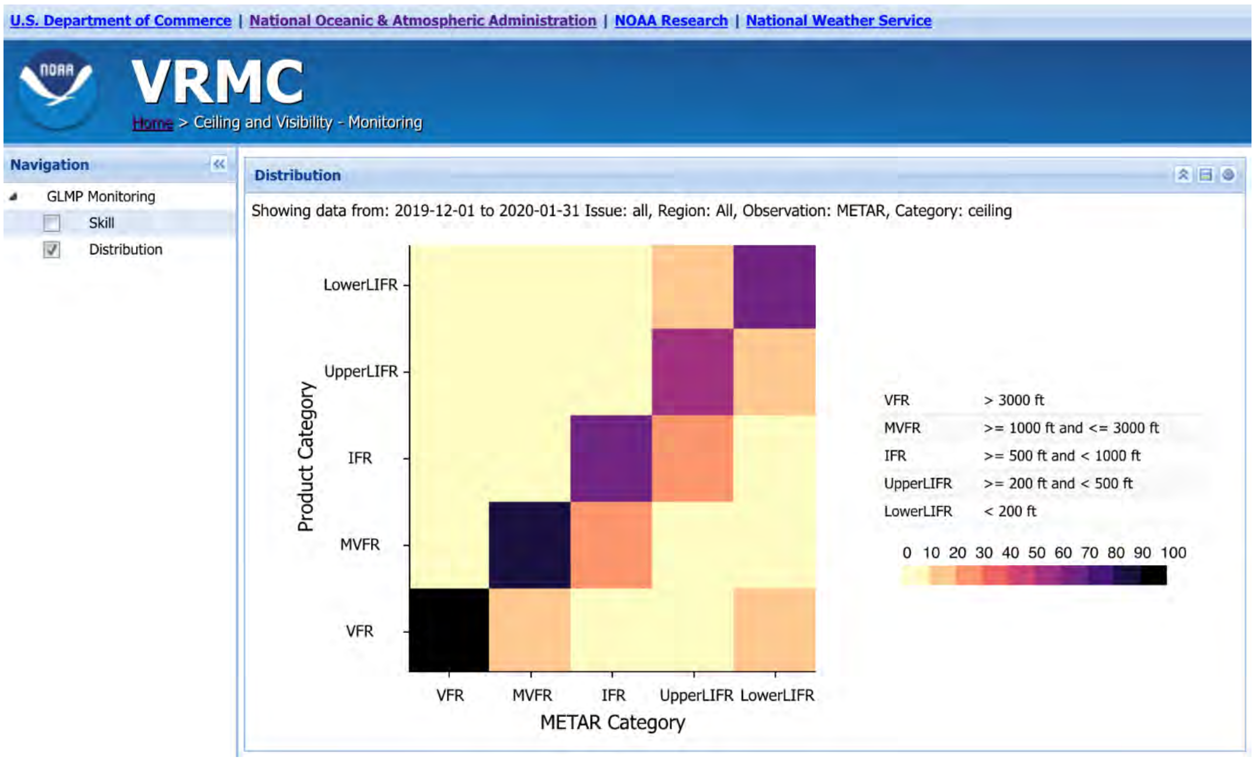


Figure 2. View of the VRMC GLMP Ceiling and Visibility Monitoring.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Environmental Applications Research - Rapid Update Cycle (RUC) Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR) Models Project, Data Distribution and Visualization

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Brian Jamison

NOAA TECHNICAL CONTACT: Curtis Alexander OAR/ESRL/GSD/ADB

NOAA RESEARCH TEAM: Stephen Weygandt OAR/ESRL/GSD/ADB

PROJECT OBJECTIVES:

Objectives for this project include:

1. Creation and management of automated scripts that generate real-time graphics of output fields,

2. Management of web sites for display of those graphics, and

3. Management of graphics for hallway public displays.

PROJECT ACCOMPLISHMENTS SUMMARY:

Each of the web pages for RAP https://rapidrefresh.noaa.gov/RAP/, HRRR https://rapidrefresh.noaa.gov/hrrr/HRRR/, and RUC https://ruc.noaa.gov/ruc/RUC/ have been refined with new developmental model versions, difference plots, better graphics, and new fields.

The operational HRRR runs at The National Centers for Environmental Prediction (NCEP). GSD receives the data and creates all graphics for GSD's HRRR web page, including all subdomains and soundings. The in-house HRRR was renamed HRRR Experimental (HRRRX) to distinguish it from the operational version.

New graphics were developed and added to the HRRR including revised cloud cover, hail size, and several radiation products.

Graphics software and workflow management were transitioned to the Linux-based Slurm workload manager, as required by ITS. Also, GSD moved to a new super computer, Hera, which has more than twice the capacity and ability as the previous system, Theia.

A new verification graphics website was established with MRMS reflectivity, MRMS rotation track, MRMS MESH, Stage IV precipitation, and lightning products. New Python scripts were developed which could easily and quickly plot the data on the native HRRR domain and subdomains.

New Real-Time Mesoscale Analysis (RTMA) models were developed and graphics web pages were created for SPC and AWC to use in spring testbeds.

GSD also receives interim versions of the RAP and HRRR from NCEP and creates graphics from these models which are displayed on GSD's RAP and HRRR web pages, along with difference plots for comparison.

A dual-monitor hallway display and a large touchscreen kiosk monitor, both on the second floor of the David Skaggs Research Center (DSRC) displays HRRR model graphics for public viewing. Currently, a montage loop of four output fields is regularly displayed and updated automatically on the dual-monitor display, and selectable HRRR and HRRR-Smoke products are automatically updated on the kiosk.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Environmental Applications Research – AWIPS I & AWIPS II Workstation Development

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: James Ramer, Evan Polster, Amenda Stanley, Yujun Guo, Kevin Manross, Nathan Hardin, Joshua Weber

NOAA TECHNICAL CONTACT: Daniel Neitfield

NOAA RESEARCH TEAM: Thomas LeFebvre, Joseph Wakefield, Susan Williams, Vivian LeFebvre, Woody Roberts; Darrel Kingfield, Chris Golden, Paul Schultz, Xiangbao Jing

PROJECT OBJECTIVES:

The ongoing objective of this program is to research and maintain AWIPS-related service solutions for researchers and operational field personnel using those solutions, as well as supporting the NWS in the future development and delivery of those solutions. AWIPS I is the original Advanced Weather Information Processing System used by the NWS Weather Forecast Offices (WFO) since the 1990's. AWIPS II (also known as A2) is the re-factored version of the AWIPS I system.

The long-term goal of this project is to develop a forecast workstation with advanced interactive display capabilities that includes inter-office and external collaboration, and integrates existing hazard services. The collaboration capability can improve forecast consistency between offices and permit better coordination with external partners.

PROJECT ACCOMPLISHMENTS SUMMARY:

AWIPS2 Hazard Services for Aviation
This project continues to move toward operational implementation, with ongoing development being completed in Hazard Services for aviation in-flight hazards. This work is being conducted in order to develop a Common Aviation Platform within Hazard Services as a replacement for In-Flight products that the Meteorological Watch Offices (MWOs) currently produce in N-AWIPS and IC4D. Per the Statement of Work, the deliverables for the past year center on integrating these workflows into the operational version of Hazard Services for the Convective SIGMET, International SIGMET, AIRMET, and Volcanic Ash

Advisory for the three MWO offices (Alaska Aviation Weather Unit, Honolulu Weather Forecast Office, and the Aviation Weather Center). In addition, CIRA/GSD personnel set up a testbed standalone system in Alaska at the Alaska Aviation Weather Unit for continued evaluation in August 2019.

The role of CIRA/GSD personnel in this project is to:

- Gather requirements based on feedback from the National Weather Service (NWS) partners (MWOs and NWS Headquarters).
- Conduct software design and code reviews with Raytheon and NWS partners.
- Develop AWIPS2 code and tools to integrate the four aforementioned products into the unified version of Hazard Services.
- Set up developmental testbed system in Alaska.

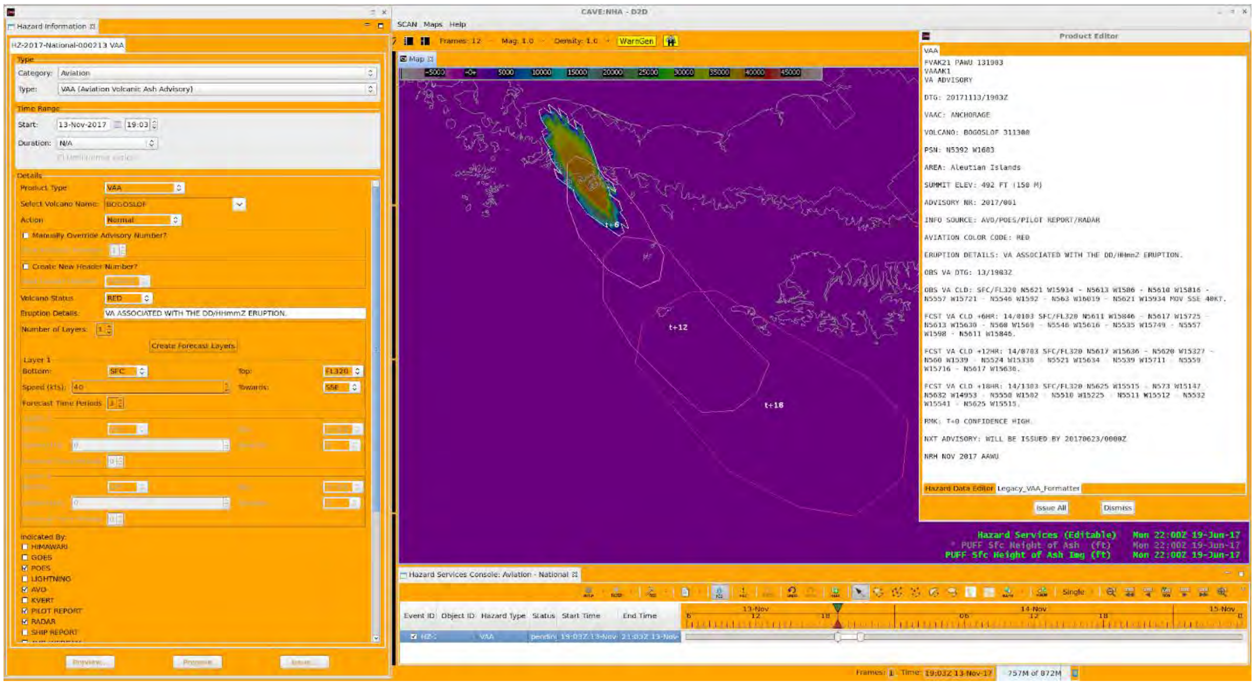


Figure 1. Sample Volcanic Ash Advisory using automated tool developed by CIRA/GSD.

A centerpiece of CIRA/GSD's development work for In-Flight capabilities is using partner input to develop automated tools that streamline the forecasting process. Figure 1 shows an example of this work, in which the user can generate a proposed Volcanic Ash Advisory using model input as a starting point. The tool also will automatically populate a variety of formatted products, including the WMO standard IWXXM version 3 XML format. This not only removes potential sources of human error, but also allows forecasters to quickly generate and issue products, thus allowing users to more quickly receive life-saving information.

This work is scheduled for check-in and delivery in March 2020.

Technologies or techniques or software developed

Software developed within Hazard Services to generate and issue 4 aviation in-flight workflows.

AWIPS2 Hazard Services for Ocean Prediction Center

An ongoing project for CIRA/GSD developers was a preliminary project with the Ocean Prediction Center (OPC) to gather requirements, and complete a software design, to generate and issue operational products using Hazard Services.

Leveraging the existing capabilities of Hazard Services to suit the needs of the OPC will help migrate the national center onto AWIPS, while also providing a solution for requirements set at the World Meteorological Organization and International Maritime Organization level. This requirement is to issue graphical, polygon-based hazards.

This project was completed by CIRA personnel, and is an important step forward in helping national center offices within the NWS move into the AWIPS generation. A preliminary software design and level of effort assessment was completed. This project served as the starting point for a JTTI-approved project running from FY20-FY21, where CIRA personnel at GSD will develop the capability to generate and issue the High Seas Product at OPC, in coordination with the National Hurricane Center and Honolulu Weather Forecast Office. This project is detailed in a separate report.

Software developed within Hazard Services to generate and issue all hazards comprising long-fused marine hazards (e.g. Small Craft Advisory, Gale Warning, etc.)

AWIPS2 Hazard Services Initial Operating Capability

The Initial Operating Capability (IOC) represents the very first version of Hazard Services that will be used to issue products operationally at WFOs. This version of Hazard Services is focused on Hydrology hazards. As of December 2019 there were test versions of Hazard Services installed at two dozen or so WFOs being used to evaluate the software. It is expected that WFOs will begin using Hazard Services operationally this coming Spring 2020.

One of the most important efforts by CIRA personnel to support IOC is participating in Focal Point Configuration Workshops being run in Norman by the Warning Decision Training Division (WDTD). During the evaluation period CIRA personnel attended one workshop in September and one in December. The plan is that by February of next year CIRA personnel will have attended 6 of these workshops in total. The goal of these is to train one person from each of the 120+ WFOs in how to configure their Hazard Services to account for their local requirements.

To support this training effort, CIRA personnel have been creating a large detailed online shared document called the “Hazard Services Focal Point User's Guide”. This document contains a combination of reference information about the code structure of Hazard Services and instructions about how to configure Hazard Services. There are over 200 pages of content including more than 50 directly usable code examples for configuring various aspects of Hazard Services. There are a large number of links in the Focal Point Guide to other related documents. A substantial effort has gone into packaging up the Focal Point Guide with several of these other related documents into standalone “html snapshots”. These snapshots are used to record previous instances of the Focal Point Guide independent of the current online living version. These snapshots have also been used to provide access to the Focal Point Guide in environments where IT security prevents connecting to the open internet, such as the WDTD training facility in Norman.

As personnel at WFOs configure their Hazard Services application in preparation for going operational, they will lean heavily on their training from the workshops and the Focal Point Guide. However, there will be times when they request additional information. CIRA personnel have been directly involved in answering these inquiries, providing user support.

CIRA personnel are also deeply involved in the testing of Hazard Services IOC. Some of this is general testing evaluating the stability and correctness of the workflows and the text products produced. Some of this is targeted testing for whether specific bugs have been successfully fixed. Finally, there is regression testing being done, which evaluates whether ongoing development and bug fixing is preserving other previously implemented capabilities.

CIRA personnel are also responsible for some python development for IOC. Much of the CIRA effort has been focused on scripting that correctly configures Hazard Services for issuing hazards for predefined impact areas. These are areas with the potential to be impacted by dam failures or areas subject to more severe runoff due to burn scars. There has also been a bit of more general work on text product formatting and GUI configuration, both in the context of bug fixes and adding new capabilities.

AWIPS2 Hazard Services Post-Initial Operating Capability

This version of Hazard Services will support issuance of Winter Weather Hazards, Marine Hazards, and other Hazards that do not involve precipitation (NPW). This version will also support adoption of new product formats for the currently supported suite of Hydrologic hazards. Finally, Post-IOC will support the native generation of Common Alert Protocol (CAP) messages by Hazard Services.

CIRA personnel did a small amount of python development during the evaluation period. Much of it was deferred fixes involving Hydrologic hazards for problems that were discovered too late to be formally included in IOC. Most important was the work that supports a “turnkey” for activating CAP and switching product formats for Hydrologic hazards. A turnkey allows a change in the workflow and/or product suite to be timed arbitrarily, rather than being dependent on the timing of when a certain release is installed.

CIRA personnel also did some testing of Post-IOC, most of it regression testing that verified that the existing suite of Hydrologic hazard still had the proper workflow and products as developed for IOC. Finally, CIRA personnel participated in an in-house workshop where staff from the WFOs and NWS headquarters came in to evaluate the winter weather capability in Post-IOC.

AWIPS2 Hazard Services Integrated Version

This version of Hazard Services is being worked on to support issuing severe convective warnings, and will not become operational earlier than 2021.

In the Integrated Version, the biggest task for CIRA personnel has been to do python development on a Storm Tracking Tool. This was a very substantial effort, taking almost a fifth of a person year over the evaluation period. There has also been a limited amount of work testing, python debugging and user documentation for the Integrated version. Finally, CIRA personnel participated in two in-house workshops where staff from the WFOs and NWS headquarters evaluated the severe convective capability in Hazard Services.

PHI into AWIPS2 Hazard Services

In 2019, Funding from the Joint Technology Transfer Initiative (JTTI) for Year Two (of three) of the project “FACETs: Developing operationally-ready Hazard Services-Probabilistic Hazard Information (PHI) for convective hazards”, allowed CIRA developers to continue to developing tools and concepts that aim to advance the National Weather Service’s watch/warning/advisory capabilities. A number of new tools were designed, developed and tested during this period.

A brief list of tools and their purposes are:

- Threats-in-Motion (TiM): The concept of continuously translating warnings that provides impacted areas with more equitable lead time for hazardous weather
- Persistence: Duration persistence is introduced as a hazard event attribute. If the persistence is set, the event duration will be preserved when the data layer updates. Both start time and end time will move forward at the same pace, and the swath poly persists as well.
- Blocking of hazard events: Hazard Events (the software unit that contains the warning information) created by automated guidance can be blocked and unblocked by forecasters. This helps in management of potential warnings.
- Lighting PHI: The ability to ingest probabilistic lightning guidance data was developed. Tools that utilize that guidance to create potential hazard events within the software platform and lightning products sent to users were implemented.
- New ProbSevere ingest: a new format for the CIMSS (Wisconsin) was introduced. CIRA developers updated the ingest scheme as well as creating a plugin for the AWIPS2 Data Access Framework (DAF) that allows python tools to extract ingested data. This led to an upgrade of the tools that utilize such input guidance
- Legacy Product Generation: For the first time in the Hazard Service project, severe thunderstorm and tornado warning output was produced. This was due to the development of a product generator that created legacy text output utilized by the NWS. Lessons from this endeavor were used in the operational version of HazardServices.
- Design for Inter-0ffice Collaboration: The tool allows two WFO offices to collaborate on the issuance of a hazard event across the WFO boundary.

These new developments were tested in a major exercise held at the NOAA Hazardous Weather Testbed (HWT) in Norman, OK during three weeks in October 2019. The experiment was unique and extensive with four groups of participants: Forecasters, Emergency Managers, and Broadcasters, with Researchers analyzing the other three groups. Forecasters utilized the software described above to create and output warnings. These warnings were sent to the other two groups in the form of Probabilistic Hazard Information grids and Threats-in-Motion polygons. The Broadcasters and EM’s utilized the new warning information to make decisions during displaced real time scenarios. At the end of each scenario, Researchers would ask questions of each group and then the whole group and document the feedback. This feedback is helping to steer the direction of further development.

The Probabilistic Hazard Information concepts, techniques and products listed above and tested in the NSSL Prototype platform have been implemented into the Experimental branch of the Hazard Services plugin for AWIPS2. Additionally, these implementations have been tested in the Hazardous Weather Testbed

Important external partners in the project: Alyssa Bates[3,4], Joseph James[5], Kim Klockow-McClain[1,4], Kristin Kuhlman[1], Chen Ling[5], Tiffany Meyer[1,4], Holly Obermeier[6], Greg Stumpf[2,4]

1. NSSL, 2. MDL, 3. WDTD, 4. CIMMS, 5. Univ of Akron, 6. CIRES

AWIPS II FxCAVE Project

The FxCAVE project mission includes providing AWIPS II meteorological data services to remote and local users of the FxCAVE meteorological workstation desktop application.

The FxCAVE project delivers AWIPS-based meteorological data services in support of fire weather resource management and the field personnel of the National Interagency Fire Center (NIFC). FxCAVE as a service solution is composed of AWIPS II Environmental Data Exchange (EDEX) servers and a pared-down version of the Common AWIPS Visualization Environment (CAVE) meteorological workstation, which has be rebranded (to distinguish itself from its NWS operational counterpart) to the Forecast eXperimental CAVE (FxCAVE).

Accomplishments:

--Migration from AWIPS II 15.2/17.3 to 18.2.2.
--Customer Support: These services include ongoing support of twenty-two (22) NIFC personnel located in eleven (11) satellite Geographic Area Coordination Center (GACC) offices
--Maintenance and support of two (2) production-oriented EDEX data servers for CONUS and Alaska localizations.
--Maintenance and support of eighteen (18) physical desktop FxCAVE workstations at NIFC field offices.
--Evaluation of EDEX server and CAVE client deployments using Docker swarm containerization
--Deployment of DMZ-housed HTTPD proxy servers for reverse-proxy and LDAP authentication

<u>AWIPS II EDEX Cluster Maintenance/Support</u>

The Evaluation Decision Support branch maintains two AWIPS II EDEX clusters (v17.1.1 and v18.2.2) for research and development in support of multiple development efforts in the WISE subsection. CIRA personnel are now responsible for the upgrades, maintenance and support of these clusters.

<u>AWIPS2 Hazard Services Marine Post-IOC</u>

A significant task for CIRA/GSD developers last year was to develop and implement the ability to generate and issue long-fused marine watch/warning/advisory products in Hazard Services. This work is funded by the National Weather Service. GSD’s role in this tasking includes:

- Develop relevant marine hazard types and underlying metadata
- Develop and implement marine hazard criteria
- Develop and implement GFE grid based hazard recommender for marine hazards

This work was completed by CIRA personnel, and is fundamental in incorporating marine hazards at the WFO level into the Hazard Services environment. A Forecaster Assessment Test (FAT) was held at GSD in October of 2019 to gather feedback from forecasters and test the workflow’s operational capability. Feedback from the FAT has driven additional development of the marine workflows, which will be tested again to approve operational implementation in June 2020.

PROJECT PUBLICATIONS:

Hardin, N.R., D. Nietfeld, D. Kingfield, J. Sienkiewicz, F. Achorn, J. Nelson, T. Trogdon, J. Rhome: Progress Towards Integrated Tools for NWS National Centers. Abstracts, 36th Conference on Environmental Information Processing Technologies. Boston, MA, January 2020.

Hardin, N.R., D. Nietfeld, D. Kingfield, B. Entwhistle, A. Cross, E. Petrescu, N. Eckstein: Generating In-Flight Hazard Information Using AWIPS Hazard Services. Abstracts, 20th Conference on Aviation, Range, and Aerospace Meteorology. Boston, MA, January 2020.

Kingfield, D.M., V. Dreisbach, K. Goertz, C. Golden, S. Gui, Y. Guo, T.L. Hansen, N. Hardin, T.J. LeFebvre, J.L. Mahoney, K.L. Manross, S. Murphy, D. Nietfeld, J.E. Ramer, R. Weingruber, S.

Williams, and S. Zhuo: Hazard Services: An Information-Centric Modernization to the National Weather Service Watch/Warning/Advisory Program and Beyond. Abstracts, Severe Local Storm Symposium. Boston, MA, January 2020.

Kevin L. Manross, CIRA/Colorado State Univ. and NOAA/OAR/ESRL/GSD, Boulder, CO; and Y. Guo, G. J. Stumpf, T. C. Meyer, D. M. Kingfield, A. V. Bates, D. Nietfeld, and T. L. Hansen: Implementing Facets: Presenting the Most Recent Updates and Testing Results for Hazard Services-PHI. Abstracts,36th Conference on Environmental Information Processing Technologies. Boston, MA, January 2020.

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: EAR - Meteorological Assimilation Data Ingest System (MADIS)

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Tom Kent, Leigh Cheatwood-Harris, Amenda Stanley, Glen Pankow

NOAA TECHNICAL CONTACT: Greg Pratt OAR/ESRL/GSL/AT

NOAA RESEARCH TEAM: Leon Benjamin (CIRES), Gopa Padmanabhan (CIRES), Michael Vrencur (ACEINFO), Michael Leon (CIRES), Joanne Wade (CSG)

PROJECT OBJECTIVES:

MADIS is dedicated toward making value-added quality control data available to improve weather forecasting. MADIS data helps provide support for use in local weather warnings and products, data assimilation, numerical weather prediction, and the whole meteorological community in general. This goal is accomplished through partnerships with both federal and state government agencies, universities, airlines, private companies, and individual citizens.

Project Objectives:

--Add new functionality and data sources to MADIS.
--Provide support to the user community.
--Transition new and enhanced MADIS research to operations at NWS NCEP.

PROJECT ACCOMPLISHMENTS SUMMARY:

The MADIS 2.2 software release was transitioned to operations at NWS National Centers for Environmental Prediction (NCEP) Central Operations (NCO) in Sept 2019. This large release took 2 years to integrate ASOS, IOOS, HADS, AFWS, CLARUS, and SNOTEL systems into MADIS IDP operations at NCO. Many other new capabilities along with several new data providers were added in addition to more automated testing and implementation processes to improve future release efficiency.

- Hydrometeorological Automated Data System (HADS) and Automated Flood Warning System (AFWS)- These very reliable and indispensable hydro systems were migrated into MADIS to achieve cost efficiencies and consolidation for NOAA. The HADS is a mission critical function that acquires, processes, and disseminates critical hydrological and meteorological data to the National Weather Service (NWS) Field Offices to protect life and property. The AFWS specifically adds alert data for flood warnings. These hydro products are disseminated through the NWS Telecommunications Gateway infrastructure and are made available to the NWS, HADS stakeholders, all levels of governments, as well as the general public. The 2.2 software release greatly improved the efficiency by making common additions dynamic as well as being able to reprocess large amounts of old data. This took a lot of effort and collaboration with many different groups within NWS.

- Automated Surface Observing System (ASOS) - A real-time connection for ASOS data was established between the FAA operational data facilities and NWS-MADIS. The WFOs covet this valuable and highly reliable data set for support in forecasting. MADIS is the only non-FAA entity getting this binary data in real time.

- Integrated Ocean Observing System (IOOS) - MADIS handles IOOS data as a National Mesonet Program (NMP) partner. The data is standardized in a CSV format that includes a header line to make it self-describing. This makes it much easier to add a new provider and not have to write new custom software for each new data source. More work on automation will continue in 2020 in addition to expanding the standard to include upper air data. There were more than a dozen new IOOS data providers added in the 2.2 MADIS release.

- CLARUS (not an acronym) - Clarus was integrated into MADIS to transition Department of Transportation Road Weather Information System (RWIS) data, metadata, and QC algorithms to operations at NCO as part of the 2.2 software release. Every year we add more states to this program, dependent on individual state DOT funding. More QC algorithms are being created for the future.

- Citizen Weather Observer Program (CWOP) database -
There are currently over 20000 active stations (citizen and ham radio operators) out of a total of ~40000 stations in the CWOP database. CWOP members send their own personal weather sensor data via internet to a server which then gets forwarded to the MADIS system every five minutes. The data undergo quality checking and then are made available to users thru the MADIS distribution servers.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Research Collaborations with Information and Technology Services

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Leslie Ewy, Patrick Hildreth, Robert Lipschutz, Richard Ryan, Amenda Stanley, and Joshua Weber

NOAA TECHNICAL CONTACT: Scott Nahman OAR/ESRL/GSD/ITS

PROJECT OBJECTIVES:

CIRA researchers in the ESRL Global Systems Division’s (GSD) Information and Technology Services (ITS) group develop and maintain systems that acquire, process, store, and distribute global meteorological data in support of weather analysis, modeling, and information systems projects throughout GSD. The CIRA team collaborates with ITS systems, networking and security specialists and numerous GSD researchers to provide reliable services that meet project requirements. The team works to improve and extend ITS data handling and monitoring capabilities to increase reliability, better utilize GSD resources and provide additional services.

CIRA staff also participate as team members of projects within other GSD branches.

PROJECT ACCOMPLISHMENTS SUMMARY:

--GSD Central Facility - The CIRA team continued to manage middleware and applications software on the collection of Central Facility (CF) hosts that support the GSD and CIRA mission. In collaboration with ITS systems, network and security staff, CIRA researchers participated in a major effort to re-architect GSD data services and decommission legacy servers. That effort significantly improved resource utilization and reduced latency for data delivery to users. The resulting set of CIRA-managed systems is illustrated in Figure 1.

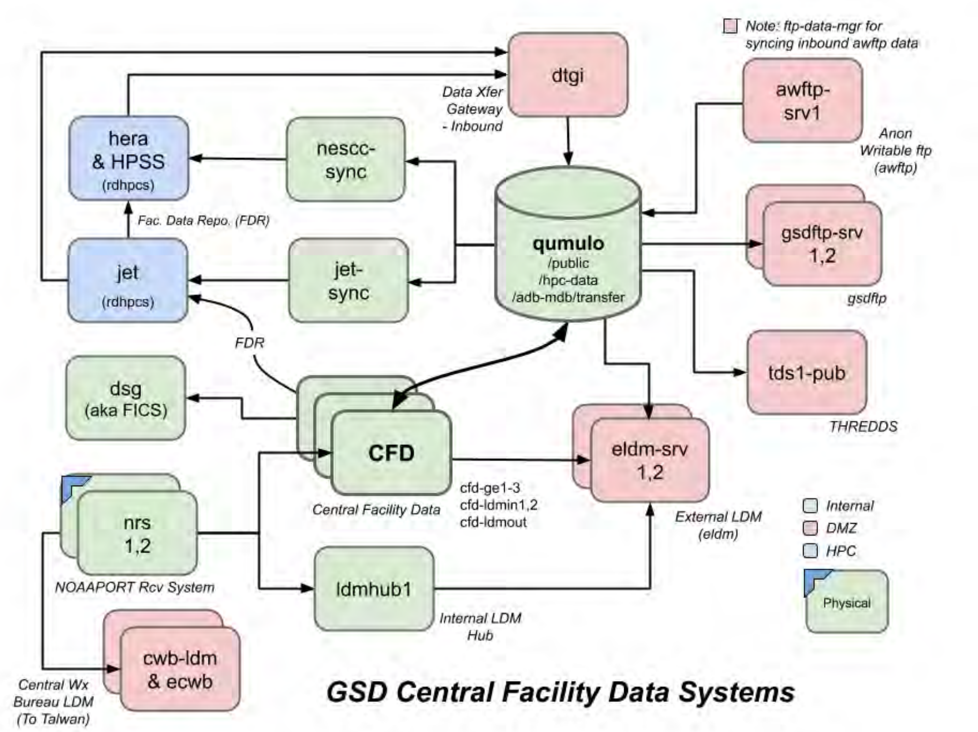


Figure 1. GSD systems with CIRA-managed data applications, Fall 2019.

CIRA staff supported the development and evaluation of RAP version 5 and HRRR version 4, which has been approved for operational implementation at NCEP by the summer of 2020. In addition to providing routine data acquisition and transport services, the team posted to the GSD ftp server a large number of retrospective data sets needed for evaluation by GSD, NWS and NCEP collaborators.

The CIRA team also established ingest, processing, and transport for a number of real-time data sets within the Central Facility and NOAA R&D High Performance Computing (HPC) environments, including:

- GFS version 15.1 from NCEP,
- RAP v5 and HRRR v4 pre-operational model data from NCEP/EMC,
- Advanced Scatterometer (ASCAT) satellite wind data from NASA/JPL,
- GOES-17 image products from Unidata,
- Multi-Radar Multi-Sensor (MRMS) Lightning Flash data from NSSL,
- Air quality particulate (PM2.5) products from Airnow Tech,

- FV3 Stand-Alone Region (SAR) data for NSSL, Storm Prediction Center (SPC), and the Aviation Weather Center (AWC),
- data from California-based radars supporting the Advanced Quantitative Precipitation Information (AQPI) project,
- GSD model graphics from the HPC systems for display by GSD web servers, and
- delivery of RTMA_3D data to the NOAA/NCEP Storm Prediction Center (SPC).

Other activities included:
- supporting the recovery of CF systems following the month-long federal furlough,
- coordinating with GSD researchers, NCEP and NWS TOC administrators to identify and resolve transfer rate issues that affected data delivery to GSD users,
- refreshing GSD's NOAAPORT ingest systems, including specifying new systems for procurement, configuration development and testing, and transition to production,
- training in the python scripting language and applications,
- working with ITS Systems Administrators to expand CPU and memory resources on Central Facility virtual servers to ensure capacity to handle growing data volume,
- migrating processing on the legacy HPC system, Theia, to a new system, Hera, including coordination with HPC administrators to ensure comparable throughput levels to the prior system,
- in coordination with HPC administrators, re-factoring the production role-based user accounts on Jet and Hera to facilitate automated transfers direct between these systems, and
- refactoring numerous ftp ingest processes to leverage more efficient and reliable methods.

--MADIS (Meteorological Assimilation Data Ingest System) - The CIRA ITS team provided direct support to GSD's MADIS project by improving reliability and flexibility of the Hydrometeorological Automated Data System (HADS) system components. We identified and resolved an issue with the RFC 2.2 HADS email handling that would have caused a failure of the IDP RFC v2.2 30-day test. Other efforts include research into database latencies on HADS systems and diagnosing issues with the QA HADS processing system. A new MADIS Aircraft Data project was initiated to understand and develop methods for handling data in BUFR and NCEP's 'BUFR Tank' formats.

--FxCAVE (FSL eXperimental Common AWIPS Visualization Environment) - The CIRA ITS team helped verify the new 3-year certificate for the FxCAVE thin-client authentication. Efforts on the production systems included monitoring, configuring and validating the EDEX servers after an upgrade to AWIPS II. Team members participated in the review and drafting of the 5-year plan, covering 2020-2024. Several custom data sets were added to the upgraded AWIPS II EDEX servers, including GINA satellite and several Alaska-specific models. System monitoring was extended to include FxCAVE systems to enhance reliability of those systems. Development of new metric visualization methods was begun.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Environmental Applications Research - Science On a Sphere® (SOS) Development

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Keith Searight, Ian McGinnis, Evan Sheehan

NOAA TECHNICAL CONTACT: Mark Govett OAR/ESRL/GSD/ATB

NOAA RESEARCH TEAM: Shilpi Gupta (CIRES), Alex Kirst (CIRES), Eric Hackathorn (OAR/ESRL/GSD/ATB)

PROJECT OBJECTIVES:

1. Develop and enhance near-real-time and other global data sets for use at SOS sites.
2. Provide software and technical support for existing SOS systems sites, new and proposed SOS installations, and travelling SOS exhibits that conduct scientific education and outreach.
3. Plan and release new versions of the SOS system software with prioritized features.
4. Research new technologies and configurations for future innovations in SOS.

PROJECT ACCOMPLISHMENTS SUMMARY:

The Science on a Sphere® (SOS) Development project advances NOAA's cross-cutting priority of promoting environmental literacy. SOS displays and animates global data sets in a spatially accurate and visually compelling way on a 6-foot diameter spherical screen. CIRA provides essential technical leadership and developments to the SOS project, particularly research and implementation of effective controls and user interfaces for the system, new visualization techniques, the project website, and new data sets.

<u>1--Near-real-time and other global data sets</u>

The SOS development team continued to support the automated transfer of large volumes of near-real-time weather model and other datasets to SOS sites via private FTP. In 2019, SOS dataset downloads averaged 21 TB per month. The SOS team also continued to collaborate with other scientific groups within and outside of NOAA to provide new, compelling, and, impactful curated datasets for SOS audiences.

Dataset highlights for this reporting period include:

--Added or updated 18 datasets. Continued maintaining current real-time datasets, including GFS weather models, global weather satellites, earthquakes, fires, land surface temperatures, ocean color, snow and ice coverage, and drought risk. The FV3 model core has now replaced the FIM in most weather-forecast datasets distributed for SOS.

New SOS Datasets:

--Warming Stripes: Global and Warming Stripes: Australia, Germany, and USA. A set of visualizations highlight how we have witnessed temperatures change across the globe over the past century or more. The color of each stripe represents the temperature of a single year, ordered from the earliest available data at each location to present time. Pairing the two datasets is useful for illustrating weather vs. climate.

--World Population Movie. A graphical simulation of human population growth over two millennia. Animation goes from 1 C.E. to 2050, with dots lighting up on a global map to represent population changes.

--Earth in True Color (GOES-16 and 17) - Real-time. NOAA's next generation geostationary weather satellites show imagery in near true color. In the daytime, land and shallow-water features appear as they do in true-color imagery. In the nighttime, the satellites' high resolution infrared imagery is mapped onto a Nighttime Lights layer. The daytime and nighttime imagery is combined to create a natural transition from day to night.

--PALEOMAP PaleoAtlas, 0 - 750 Million Years Ago. The PaleoAtlas illustrates the ancient configuration of the ocean basins and continents, as well as important topographic and bathymetric features such as mountains, lowlands, shallow sea, continental shelves, and deep oceans.

--Shark Tracks. Live Program. This scripted presentation focuses on three sharks, Mary Lee, Katharine, and Lydia, and their observed paths of travel in the ocean. All of the sharks migrated seasonally from Massachusetts waters and the northeast shelf in the summer to overwintering habitat off the southeastern US and the Gulf of Mexico. These findings extend the known essential habitat for the white shark in the North Atlantic beyond existing protection with implications for future conservation.

--HOLOSCENES / Little Boxes. A narrated movie by internationally-acclaimed artist Lars Jan/Early Morning Opera, immersive media artist/technologist Pablo N. Molina, and a team of scientists, engineers, and artists in the original live performance work HOLOSCENES. This art/science film is based on the original HOLOSCENES and specially adapted for Science On a Sphere®. The film inspires us to reflect on how we can take a step out of our habits and what we know - our daily rhythms within our “little boxes” - and consider our interconnectedness and how our personal decisions affect a global scale.
--Earthquakes of the 20th Century. This animation shows earthquakes from January 1, 1901, through December 31, 2000, at a rate of 1 year per second. The earthquake hypocenters first appear as flashes then remain as colored circles before shrinking with time so as not to obscure subsequent earthquakes. The size of the circle represents the earthquake magnitude while the color represents its depth within the earth. Several other related visualizations are shown at the end of the animation.
--Animals on the Move. This presentation shows animal migration over land and under sea through different rates of change and movement--like seasonal, rapid, or long term and different ways of observing--like satellite tracking, participatory science reporting, or mathematical modeling.
--Seasonal 3-Month Outlook: Temperature - Real-time and Seasonal 3-Month Outlook: Precipitation - Real-time. These datasets project a real-time seasonal outlook for temperature and precipitation out to three months into the future. It is an experimental probabilistic seasonal climate forecast product using an ensemble of prediction models to form reliable probability forecasts.
--Sea Ice Extent (Arctic only) - 1850 - Present. Since the late 1970s, sea ice has been monitored with data from a series of satellites. Much earlier, whaling ship log entries in the 1800s recorded ice conditions. In the 1890s, the Danish Meteorological Institute began compiling ice observations from ships in the Arctic. Militaries began to chart ice conditions by air beginning in the mid-20th century. All these observations are combined to reconstruct or approximate what the Arctic-wide sea-ice extent looked like since 1850.

Figure 1. HOLOSCENES / Little Boxes movie by internationally-acclaimed artist Lars Jan & Early Morning Opera, immersive media artist/technologist Pablo N. Molina, and a team of scientists, engineers, and artists.

<u>2--Software and technical support for SOS systems; scientific education and outreach</u>
The SOS team provides regular support to SOS sites by email, telephone, remotely, and occasionally in person. Issues handled include upgrades and solving problems with the SOS software, hardware, and equipment, finding and accessing datasets, and questions about operating the SOS system. In 2019, the

SOS team also improved customer support management by moving from email to the Spiceworks help desk software.

During this reporting period, 14 new SOS systems were installed at venues worldwide: ITAIPU Binacional (2 in Parana, Brazil), Tamilnadu Science and Technology Centre (Chennai, India), Ministry of Oceans and Fisheries (Sejong City, Korea), Beijing Science Center (Beijing, China), Shenzhen Meteorological Bureau (Shenzhen, China), Tianjin Lovol Heavy Industry CO. (Tianjin, China), Binhai Cultural Center (Binhai, China), China Science and Technology Museum - Polar Experience Hall (Mohe, China), Museum of Life and Science (Durham, NC), Michigan State University Museum (East Lansing, MI), IMAG History and Science Center (Fort Myers, FL), Museum of the Southwest (Midland, TX), Metropolitan Community College (Omaha, NE).

CIRA staff conducted three of this years' US installs onsite and presented tutorials to museum staff on SOS operations, making presentations, and creating custom content. The total number of SOS systems installed worldwide is now over 175 with a total viewership estimated at over 37M people annually.

In the SOS Planet Theater at the NOAA Skaggs building in Boulder, SOS educational shows were viewed by an average of 294 visitors per month, with SOS staff conducting some of the presentations or providing technical backup to presenters when needed.

Science On a Sphere was also selected as the cover story article for the Dec. 2019 issue of the Computers in Libraries journal with the accompanying article "EDTECH: Leveraging Earth Observations for Education".

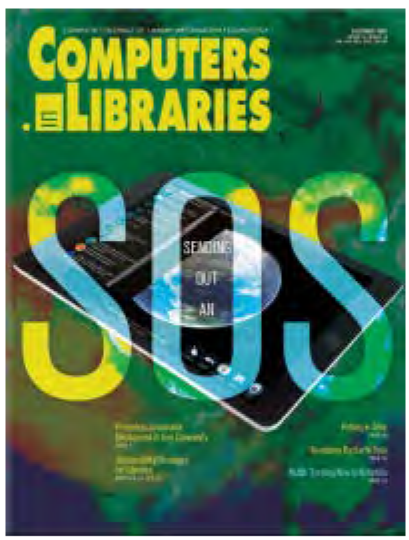


Figure 2. "Sending out an SOS": Computers in Libraries journal cover, Dec. 2019 issue.

<u>3--Plan and release new SOS capabilities</u>

Under CIRA staff leadership, the SOS team planned and executed a major software release, SOS 5.5 (Oct. 2019), with a few smaller maintenance releases following that. Significant highlights for version 5.5 included:

--Porting SOS to run on the Ubuntu 18.04 LTS operating system, which provides 2-years' worth of Linux feature additions and bug fixes since 16.04, which was the last long-term support version used with SOS.

--Improving SOS system configuration by implementing a settings manager with a user interface.

--Adding Projector On/Off controls to the automation control protocol and putting controls in the Remote App.

--In the Visual Playlist Editor and Remote App, appending a diamond icon to the name of every Site-

Custom dataset to quickly identify datasets that are specific to that site vs. those managed and distributed by NOAA.
--Kiosk: Upgrading the default datasets provided with the kiosk with new and updated datasets.
--Making a set of smaller fixes and enhancements across the SOS application suite of products.

During 2019, CIRA staff led the improvement of SOS development practices by moving the SOS team to git and GitLab for code management, issue tracking, continuous integration, code reviews, and software containerization. Additionally, the team employed various agile techniques, including iterative development, retrospectives, and collaborative work estimation.

4--Research new technologies and configurations for future innovations in SOS
The CIRA staff and the rest of the SOS team aims to keep SOS exciting, relevant, and accessible to its audiences. Several new technical areas are now being evaluated for consideration in future versions of SOS, including:
--The feasibility of porting SOS to run on LED spheres.
--The potential use of Machine Learning to clean up glitches and fill in missing frames of SOS satellite images

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Environmental Applications Research - TerraViz (branded as SOS Explorer)

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Keith Searight, Jebb Stewart, Jeff Smith

NOAA TECHNICAL CONTACT: Mark Govett OAR/ESRL/GSD/ATB

NOAA RESEARCH TEAM: Eric Hackathorn (OAR/ESRL/GSD/ATB), Jonathan Joyce (CIRES)

PROJECT OBJECTIVES:
1. Add and enhance datasets from SOS and develop custom 3D datasets for use with SOS Explorer (SOSx).

2. Provide software and technical support for existing and prospective SOSx customers and traveling SOSx exhibits to conduct scientific education and outreach.

3. Plan and release new versions of the SOSx system software with prioritized features.

4. Research new technologies and configurations for future innovations in SOSx.
PROJECT ACCOMPLISHMENTS SUMMARY:
The TerraViz™ project greatly supports and expands NOAA's mission to promote environmental literacy. Conceptually, SOS Explorer (SOSx) is a flat screen version of the widely popular Science On a Sphere® (SOS) by extending the NOAA-developed TerraViz™ visualization engine and adding virtual reality extensions using the Oculus Rift. SOSx is an easy-to-use interactive application on PCs and mobile devices that seamlessly combines and visualizes many types of 2D and 3D environmental data across time and from the ocean floor, through the atmosphere, and into space. SOSx displays many popular SOS datasets, which were previously seen exclusively on a 6-foot sphere in large museum spaces.

SOSx makes SOS images and movies much more accessible to teachers, students, and the general public, as well as new visualizations that go beyond the limitations of a physical sphere.

1--Add and enhance datasets from SOS and develop custom 3D datasets for use with SOSx

Through the end of 2019, the SOSx Exhibit had over 150 datasets, including:
--17 real-time datasets
--91 movies, 28 with narration
--19 datasets exclusively on SOSx, including 6 3D datasets
--3 first-person Experiences, including Tornado Safety using Virtual Reality
--34 360-degree "bubbles" that users can fly into and look around in all directions.

During this reporting period, these datasets were added to the exhibit version of SOSx:
--Copied from SOS (described in the SOS project report): Sea Ice Extent (Arctic only) - 1850 - Present, HOLOSCENES / Little Boxes, Warming Stripes: Global, and World Population Movie.
--Exclusive to SOSx: Population Density at Night (Interactive). The SOSx user can click on the map to calculate the population density of any area on Earth. This image combines the Earth's Gridded Population of the World from 2000 with Defense Meteorological Satellite Program (DMSP) nighttime lights data to show the distribution of human population across the globe.

2--Provide software and technical support for existing and prospective SOSx customers and traveling SOSx exhibits to conduct scientific education and outreach

During 2019, 10 new SOSx Exhibits were installed at various venues: Palmyra Cove (Palmyra, NJ), New Mexico Military Institute (Roswell, NM), BWC Visual Technology (Upper Marlboro, MD), Monte L. Bean Museum (Provo, UT), Madatech, Israel National Museum of Science, Technology and Space (Haifa, Israel), National Marine Sanctuary of American Samoa (Pago Pago, AS), Papahanaumokuakea Marine National Monument (Hilo, HI), University of Texas Marine Science Institute (Port Aransas, TX), NOAA Fisheries (Pascagoula, MS), Penn Yan School District (Penn Yan, NY). There are now 36 installed SOSx Exhibits worldwide.

The SOSx team participated in a number of workshops and conferences where SOSx Exhibit and/or Mobile were demonstrated, including the 2019 AMS annual meeting (Phoenix), VISUALISE: Visualization for Informal Science Education (San Francisco), Space Science Symposium (Colorado Springs), Association of Science-Technology Centers (ASTC) annual meeting (Toronto), American Indian Science and Engineering Society (AISES) national conference (Milwaukee), AGU Fall meeting (San Francisco), and NCAR Super Science Saturday (Boulder).

3--Plan and release new versions of the SOSx system software with prioritized features

Under CIRA staff leadership, the SOSx team planned and executed a significant software release with new features and fixes, version 1.4.2, which included support for right-to-left languages, including Hebrew, and some key fixes.

The highlight of the year was the first release of a new SOSx Mobile App in Sep. 2019 that runs on Apple and Android phones and tablets. SOSx Mobile has many of the same features as the Exhibit version, except that it serves data using an innovative adaptive data streaming approach hosted on the cloud.

SOSx Mobile's current collection of over 115 datasets includes:
--75 mpeg4 movies hosted on the Vimeo video cloud service. Each movie has 4 different resolution levels that are switched between automatically while streaming depending on the Wi-Fi bandwidth available to the device.
--41 images hosted in Amazon AWS S3 buckets. One of these is the default display on the sphere, which is a composite satellite image that is refreshed in real-time so that the most recent frame is shown.
--2 asset bundles also hosted on AWS: Saturn with its rings and the Comet 67p. These 3D visualizations are composed of a combination of textures, models, and code executed at runtime.

SOSx Mobile was featured in a Washington Post article on Aug. 10 and was selected for the 2020 Federal Labs Consortium (FLC) Planner as the featured tech transfer product for the month of June. To date, the app has had tens of thousands of downloads, about ⅔ to Apple devices running iOS and ⅓ to different Android-based devices.

Figure 3. SOSx Mobile featured in the 2020 FLC planner for the month of June.

4--Research new technologies and configurations for future innovations in SOSx

The SOSx team experimented with newer virtual reality equipment to replace the previous Oculus Rift hardware that was recently discontinued. A graduate student from Taiwan was also hired as a summer intern and he created a compelling 3D landslide visualization that may be included in the future as a new SOSx Experience.

Figure 4. 3D landslide simulation prototype for an SOSx experience.

Technologies or techniques or software developed
SOS Explorer Mobile is a free App first released in 2019 that runs on Apple and Android phones and tablets. It serves data using an innovative adaptive data streaming approach hosted on the cloud.

Teaching/education impact
SOS, SOSx Exhibit, SOSx Mobile, and the SOS website are all focused on delivering science education, both formal and in-formal, to students, teachers, and the general public.

New physical and or computing resources
SOS and SOSx Exhibit: using Qumulo mounted disks for writing dataset files to our FTP servers and for backing up datasets to a long term archive.

SOSx Mobile: using the Vimeo video cloud service for hosting mpeg4 movies and cloud-based AWS S3 buckets for hosting global images.

Technology to operations
SOS and SOSx Exhibit technology is transferred on an ongoing basis to operational government and private customers under MOUs, including museums, schools, and universities. In 2019, SOS v5.5 and SOSx v.1.4.2 transferred the updated technology to these customers.

SOSx Mobile was first released in 2019 and it transfers technology to operations on an ongoing basis to students, teachers, and the general public when they download and install the free App on a phone or tablet. Several updates to the App were pushed to App stores and these were transferred to everyone that updated their devices. To date, the App has been downloaded tens of thousands of times.

The SOS website provides operational capabilities on an ongoing basis to provide information to existing SOS/SOSx sites and prospective purchasers. It also operationally provides science-related dataset information, images, and movies to all website visitors looking for scientific content.

PROJECT PUBLICATIONS:

Peddicord, H., S. Cobb, and B. Russell, EDTECH, Leveraging Earth Observations for Education, 2019. Computers In Libraries, Vol. 39 No. 10.

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Weather Archive and Visualization Environment (WAVE)

PRINCIPAL INVESTIGATOR: Bonny Strong

RESEARCH TEAM: Jeff Smith, Jebb Stewart

NOAA TECHNICAL CONTACT: Mark Govett OAR/ESRL/GSD/ATB

NOAA RESEARCH TEAM: Jonathan Joyce (CIRES)

PROJECT OBJECTIVE:

Extend the existing WAVE (Weather Archive and Visualization Environment) created by the National Weather Service (NWS) with new features and a more scalable architecture that supports more concurrent users and larger volumes of data.

PROJECT ACCOMPLISHMENTS SUMMARY:

WAVE is a community-driven, "one-stop shop" for data visualization, with the goal of generating consistent, understandable graphics. It provides web-based access to diverse datasets, including experimental models. Archives going back four or more years provides for case-study analysis and training opportunities.

During the most recent period of performance there were a number of significant WAVE enhancements made:

--Introduction of a new, cloud-native software solution that supports scaling as needed to handling larger datasets and more users. This approach provides the ability to scale services with use and scale storage as the size of the archive grows. It also provides a path to easily migrate to a commercial cloud provider.

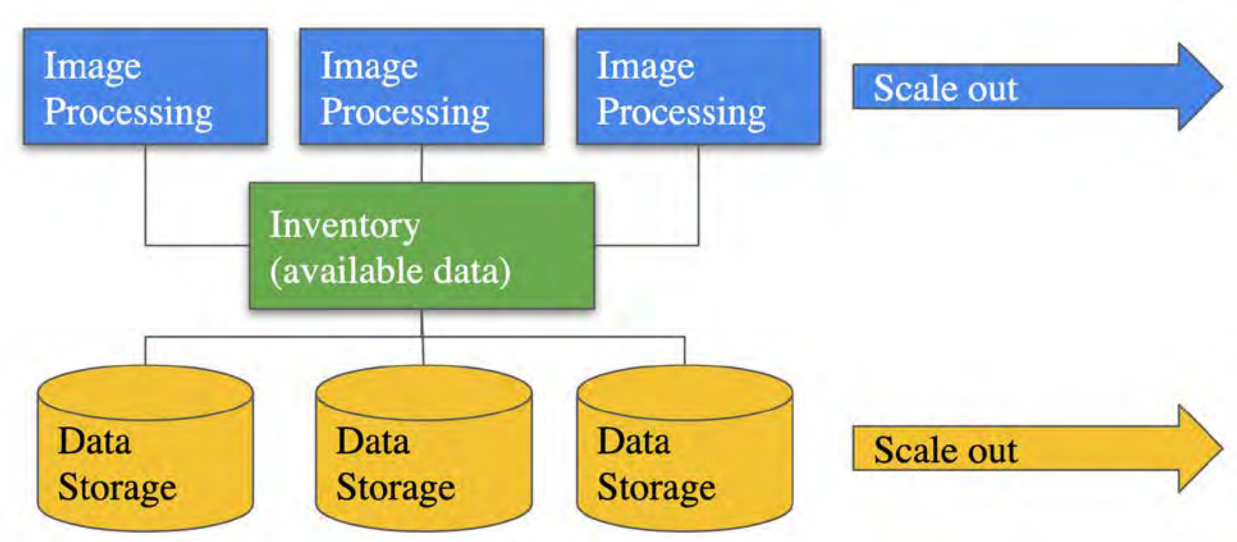


Figure 1. Cloud-Native Support Schematic

--Creation of a public API that supports custom, downstream products. This allows automatic pulling of graphics from WAVE into Google Slides, saving forecaster's time. Only one website is needed that has consistent graphics. Shareable links are provided for use in social media, presentations, and collaborations.

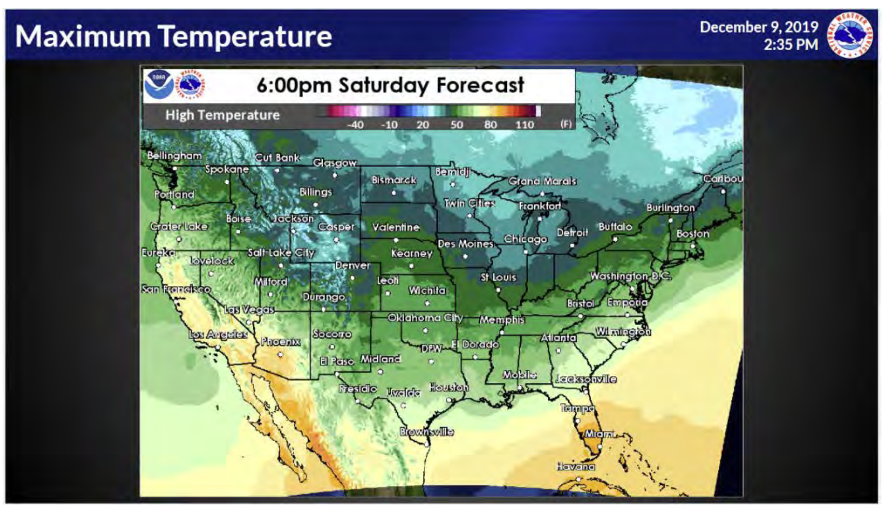


Figure 2. Example of Graphics from WAVE Inserted into a Slide

--Added a National Blend of Models (NBM) Viewer. This provides a probability analysis for specific points and adds confidence to forecast communications. It also improves WAVE's capabilities to provide meaningful forecast information.

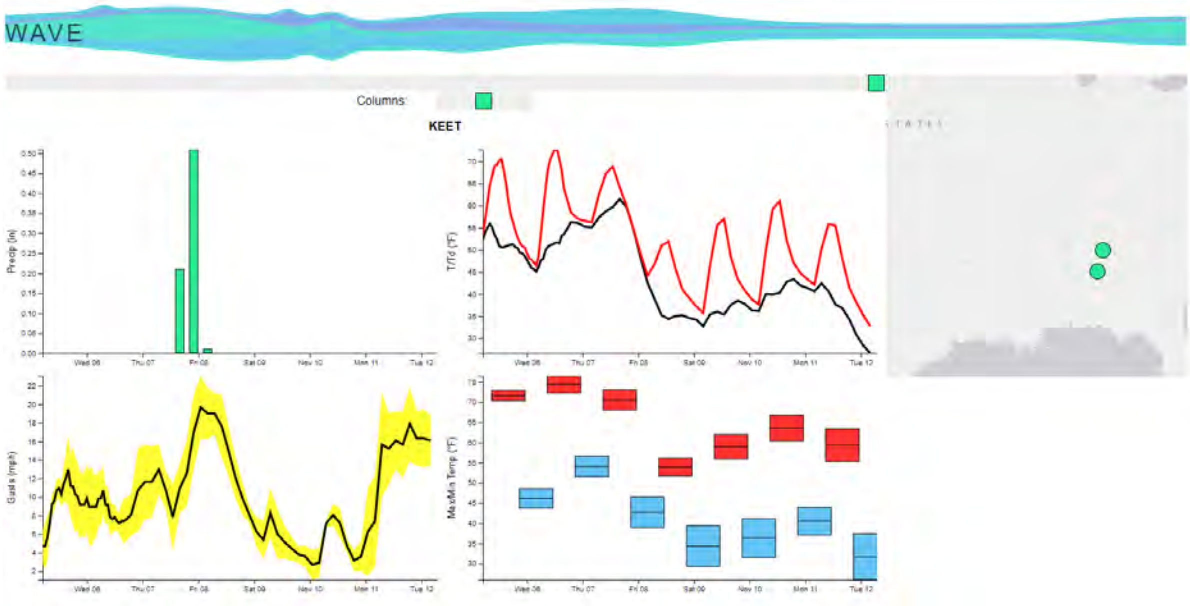


Figure 3. National Blend of Models (NBM) Viewer Example.

--Added new datasets: GOES-16 and RADAR, as well as the NBM.

--Created a robust and collaborative workflow to allow the NWS community to contribute to development and support rapid prototyping of capabilities. A Continuous Integration (CI) pipeline was introduced to support automated builds and automated testing for a more stable system.

Ties to the IDSS Project:

WAVE technology is also part of a larger research effort, the Impact-based Decision Support Services (IDSS) which is being developed under separate NOAA funding.   IDSS is intended to provide relevant information and interpretive services that enable partners to prepare for and respond to extreme weather, water, and climate events. In the current year, IDSS work completed included connecting WAVE to the NWS IRIS event database, as well as ingesting and visualizing NDFD prob snow guidance, and HRRRe guidance.

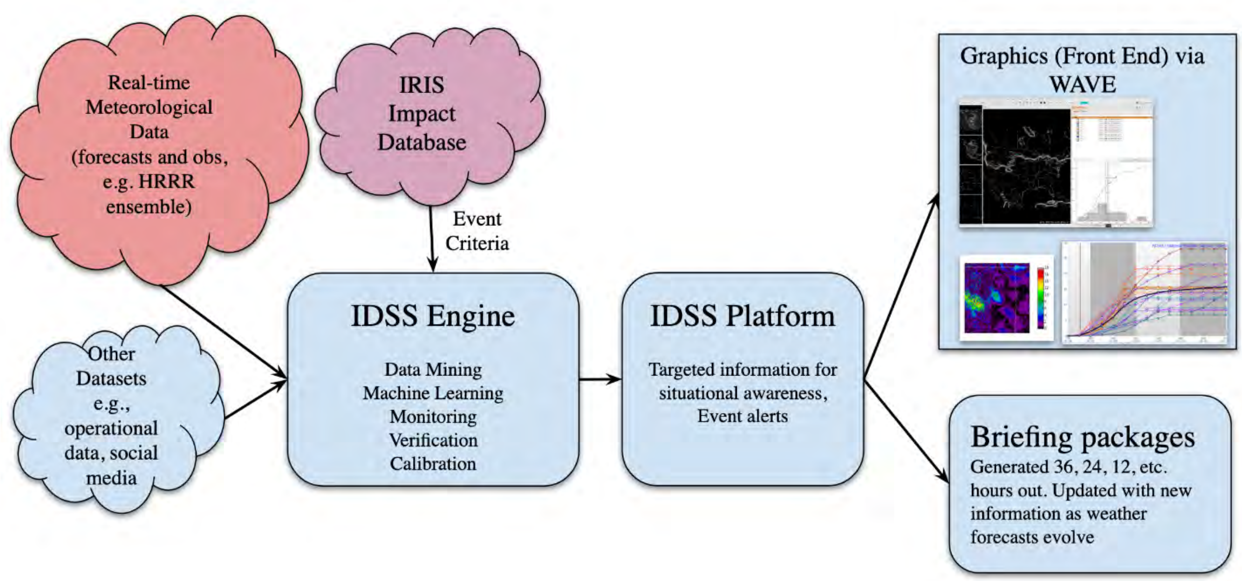


Figure 4. IDSS Schematic.

Future Plans:

--WAVE: Include Python graphics capability to simplify community involvement, modernize the UI and support a mobile interface, add on-demand ensemble analysis, implement more probabilistic graphics integration, leverage existing NOAA Big Data archives for GOES-16/17 and RADAR datasets, and deploy to the commercial cloud.

-- IDSS Engine: Add ingesting of the PRISM climatological dataset. All the information collected in WAVE will be consolidated into a Heads Up Display (HUD). Forecasters will use the HUD to assess information from IRIS and model data to help give them situational awareness and confidence of upcoming impacts based on probabilistic and deterministic forecast information. The IDSS engine capabilities will be available via cloud services where determined to be cost effective and technically feasible.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Joint GOES-R, JPSS, and NASA Summer Workshop on the Theory and Use of Satellite Data

PRINCIPAL INVESTIGATOR: Steven J. Fletcher

RESEARCH TEAM: Steven J. Fletcher

NOAA TECHNICAL CONTACT: Daniel Linsey

NOAA RESEARCH TEAM: NESDIS-GOES-R and JPSS Programs

PROJECT OBJECTIVE:

To facilitate hands on learning and applications of theory and use of Satellite data.

PROJECT ACCOMPLISHMENTS SUMMARY:

In July 2019 the Cooperative Institute for Research in the Atmosphere (CIRA) hosted a two-week international workshop for Ph.D. students from both domestic and international universities.
The workshop lasted for two weeks, and the attendees had a combination of lectures and had on practicals. Also as part of the workshop the attendees also undertook an excursion to COMET and UNIDATA at NCAR in Boulder where they were able to have hands on experience with new educational tools, while at UNIDATA the attendees were introduced to different visualization tools for satellite. The attendees had all of their travel expenses covered, as well as hotel accommodation and per diem for the two weeks of the workshop.

This award provided support for attendees from Brazil, Argentina, USA, as well as from Bermuda. This enable the attendees to build international networks not just with their own peer group but also leading scientists from different NASA and NOAA satellite programs.

All of the attendees gave a short presentation on the work that they are undertaking at their institutions.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Aerosol Size Distribution and Composition Evolution during FIREX Activities: Closure Analyses and Climate Impacts

PRINCIPAL INVESTIGATOR: Jeffrey Pierce

RESEARCH TEAM: Anna Hodshire, Matt Alvarado, Chantelle Lonsdale, Shantanu Jathar, Ali Akherati

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

1. *Closure in FIREX lab studies*: We will quantify how various processes (e.g. OA formation/evaporation, coagulation, wall losses) contribute to changes in aerosol composition and size throughout FIREX laboratory studies from the Missoula fire lab (late 2016) and from the CU Boulder chamber (2017). This will be done through closure studies using the ASP smoke chemistry/physics model and the laboratory data.

2. *Closure in FIREX field studies*: We will quantify how these processes contribute to changes in aerosol composition and size throughout FIREX field studies (2018). This will be done through closure studies using the coupled SAM-ASP plume dispersion and chemistry model and the airborne measurements from the NOAA P-3.

3. *Comparison of lab and field data*: We will identify lab experiments where similar fuels were burned as in smoke plumes observed in the field, and we will determine if the evolution of the aerosol size distributions observed in the lab are consistent with the field. We will identify processes contributing to any differences (e.g. wall losses, dilution, concentrations).

4. *Regional and global modelling*: Through our closure studies, we will develop a parameterization of sub-grid aging of biomass-burning aerosol. We will test this parameterization in the GEOS-Chem-TOMAS global/regional aerosol microphysics model and quantify climate forcings.

We have made contributions in each of these areas, although because the FIREX field study was delayed by one year until last August/September, we have no analyzed this campaign yet, but rather focused on other recent field campaigns focused on smoke.

PROJECT ACCOMPLISHMENTS SUMMARY:

Objective 1 (FIREX lab studies): Through our collaborations with Shantanu Jathar (funded on a separate NOAA grant through CIRA; Shantanu's grant funded the experiments and the first-author on the publication, Ali Akherati), we have worked to understand secondary organic aerosol (SOA) formation during the FIREX laboratory campaign. Our major, novel finding is that oxygenated organics (phenolic species) appear to be the dominant contributors to SOA formation even though they are a relatively minor fraction of the volatile organic compounds emitted by fires (Figure 1). This work is soon to be submitted to Environmental Science and Technology (Akherati et al., 2020).

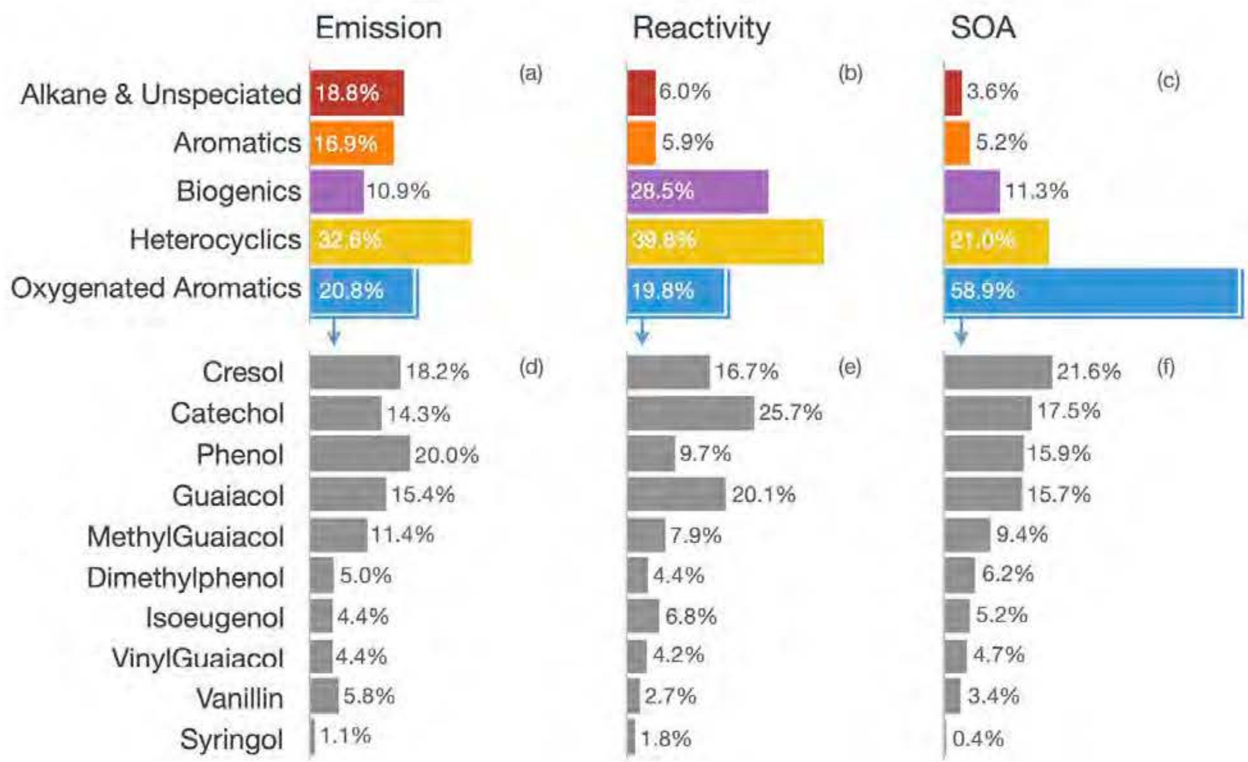


Figure 1: Fractional contributions to (a) emissions, (b) OH reactivity, and (c) SOA production of the various SOA-precursor classes (the average of the eleven chamber experiments analyzed in this work). Some of the SOA precursor classes are lumped for clarity (e.g., alkanes+unspeciated, all aromatics). Top panels show results for all SOA precursors and bottom panels show results for just the oxygenated aromatic precursors.

Objective 2 (FIREX field studies): Because the FIREX field study was delayed from 2018 until 2019, we have not focused on analyzing the FIREX field study. Rather, we have focused on the related Biomass Burning Observation Project (BBOP). I have just received funding from NSF to continue work on the FIREX field study. In BBOP, we have found the cores and edges of plumes differ in aerosol properties, particularly markers of organic aerosol oxidation (f60, f44, and O:C) as well aerosol size and number (Figure 2). We hypothesize that these core-edge differences are due to dilution and faster photooxidation at the plume edges. This paper is close to submission to Geophysical Research Letters. We also created and published a climatology of smoke composition and optical properties from a decade of IMPROVE and AERONET measurements (Bian et al., 2020).

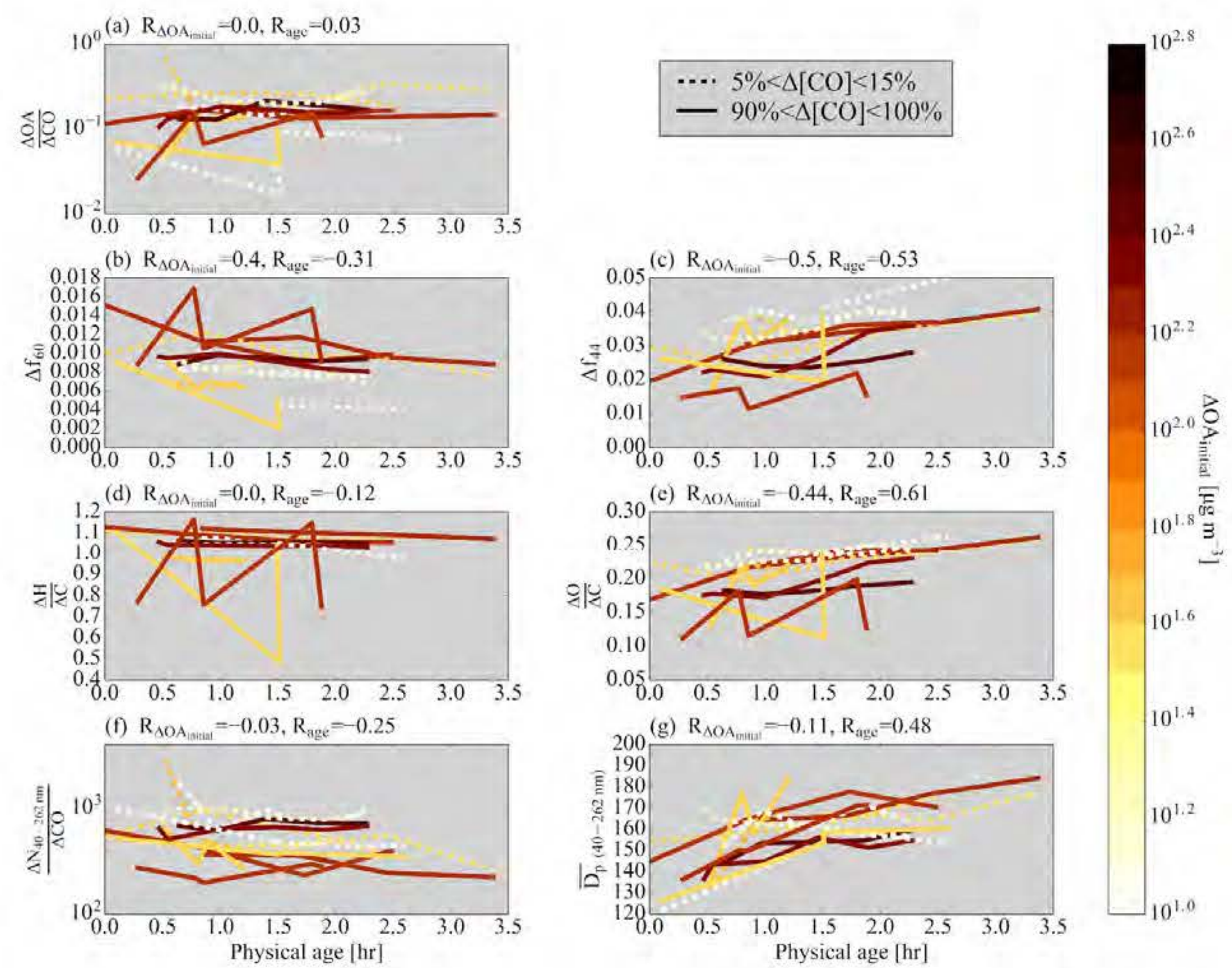


Figure 2. Various normalized parameters as a function of age for the 7 sets of pseudo-Lagrangian transects. Separate lines are shown for the edges (lowest 5-15% of ΔCO; dashed lines) and cores (highest 90-100% of ΔCO; solid lines). (a) ΔOA/ΔCO, (b) Δf60, (c) Δf44, (d) ΔH/ΔC, (e) ΔO/ΔC, (f) ΔN40-262 nm/ΔCO, and (g) Dpbetween 40-262 nm against physical age for all flights, colored by ΔOAinitial. Some flights have missing data. Also provided is the Spearman correlation coefficient, R, between each variable and ΔOAinitial and physical age for each variable. Note that panels (a), (d), and (g) have a log y-axis.

Objective 3 (Lab/field comparison): This year, we performed and published a critical review of organic aerosol (OA) production/loss in biomass burning lab and field experiments. We show that, on average, lab studies tend to show that OA is produced (net SOA production) while field studies do not (Figure 3). On the other hand, lab studies tend to show the OA becomes more oxidized than in the lab studies (Figure 3). We present 4 hypotheses for these differences, and we provide suggested guidelines for future field and lab analysis that we are using in objectives 1 and 2 above to help reduce biases between the lab and field. This work was published in Environmental Science and Technology (Hodshire et al. 2019a).

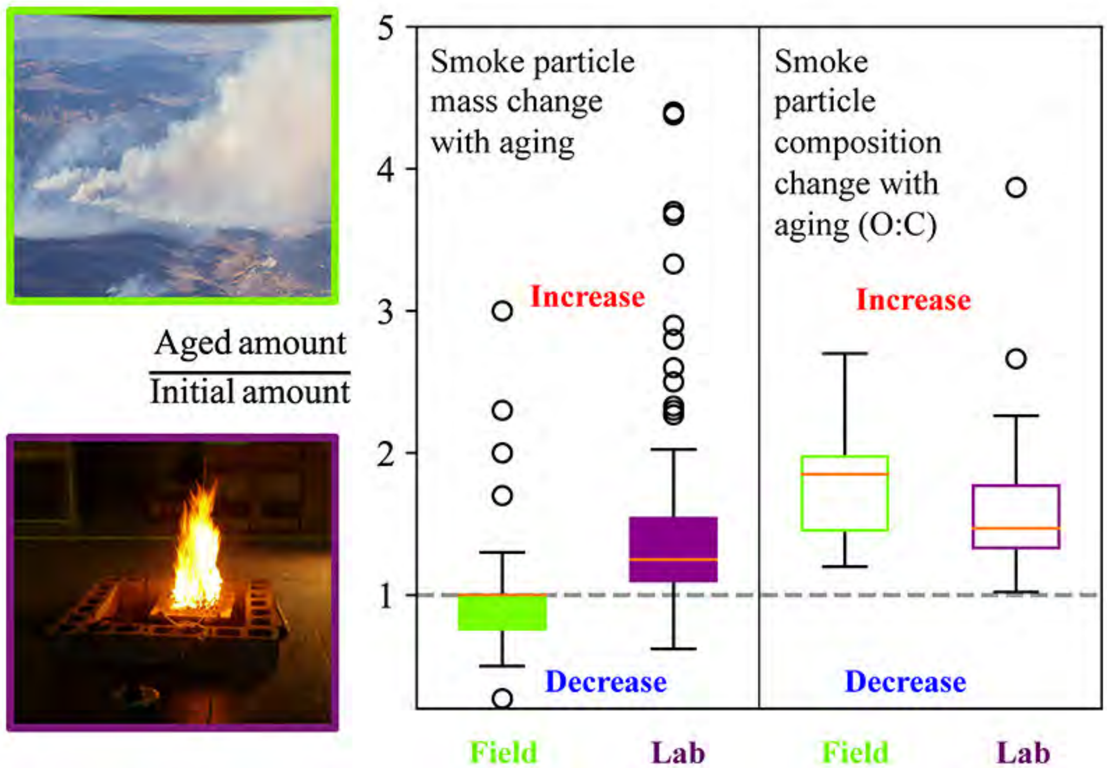


Figure 3: Box-whisker plots showing the ratio of aged to fresh OA mass and O:C ratio across all available biomass burning field and lab experiments.

Objective 4 (Modelling): We had several smoke modelling papers this year (Lonsdale et al., 2019; Hodshire et al., 2019b; Ramnarine et al., 2019). Briefly, we highlight the results of Ramnarine et al., (2019), where we quantified the impact of in-plume aerosol coagulation on CCN and global radiative effects. Figure 4 shows the change in our estimated aerosol indirect and direct radiative effects when omitting and accounting for these near-source coagulation effects.

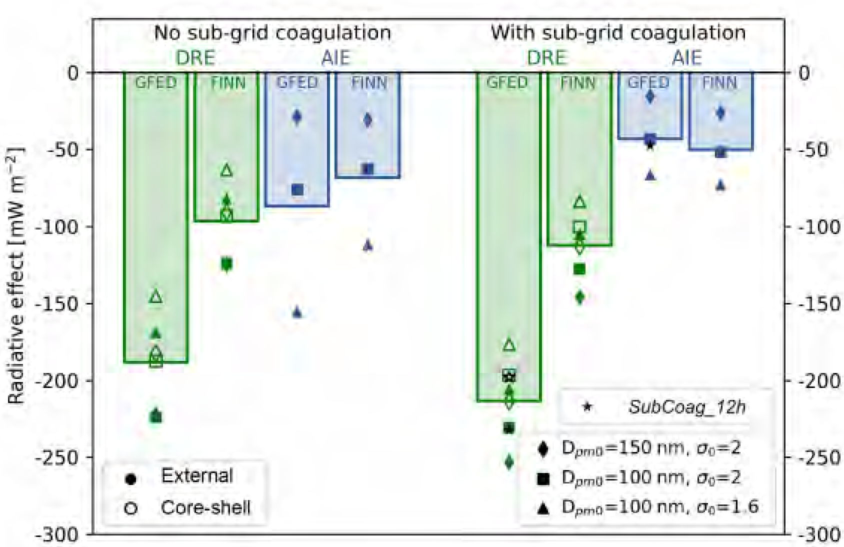


Figure 4: Global-mean all-sky direct radiative effect due to biomass burning (DRE) and cloud-albedo aerosol indirect effect due to biomass burning (AIE) for all sensitivity simulations with and without sub-grid coagulation.

PROJECT PUBLICATIONS:

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Hodshire, A.L., Pierce, J.R. et al., “Dilution impacts on aerosol aging in biomass burning plumes: combining WE-CAN and BBOP measurements with modeling to learn how dilution rates and cross-plume concentration gradients impact smoke aerosol, AGU, San Francisco, 12/2019.

Kleinman, L.I., Pierce, J.R., et al. “Time Evolution of Trace Gasses, Aerosols, and Their Optical Properties in Nine Wildfire Plumes Sampled During the BBOP Field Campaign”, AGU, San Francisco, 12/2019.

Jathar, S., Akherati, A., Pierce, J.R., et al., “Oxygenated Aromatic Compounds Contribute Substantially to Secondary Organic Aerosol Formation from Photooxidation of Wildfire Emissions”, AGU, San Francisco, 12/2019.

Pierce, J.R., et al., “Representing sub-grid biomass burning processes in regional and global models”, International Aerosol Modeling Algorithms Meeting, Davis, CA 12/2019.

Hodshire, A.L., Pierce, J.R. et al., “Dilution impacts on aerosol aging in biomass burning plumes: using a novel coupled aerosol, chemistry and large-eddy simulation model to learn about the impacts of dilution rates and cross-plume concentration gradients on smoke aging”, International Aerosol Modeling Algorithms Meeting, Davis, CA, 12/2019.

QIJING BIAN, Bonne Ford, Jeffrey R. Pierce, Sonia Kreidenweis, “Chemical and Physical Properties of Smoke Plumes in the Western and Southeastern US Using Hazard Mapping System (HMS) and AERONET/IMPROVE Data”, AAAR, Portland, OR, 10/2019.

Hodshire, A.L., Pierce, J.R. et al., “Where’s the Mass: Why Might Field and Laboratory Studies on Aging of Biomass Burning Aerosols Disagree on Mass Enhancements?”, AAAR, Portland, OR, 10/2019.

Chantelle Lonsdale, MATTHEW ALVARADO, Anna Hodshire, Emily Ramnarine, Jeffrey R. Pierce, “Simulating the Near-Source Forest Fire Plume Chemistry and Secondary Particle Formation Using SAM-ASP”, AAAR, Portland, OR, 10/2019.

Ali Akherati, Charles He, Matthew Coggon, Abigail Koss, Carsten Warneke, Joost de Gouw, Christopher Cappa, Jeffrey R. Pierce, Michael Kleeman, Shantanu Jathar, “Large Contribution of Oxygenated Aromatic Compounds in Biomass Burning Emissions to Secondary Organic Aerosol Formation.”, AAAR, Portland, OR, 10/2019.

Pierce, J.R., et al., “Aerosol evolution in diluting smoke plumes: Should we be thinking more like cloud researchers?”, University of Wyoming, Atmospheric Science Seminar, Laramie, WY, 3/2019.

PROJECT TITLE: Implementation and testing of stochastic perturbations within a stand-alone regional (SAR) FV3 ensemble using the Common Community Physics Package (CCPP)

PRINCIPAL INVESTIGATOR: Jeff Beck

RESEARCH TEAM: Ka Yee Wong

NOAA TECHNICAL CONTACT: Georg Grell NOAA/ESRL/GSD/MDB

NOAA RESEARCH TEAM: Jamie Wolff, Michelle Harrold, Laurie Carson, Judith Berner, Grant Firl, Phil Pegion

PROJECT OBJECTIVES:

The ad-hoc stochastic physics options used in the Global Ensemble Forecast System (GEFS), including Stochastic Kinetic Energy Backscatter (SKEB), Stochastically Perturbed Parameterization Tendencies (SPPT), and Specific HUMidity (SHUM), have been ported to the FV3 code base. All three stochastic methods are now available through the use of a random pattern generated in spectral space, transformed to a Gaussian grid, and then interpolated to the native FV3 grid. The perturbations are then communicated to the parameterization schemes within the Common Community Physics Package (CCPP) framework. An additional stochastic technique, Stochastically Perturbed Parameterizations (SPP), which targets uncertainty directly within the physical parameterization schemes is also of interest. This project will test and evaluate stochastic physics in the stand-alone regional (SAR) FV3, with an emphasis on convective-allowing resolutions (3 km). These evaluations will be done initially with the Rapid Refresh (RAP)/High Resolution Rapid Refresh (HRRR) physics packages. To facilitate the further development of stochastic physics within the SAR-FV3, a goal during the first year will involve ensuring a successful integration of the stochastic pattern generator in connection with the CCPP. Following the completion of this ground work, tests with the RAP/HRRR physics suite at convection-allowing scales, using SKEB, SPPT, SHUM, and SPP, will begin in order to assess the resulting impact on spread. It is anticipated that the process-level studies conducted to understand the impacts of the methods being used to address model uncertainty will continue into year two. In addition, the application of SPP to a variety of parameters in multiple RAP/HRRR physics schemes through the CCPP will be tested. As more extensive testing occurs over a longer period of time using a 10-member ensemble during the second year, the performance of the SAR-FV3 stochastic ensemble will be compared against the operational HREF. Finally, in year three, the focus will be on real-time testing and in-depth post-experiment evaluation of the most promising configuration determined in year two during the Hazardous Weather Testbed (HWT) Spring Forecasting Experiment (SFE).

PROJECT ACCOMPLISHMENTS SUMMARY:

Major activities and objectives met during this period of performance involved close coordination with Phil Pegion to introduce modifications to the SAR-FV3 community workflow to allow for the inclusion of ad-hoc (SKEB, SPPT, and SHUM) stochastic physics with CCPP. Namelist settings were introduced to control all stochastic physics options, and tests were conducted to assess the stochastic pattern generator and various model output through deterministic simulations. Through these tests, four bugs were fixed related to 1) the allocation of the pattern generator vertical structure function based on the time step, 2) stochastic pattern update frequency, 3) initialization of dissipation estimate in the halo region (zeros instead of NaNs), and 4) vertical structure of the stochastic patterns in the model output. In addition, a baseline for sensitivity tests was created using optimal stochastic physics decorrelation lengths and times chosen based on the WRF-ARW during the JTTI project entitled "Use of the stochastic-dynamic approach in a single dynamic-core storm-scale ensemble for improved spread and reliability of QPF and surface variables."

Implementation of the ad-hoc stochastic physics schemes in the SAR-FV3 will contribute toward the development of the future Rapid-Refresh Forecast System (RRFS). The RRFS, which is anticipated to be implemented into operations at NCEP in 2023, will be based on a single (FV3)-core and potentially single physics ensemble, where stochastic physics may be able to play a large role. Forecasts from this system will directly benefit NOAA and the National Weather Service (NWS).

The addition of a stochastic physics option into the SAR-FV3 community workflow will allow the weather enterprise and the public as a whole to download and test code through the publicly available GitHub repository once a formal public release of the SAR-FV3 has been distributed. In addition, future Unified Forecast System (UFS) tutorials will address the SAR-FV3 and the option to run an ensemble with stochastic physics. Knowledge regarding the use of stochastic physics in the SAR-FV3 will be directly transferred to decision makers and others in NOAA to inform them regarding the future design of the RRFS.

Monthly team meetings provided the opportunity for staff to gather and discuss progress made on the project. Modification of the SAR-FV3 community workflow provided opportunities for others involved in this project to learn how to run the regional SAR-FV3 system using the community workflow, including the option to run with stochastic physics turned on. This opportunity also helped members of the team advance their knowledge of the Rocoto workflow management system and shell scripting necessary to run the SAR-FV3.

Information related to the successful deterministic SAR-FV3 simulations using all ad-hoc stochastic physics options were provided to the larger convective-allowing model (CAM) community in GSD, NCAR, EMC, and NSSL through recurring telecons, in-person meetings, at conferences, and e-mails. The project was also discussed during an invited presentation to the Atmospheric Sciences Group at Texas Tech University.

PROJECT PUBLICATIONS: N/A

PROJECT PUBLICATIONS/CONFERENCES: N/A

PROJECT TITLE: Improved Understanding of Air-sea Interaction Processes and Biases in the Tropical Western Pacific using Observation Sensitivity Experiments and Global Forecast Models

PRINCIPAL INVESTIGATORS: Aneesh Subramanian, Kris Karnauskas, Matthew Mazloff, and Charlotte DeMott

RESEARCH TEAM: Charlotte DeMott

NOAA TECHNICAL CONTACT: Sandy Lucas

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

Objective 1: Process understanding for air-sea interaction at Western Pacific warm pool edge

Objective 2: Predictive understanding for ENSO / MJO

Objective 3: Observational needs to help improve process understanding in the region

PROJECT ACCOMPLISHMENTS SUMMARY:

Objective 1:

- Climatological temperature and salinity profiles in the western tropical Pacific were analyzed in the ORAS ocean reanalysis product and the NCAR CESM2 to understand how mean state conditions affect the formation of ocean barrier layers, which can affect the eastward extension of the Warm Pool edge in response to MJO-driven low-level westerly winds. We find that CESM biases in mean state temperature and salinity profiles inhibit the formation of deep barrier layers in the western Pacific, which can reduce the Warm Pool extension response to wind forcing.
- A manuscript describing these findings is under internal review.

Objective 2:

- We analyzed the ability of coupled forecast models to predict Warm Pool extension events using output from five models from the S2s database. NOAA CVP collaborators S. Chen and Y. Jauregui (U. Washington) provided a list of dates of westerly wind bursts over the western Pacific. The distribution of observed and modeled Warm Pool extension was computed by tracking the eastward and westward migration of the equatorial 28.5C contour (Figure 1). In general, models fail to reproduce as many strong extension events as observed. We are currently studying whether the source of this bias lies with wind forcing or ocean processes biases.

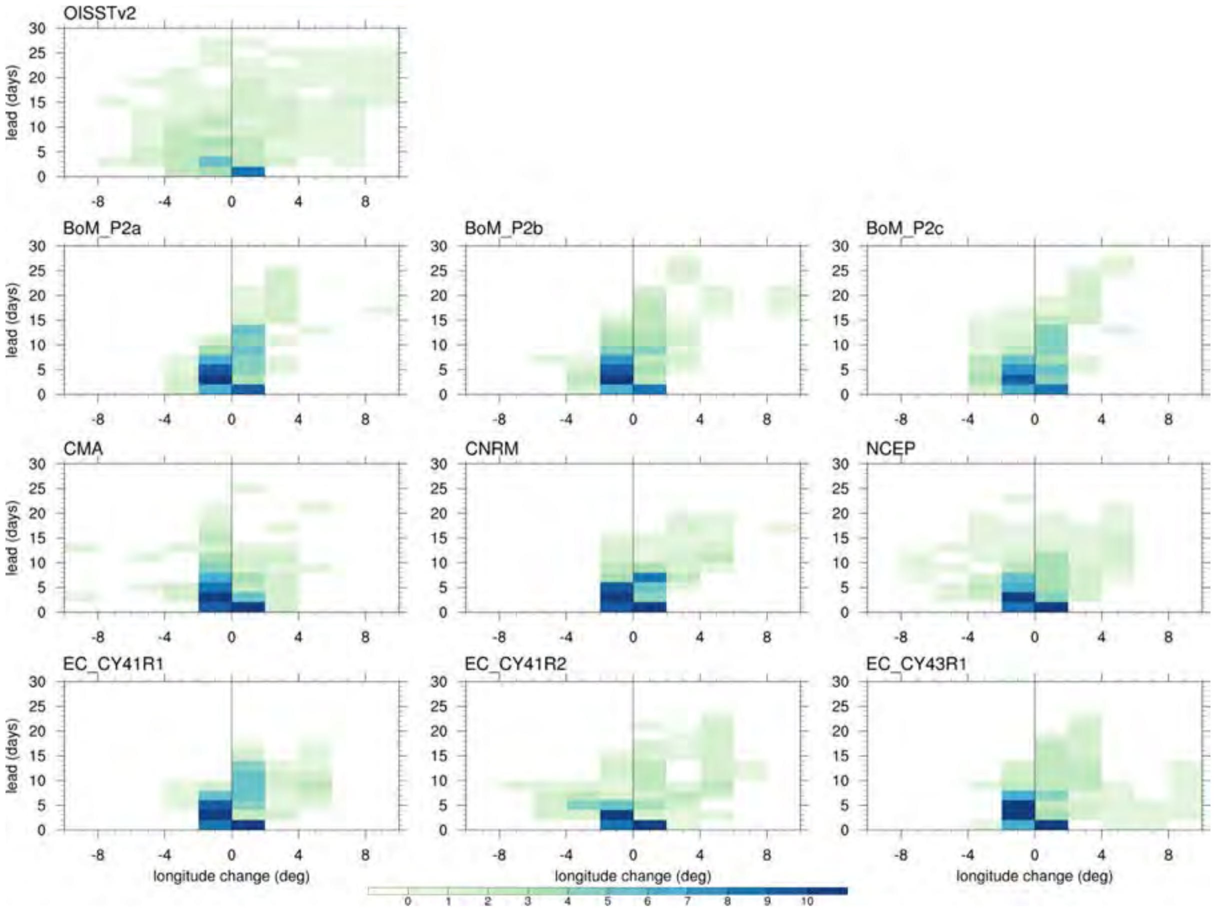


Figure 1. Frequency distribution of westward or eastward movement of western Pacific 28.5C contour (5S-5N averaged) following a westerly wind event for observations (OISST) and S2S forecast models.

PROJECT PUBLICATIONS:

Wei, H.-H., A. C. Subramanian, K. B. Karnauskas, C. A. DeMott, M. Mazloff, and M. Balmaseda, 2020: Tropical Pacific Air-sea Interaction Processes and Biases in CESM2 and their Relation to El Nino Development. *Under internal review.*

PROJECT PRESENTATIONS/CONFERENCES:

Wei, H.-H., A. Subramanian, K. B. Karnauskas, C. A. DeMott, M. R. Mazloff, and M. A. Balmaseda, 2020: Tropical air-sea interaction processes and biases in CESM2. American Geophysical Union Ocean Sciences Meeting, 16-21 February 2020, San Diego, CA, USA.

PROJECT TITLE: Modeling the Complex and Dynamic Physico-chemical Evolution of Primary and Secondary Organic Aerosol from Wildfire Smoke

PRINCIPAL INVESTIGATORS: Shantanu Jathar, Jeffrey Pierce

RESEARCH TEAM: Ali Akherati, Anna Hodshire

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

Objective 1 (revised scope): We will perform environmental chamber experiments at the Fire Sciences Laboratory in Missoula, MT to characterize the chemical evolution of organic aerosol from wildfire smoke samples representative of the Western United States.

Objective 2: We will develop a state-of-the-science organic aerosol model that combines the statistical oxidation model (SOM) with the TwO Moment Aerosol Sectional (TOMAS) model to simulate the chemistry, thermodynamics, and microphysics of wildfire OA.

Objective 3: We will use the SOM-TOMAS model to simulate organic evolution in laboratory chamber experiments and wildfire plumes.

PROJECT ACCOMPLISHMENTS SUMMARY:

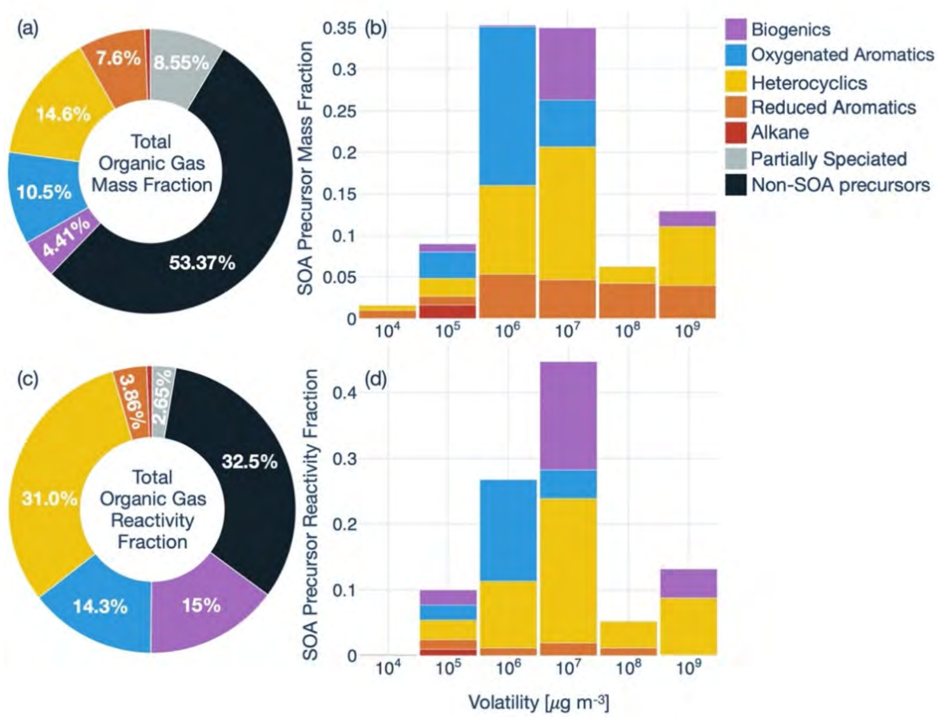


Figure 1: (a) SOA precursor classes as a mass fraction of the total VOCs and (b) normalized distribution of SOA precursor emissions in volatility space. (c) SOA precursor classes as a fraction of the total VOC reactivity and (d) normalized distribution of SOA precursor reactivity in volatility space. Data are presented as an average of the emissions over the eleven chamber experiments.

Objective 1: Further analysis of the environmental chamber data revealed that oxygenated aromatics, that included phenols and methoxyphenols, and heterocyclic compounds, that included furan and methylfurans, accounted for a large fraction of the mass and reactivity of SOA precursors in wildfire emissions (see Figure 1). These compounds dominated the VOC emissions at relatively lower volatility. Additionally, we found that a modest amount of SOA precursors was lost in the experimental transfer line when transferring smoke from the FSL stack to the environmental chamber (Figure 2). The losses were scaled inversely with volatility, i.e., the lowest volatility precursors had the largest losses and vice versa.

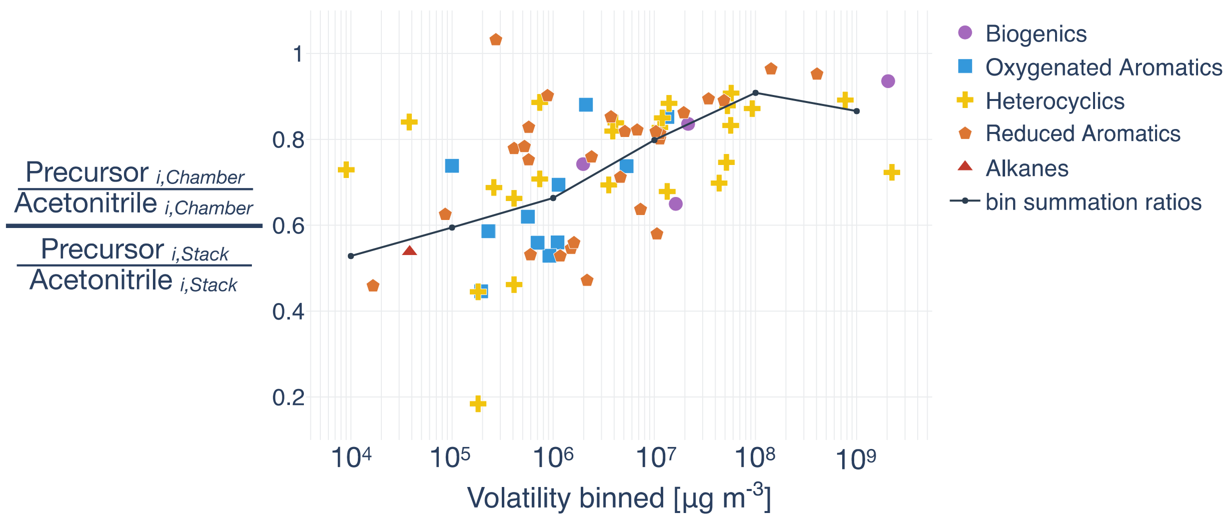


Figure 2: Emissions ratios of individual SOA precursors to acetonitrile ratioed between those measured in the chamber to those measured in the stack for Fire007. The data are resolved by SOA precursor class. A ratio of 1 indicates no loss in the transfer duct and a ratio of 0 indicates a complete loss in the transfer duct. The solid black line represents the chamber-to-stack ratio if the species were binned by volatility.

Objective 2: We used historical environmental chamber data to develop parameters to represent the SOA formation from sample oxygenated aromatics and heterocyclic compounds, both of which are likely to be important precursors classes for SOA formation from wildfire smoke (Figures 3 and 4). These parameters were vital in evaluating the SOM-TOMAS model in Objective 3.

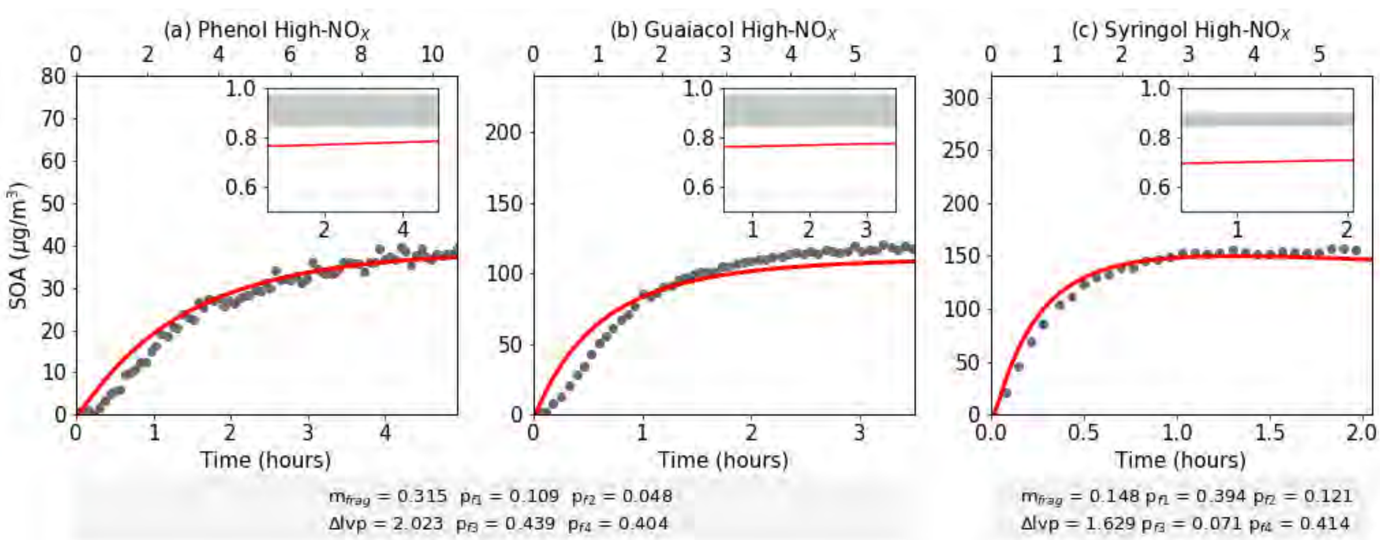


Figure 3: Model predictions of SOA mass concentrations and O:C ratios for (a) phenol, (b) guaiacol, and (c) syringol compared against measurements from Yee et al.[1] and Chhabra et al.[2]

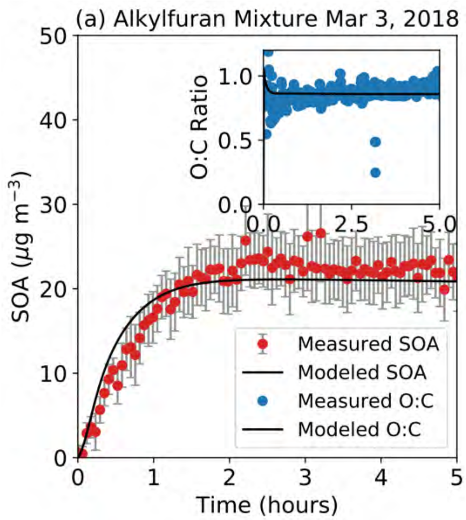


Figure 4: SOM-TOMAS model predictions based on parameter fits (solid black lines) compared to measurements (symbols) of SOA mass concentrations and SOA O:C for the alkylfuran mixture. Model predictions for O:C are shown only after the first half hour as they were found to be unreliable at earlier times when the SOA mass concentrations were lower than 0.5 µg m^{-3}.

Objective 3: The SOM-TOMAS model was used to simulate the organic aerosol evolution in eleven photooxidation experiments by leveraging detailed composition of SOA precursors measured by Koss et al.[3] Results from a sample experiment are shown in Figure 5 and the model-measurement comparison across all experiments in shown in Figure 6. The primary finding was that the SOM-TOMAS model was able to reproduce the OA mass enhancement ratio and SOA production to within a factor of 2 across all chamber experiments, despite significant differences in the fuel type (pines to shrubs), initial OA loading (10 to 58 µg m^{-3}), initial seed surface area (120 to 740 µm^2 cm^3), and OH exposure (<10^6 to 1.4×10^7 molecules-h cm^{-3} or <1 to ~10 hours of photochemical aging assuming an OH concentration of 1.5×10^6 molecules cm^{-3}). Oxygenated aromatics and heterocyclic compounds were found to be the most important SOA precursors and accounted for more than 80% of the SOA formed.

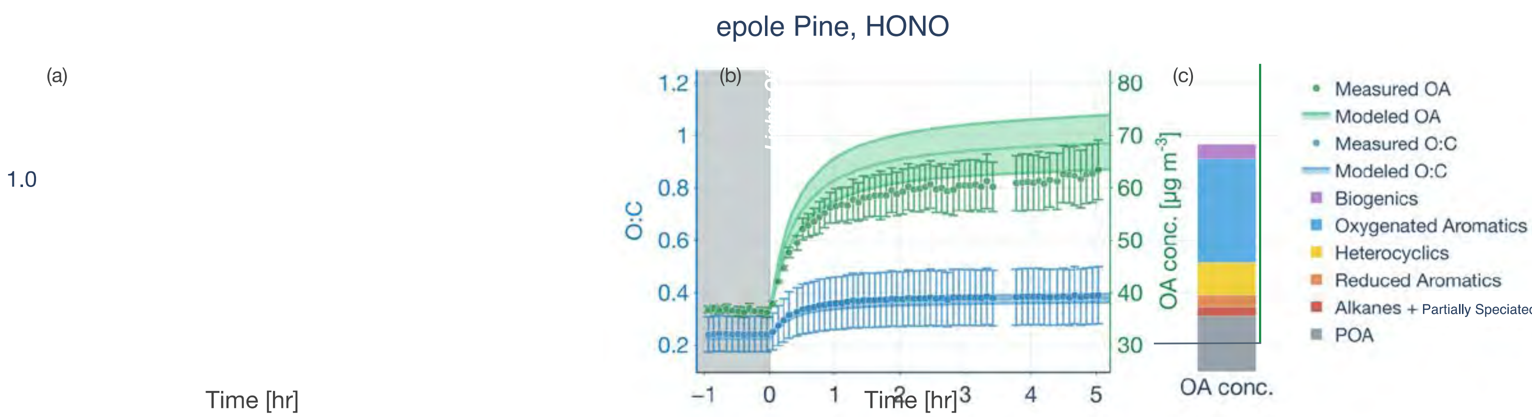
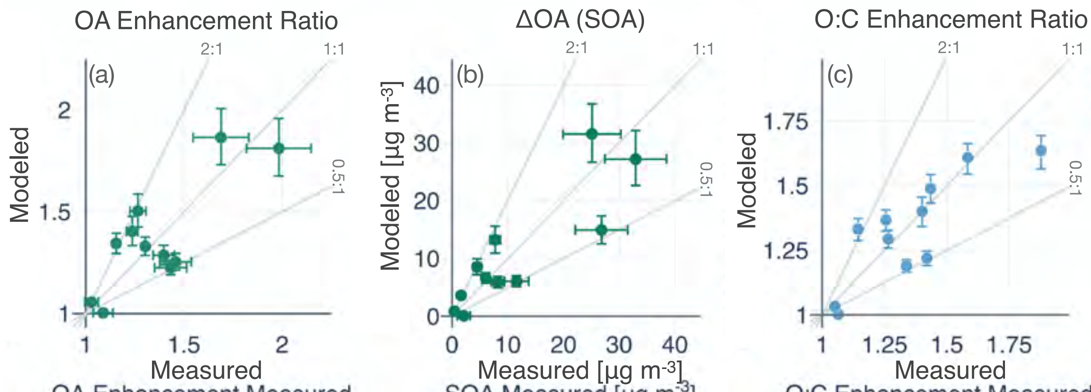


Figure 5: (a) Decay of D9 (deuterated butanol, pink) and VOCs, summed by class, with time and the OH exposure estimated based on the decay of D9; color scheme for VOCs can be found in the legend to the extreme right. (b) Model predictions of OA mass concentrations (green) and O:C ratio (blue) compared with measurements. Both results are for a lodgepole pine experiment performed at high NO$_X$ conditions (Fire007). (c) The bar to the right shows the modeled contributions of POA and precursor-resolved SOA to the end-of-experiment OA.



Slope	Intercept	R^2	RMSE
0.79	0.29	0.66	0.17

Slope	Intercept	R^2	RMSE
0.79	1.61	0.77	5.21

Slope	Intercept	R^2	RMSE
0.73	0.35	0.70	0.11

Figure 6: End-of-experiment model-measurement comparison for (a) OA mass enhancement ratios (ratio of final to initial particle-wall-loss-corrected OA mass), (b) SOA production (μg m^{-3}), and (c) OA O:C enhancement ratios (ratio of final to initial O:C ratios) for all eleven chamber experiments. Statistical metrics based on a linear fit to the model-measurement comparison are presented at the bottom of each panel. RMSE = Root Mean Squared Error.

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PROJECT PRESENTATIONS/CONFERENCES:

Hodshire, A.L., “Dilution impacts on aerosol aging in biomass burning plumes: combining WE-CAN and BBOP measurements with modeling to learn how dilution rates and cross-plume concentration gradients impact smoke aerosol, AGU, San Francisco, 12/2019.

Jathar, S. H., “Oxygenated Aromatic Compounds Contribute Substantially to Secondary Organic Aerosol Formation from Photooxidation of Wildfire Emissions”, AGU, San Francisco, 12/2019.

Pierce, J.R., et al., “Representing sub-grid biomass burning processes in regional and global models”, International Aerosol Modeling Algorithms Meeting, Davis, CA 12/2019.

Hodshire, A.L., “Dilution impacts on aerosol aging in biomass burning plumes: using a novel coupled aerosol, chemistry and large-eddy simulation model to learn about the impacts of dilution rates and cross-plume concentration gradients on smoke aging”, International Aerosol Modeling Algorithms Meeting, Davis, CA, 12/2019.

Hodshire, A.L., “Where’s the Mass: Why Might Field and Laboratory Studies on Aging of Biomass Burning Aerosols Disagree on Mass Enhancements?”, AAAR, Portland, OR, 10/2019.

Akherati, A., et al., “Large Contribution of Oxygenated Aromatic Compounds in Biomass Burning Emissions to Secondary Organic Aerosol Formation.”, AAAR, Portland, OR, 10/2019.

He, Y. et al., “Translating environmental chamber data for secondary organic aerosol for use in atmospheric models”, AAAR, Portland, OR, 10/2019.

Hodshire, A.L., “Where’s the Mass: Why Might Field and Laboratory Studies on Aging of Biomass Burning Aerosols Disagree on Mass Enhancements?”, GRC, Sunday River, MA, 7/2019.

Jathar, S. H., “Carbon-, oxygen-, and size- resolved model to simulate the microphysics, chemistry, and thermodynamics of wildfire organic aerosol” AMS, Phoenix, AZ, 1/2019.

PROJECT TITLE: Use of the Stochastic-dynamic Approach in a Single Dynamic-Core Storm-Scale Ensemble for Improved Spread and Reliability of QPF and Surface Variables

PRINCIPAL INVESTIGATOR: Isidora Jankov

RESEARCH TEAM: Jeff Beck

NOAA TECHNICAL CONTACT: Jacob Carley NCEP/EMC

NOAA RESEARCH TEAM: Judith Berner (NCAR), Evan Kalina (CIRES), Joseph Olson (NOAA/GSD), Trevor Alcott (NOAA/GSD), Curtis Alexander (NOAA/GSD), David Dowell (NOAA/GSD)

PROJECT OBJECTIVES:

- Develop Stochastically Perturbed Physical Parameterizations (SPP) within boundary layer, surface layer, gravity wave drag, radiation, microphysics, and horizontal diffusion schemes as a part of HRRR physics suite

- Evaluate performance of a HRRR Ensemble (HRRRE) as a single dynamic core, single physics suite ensemble as an alternative for future operational system. In this system model related uncertainty has been addressed by use of SPP.

PROJECT ACCOMPLISHMENTS SUMMARY:

It is the stated goal of the National Center for Environmental Prediction (NCEP)/Environmental Modeling Center (EMC) to move towards a more unified and sustainable operational forecasting system using a single dynamic core, FV3 and - if possible - a single physics suite for an ensemble application. Under this grant, we have developed a **stochastic parameter perturbation scheme (SPP)** designed to represent process-level uncertainty at the storm scale.
In close collaboration with parameterization scheme experts, perturbations to key parameters or variables were introduced in multiple parameterization schemes, such as the boundary layer, surface layer, gravity wave drag, radiation, microphysics, and horizontal diffusion schemes. While correlated in time and space, these perturbations vary at each timestep, so that the resulting ensemble members draw all from the same underlying distribution. Different from static parameter perturbations, this results in a statistically consistent ensemble system.
The impact of SPP was verified against two experiments: firstly, an unperturbed HRRR ensemble in which the ensemble members differ only in the initial and lateral boundary conditions. Secondly, SPP was performed against two widely used stochastic parameterization schemes, SKEB and SPPT, developed for convection-parameterizing global models.
A detailed probabilistic verification of on surface variables (2-m temperature, 2-m mixing ratio, 10-m wind and precipitation) confirmed that SPP reduces near-surface underdispersion without increasing the RMS error of the ensemble mean significantly or introducing additional systematic biases. These results were consistent across two different verification periods, one in July 2019, one spanning several days of September and October, 2019, and a subperiod of the Hazardous Weather Testbed (HWT) at the beginning of June 2019, in which the HWT configuration remained unchanged.
All results indicated that all storm-scale ensemble simulations, where process-level uncertainty is

represented by SPP, showed an improved probabilistic skill. This shows that a single dycore/single physics suite together with stochastic parameterizations is a viable alternative to statistically inconsistent multi-model approaches.
While the current work was conducted within the operational HRRR system, we anticipate that the scientific findings will carry over to other next-generation high-resolution regional ensemble systems such as e.g. the FV3-SAR framework. Also, a part of SPP has been transferred to HRRR Data Assimilation System (HRRRDAS) that became operational at EMC in January of 2020.

Milestones	**Y1**	**Y2**	**Teams**
Finalize code changes for SPP in MYNN PBL and RUC LSM	✓		CIRA, CIRES
Perform sensitivity tests using different spatial and length scales for SPP perturbations of PBL and LSM scheme	✓		CIRA, CIRES
Implement a SPPT scheme for soil moisture and temperature tendency perturbations in RUC LSM	✓		NCAR
Improve computational performance of underlying stochastic pattern generator	✓	✓	NCAR
Perform preliminary HRRR ensemble simulations with and without SPP and soil SPPT	✓		CIRA, CIRES
Evaluate results and feedback from the HWT participants	✓	✓	CIRA, NCAR, CIRES
Perform additional tests to identify optimal perturbation settings for SPP and soil SPPT		✓	CIRA, CIRES, GSD
Depending on ensemble spread, augment SPP and soil SPPT with SKEBS and SPPT for optimal reliability. Depending on availability, add stochastic microphysics scheme and perturbed radiation scheme.		✓	CIRA, NCAR, CIRES
Finalize the stochastic suite and deliver the stochastic perturbation scheme (SPP) to operational users.		✓	CIRA, NCAR, CIRES

PROJECT PUBLICATIONS:

Jankov, I., J. Beck, J. Wol, M. Harrold, J. Olson, T. Smirnova, C. Alexander, and J. Berner, 2018: “Stochastic Parameter Perturbations in a HRRR-Based Ensemble", Mon. Wea. Rev. https://doi.org/10.1175/MWR-D-18-0092.1

Kalina E., Jankov I., Alcott T., Olson J., Beck J., Berner J., Dowell D. and Alexander: Leveraging Stochastic Physics and the Hazardous Weather Testbed to Develop a Next Generation Model Ensemble. (In preparation for submission to WAF)

PROJECT PRESENTATIONS/CONFERENCES:

Isidora Jankov. Stochastically Perturbed Parameterizations (SPP) in High Resolution Rapid Refresh Ensemble (HRRRE). Sponsored by: EUMETNET Location: Madrid, Spain, 22-24 October, 2019.

Isidora Jankov. Development of Stochastically Perturbed Parameterizations (SPP) for application in High Resolution Rapid Refresh Ensemble (HRRRE). Sponsored by: University of Oklahoma, Uncertainty Workshop Location: Norman, Oklahoma, October 31 – November 2, 2018.

Judith Berner. Use of Stochastic Modeling to improve predictions”, Workshop on “Uncertainty in Radar Retrievals, Model Parameterizations, Assimilated Data and In-situ Observations: Implications for the Predictability of Weather,Workshop on Predictability and Uncertainty in Models and Retrievals”. Sponsored by: Oklahoma University Location: Norman, Oklahoma, Oct 31- Nov 2, 2018

Some aspects of this work have been presented as a part of multiple AMS and AGU presentations by GSD scientists Trevor Alcott, Curtis Alexander and Therresa Ladwig.

Evan Kalina, Isidora Jankov, Judith Berner, Trevor Alcott, Joseph Olson, David Dowell, Jeff Beck and Curtis Alexander: “Using Model Ensembles and Stochastic Parameter Perturbations to Forecast Severe and Hazardous Weather”, AGU, San Francisco, December 2019.

PROJECT TITLE: Using dynamically-based probabilistic forecast systems to improve the National Hurricane Center wind speed probability products

PRINCIPAL INVESTIGATORS Andrea Schumacher

RESEARCH TEAM: Alan Brammer, Kate Musgrave

NOAA TECHNICAL CONTACT: Mark DeMaria

NOAA RESEARCH TEAM: Mark DeMaria

PROJECT OBJECTIVES:

1 -- Begin collecting near-surface wind field data for NCEP global and regional ensemble prediction systems for the last 3 years.

2 -- Begin modifying the current operational MC model code to calculate WSPs from ensemble near-surface wind fields.

3 -- Determine bias corrections needed for R34, R50, and R64.

4 -- Finish preliminary version of new MC model.

PROJECT ACCOMPLISHMENTS SUMMARY:

1 -- GEFS model data available for 2016-2018 has been archived at CIRA, forecast output from ECMWF and UKMet Office are also being archived for testing multi-model probabilities after the 2019 hurricane season.

2 -- A new algorithm for calculating bias corrected WSPs from GEFS near-surface wind fields has been developed and has been run in real-time during the 2019 season. Preliminary output utilizing this bias correction is shown in figure 2.

3 -- An initial linear regression bias-correction model has been developed this was trained on the 3 years preceding the test cases and showed approximately a 20-kt reduction in the bias and over 10-kt improvement in the absolute error (Figure 1).

4 -- A wind-speed probability algorithm has been developed which relies on the surface wind speeds from ensemble model output. This version has been run in real-time since early August for the 2019 season.

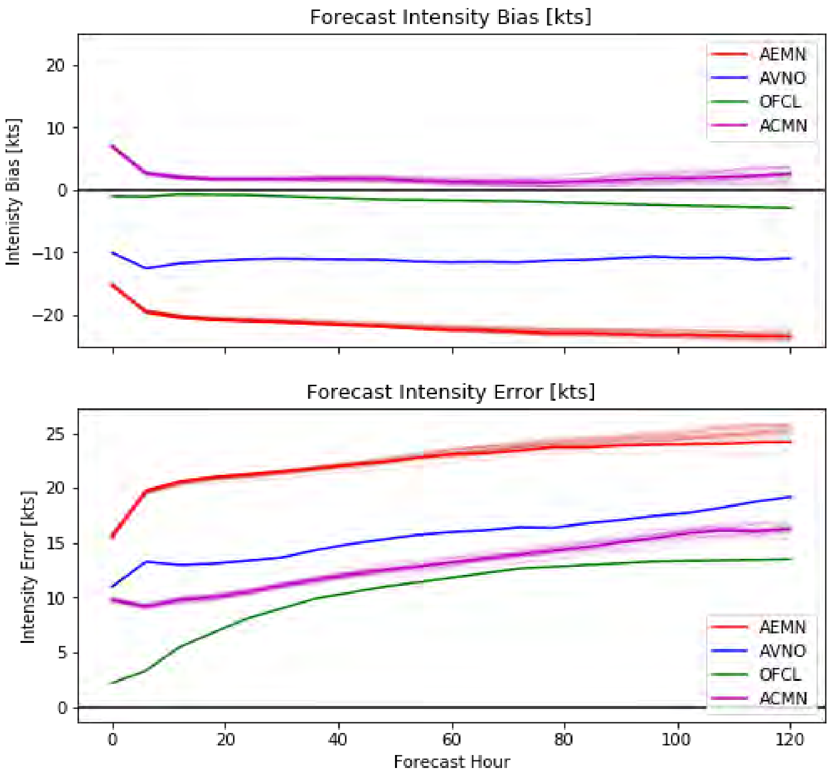


Figure 1: Comparison of bias-corrected 2018 forecasts (ACMN; purple) based linear-regression trained on data from 2015-2017, with raw GEFS tracks (AEMN; red). Also plotted for comparison are the deterministic GFS (AVNO; blue) and OFCL (green). Top) Forecast intensity bias for all storms during 2018. Verified against the working best-track files. Bottom) Mean-absolute error for Intensity forecasts during 2018.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Brammer, A., A. Schumacher, and K. Musgrave, 2020: Development and Evaluation of a Multimodel Global Ensemble Tropical Cyclone Wind Speed Probability Product. *30th Conference on Weather Analysis and Forecasting (WAF)/26th Conference on Numerical Weather Prediction (NWP), AMS Annual Meeting,* 12-17 January 2020, Boston MA.

PROJECT TITLE: ABI (CLP) CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting

PRINCIPAL INVESTIGATOR: John. M. Haynes

RESEARCH TEAM: Yoo-Jeong Noh, Steven D. Miller

NOAA TECHNICAL CONTACT: Dan Lindsey, Andrew Heidinger (NOAA/NESDIS)

NOAA RESEARCH TEAM: Andrew Heidinger (NOAA NESDIS)

PROJECT OBJECTIVES:

- To improve the classification and categorization of multilayer cloud scenes view by the GOES Advanced Baseline Imager (ABI)
- To bring these changes to an algorithm and interface that can be implemented operationally by NOAA

PROJECT ACCOMPLISHMENTS SUMMARY:

During this reporting period, significant improvements were made in the construction of an algorithm to determine the presence of low clouds in multilayer ABI scenes. The algorithm we are testing has achieved approximately 84% accuracy (all scenes) in prediction of low clouds by the ABI. This algorithm consists of a machine learning implementation that trains on joint ABI and CloudSat/CALIPSO observations, combined with external information about low-level relative humidity (in this case, from a forecast model). This algorithm is the culmination of the lessons learned during the first years of the project, including investigation of the behavior of low cloud clouds at a variety of wavelengths (including the 0.64 and 1.38 μm brightness temperature ratio, and 3.9 and 11.2 μm brightness temperature difference), and the utility of low-level atmospheric moisture as a predictor of low clouds.

Overall, we made rapid progress toward the goals of the project by making advances on two fronts. First, we continued to refine our cloud geometric thickness algorithm, experimentally implementing a version including five flight-levels rather than the traditional three pressure-based levels, with the encouragement of our operational partners. Second, as described in the previous paragraph, a machine learning approach was adopted that utilizes information from ABI channels (including various differences and ratios that are relevant for low cloud detection) as well as external information about layer moisture content. This algorithm, using a Random Forest implementation, predicts whether low cloud is present in a given ABI scene. During training, CloudSat and CALIPSO observations of vertically resolved clouds serve as the truth that forms the basis for the model predictions.

The three-layer version of the product is disseminated in near real-time at CIRA through SLIDER. Figure 1 shows a four-panel display of the improved CCL product showing a Pacific low pressure system from GOES-17 ABI on 4 March 2019, including the Geocolor image and corresponding representations of cloud top height, cloud geometric thickness, and the resulting cloud cover layers retrieval. The thickest clouds are located along the position of the warm and cold fronts, with a vast area of low cloud behind the system, consistent with our synoptic scale knowledge of these systems.

Figure 2 shows an observed CloudSat/CALIPSO cross section through a cyclone over the central U.S., and the corresponding CCL representation for GOES-16 ABI (1945 UTC on September 20, 2018). We implemented a number of fixed low-level relatively humidity (RH) thresholds to capture the “low plus high” cloud category as shown in the sample figure, which is not possible using only the cloud geometric thickness approach. As indicated in previous reporting periods, our research has shown that RH thresholds associated with the presence of low cloud vary in both time and space. The threshold approach shows a potential for CONUS cases but is not particularly useful outside the middle latitudes. We therefore allow our machine learning algorithm to determine where and when RH is useful as a predictor of low cloud (and how it can be combined with other ABI observations) directly from the training data. In doing so, we increased the detection of low clouds under cirrus (as determined from the baseline algorithm) from 22% to 69%. This was tempered by an increase in the false alarm ratio from 4% to 24%, which is mostly a consequence of adding a degree of freedom to the retrieval, namely the removal of the restriction that clouds can only occur in the lowest bin if the retrieved geometric thickness requires a mid-level cloud to extends downward into that bin. We are currently exploring how to include more physical information (like surface type) to increase detections and decrease false alarms.

The PI visited the Aviation Weather Center (AWC) in August 2019, furthering development of an operation display for this product. An initial N-AWIPS implementation has been developed, opening the possibility of a Local Data Manager (LDM) feed from CIRA to the AWC to allow forecaster evaluation of the product.

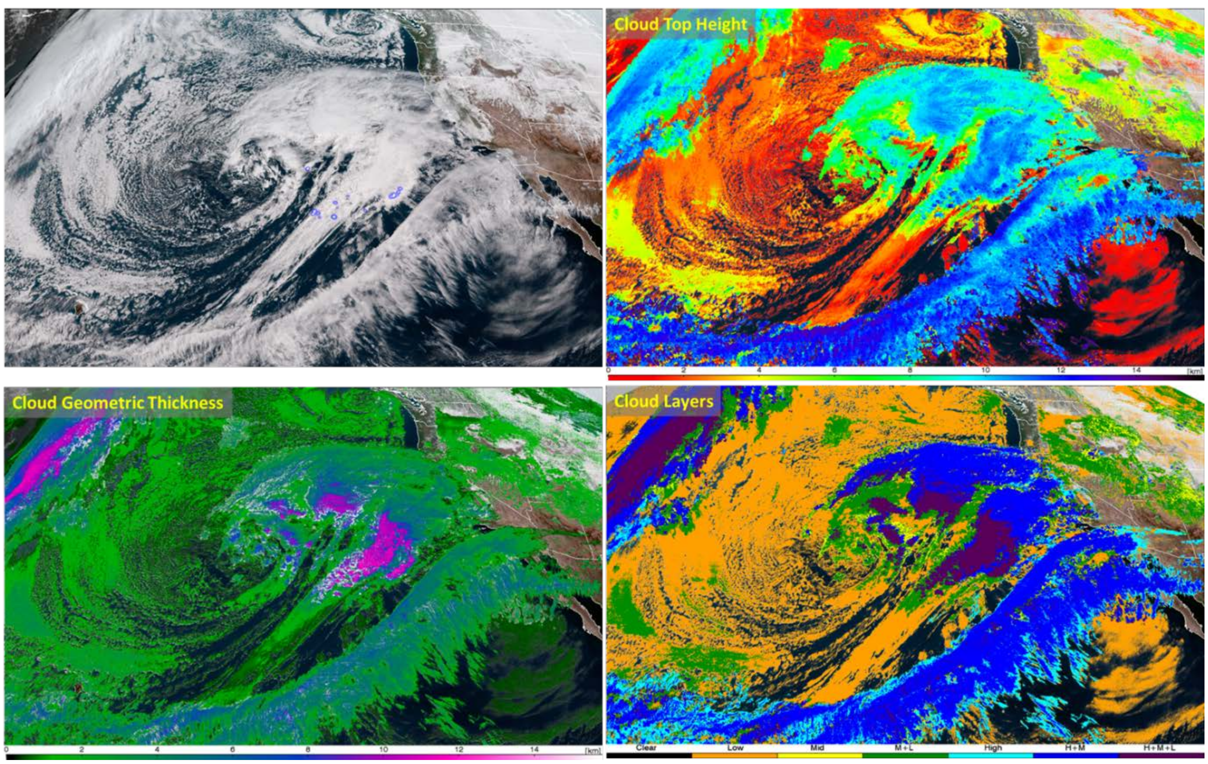


Figure 1. Sample GOES-17 cloud top height, geometric thickness, and layers over CONUS with the ABI GeoColor image (top left; GLM group energy overlaid in violet) produced from the CLAVR-x processing system at CIRA (1857 UTC on 04 March 2019). The cloud base and layer algorithm has been implemented for GOES-17 ABI in the CLAVR-x system. Cloud Layers and Cloud Geometric Thickness products are currently being displayed in CIRA's SLIDER (https://rammb-slider.cira.colostate.edu) with other cloud retrieval products and imagery for both GOES-16 and GOES-17 ABI for all four sectors in real time.

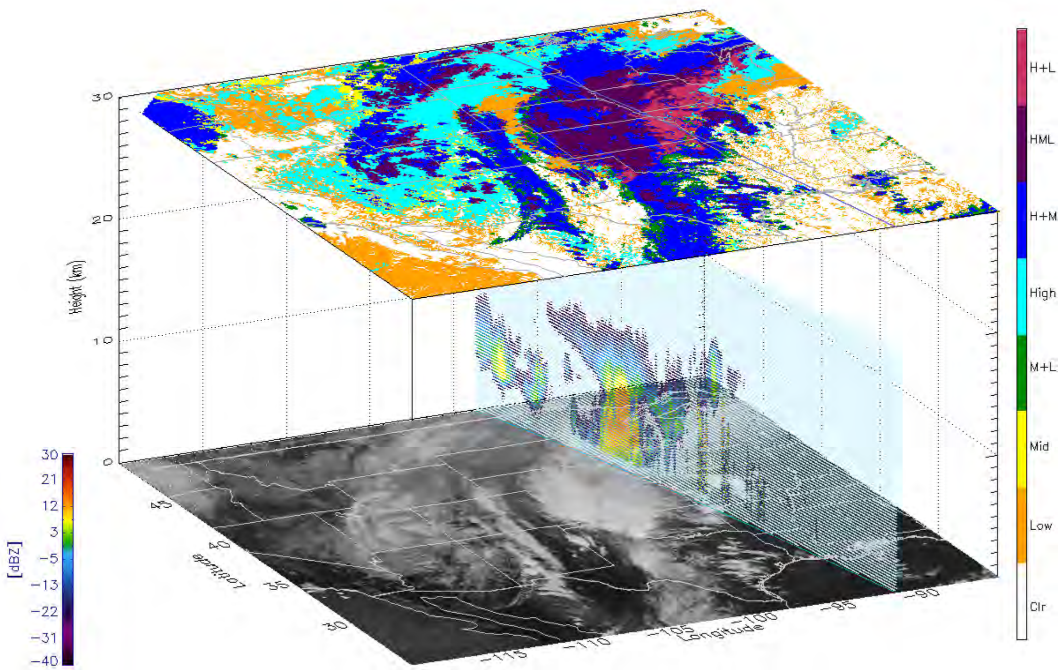


Figure 2. Improved Cloud Layers with CBH information over CONUS (top) for GOES-16 ABI at 1945 UTC on September 20, 2018. A preliminary result with 'High + Low' category (in magenta) using NWP surface humidity thresholds statistically derived for multi-layer scenes is shown at the bottom. An 80 % surface humidity threshold has been applied for cloudy pixels with 'Overlap' cloud type and high cloud fraction greater than 0.7 for the sample case. For comparisons, vertical cross-sections from CloudSat radar is also shown over the 11.2-μm IR image.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Haynes, J. M., Y. J. Noh, S. D. Miller, A. K. Heidinger, and J. M. Forsythe, 2019: Cloud boundary Detection in multilayer scenes with the GOES ABI. 2019 American Meteorological Society / EUMETSAT Joint Satellite Conference, Boston, Massachusetts.

Project Title: ADEB Support CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting

PRINCIPAL INVESTIGATOR: Tom Vonder Haar

RESEARCH TEAM: N/A

NOAA TECHNICAL CONTACT: Dan Lindsey NOAA/NESDIS

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVE:

Professor Tom Vonder Haar, Member of the National Academy of Sciences, Engineering and Medicine (NASEM), continued to serve on the Independent Advisory Committee (IAC) for GOES-R. The IAC reports directly to the GOES-R SDEB. It supports tasks assigned to them and by the GOES-R Program Office.

PROJECT ACCOMPLISHMENTS SUMMARY:

- Participate in IAC reviews, advisory telecons.

- Participation in a GOES IAC meeting held at the Annual AMS Satellite Meeting in Boston, 28 Sep – 4 Oct 2019.

Tom Vonder Haar participated in IAC reviews, advisory telecons. He also attended the Annual AMS Satellite Meeting in Boston, 28 Sep – 4 Oct 2019. Where he participated in a GOES IAC meeting. The range of advisory tasks included all aspects of the Program such as algorithm development and testing; Instrument and Product Cal/Val.; User preparation and outreach; Science and operational applications; and combined products from GOES and JPSS.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Support for Assessment of New Calibrated NNP and NOAA-20 ATMS Window and Water Vapor Channel Radiance and JPSS-2

PRINCIPAL INVESTIGATOR: Christian Kummerow

RESEARCH TEAM: Wes Berg (ATS), John Forsythe (CIRA)

NOAA TECHNICAL CONTACT: Quanhua (Mark) Liu, NOAA NESDIS

NOAA RESEARCH TEAM: Ninghai.Sun NOAA/NESDIS/STAR/SMCD

PROJECT OBJECTIVES:

To assess the calibration differences between ATMS water vapor channels and the corresponding channels on the GMI instrument on board the GPM satellite. Given GPM’s 65° inclination, frequent coincident overpasses are available with NPP/ATMS. Specifically, we will perform the following tasks:

- Apply geophysical retrievals from a 1DVAR retrieval developed for GPM GMI as a basis for double difference computations to assess the accuracy and stability of ATMS and GMI channel differences. Compare with double difference results based on geophysical parameters from the NASA GEOS5 global analysis.
- Investigate calibration changes/differences using specified double difference approach for both NPP and JPSS1 ATMS SDR reprocessing.
- Compare GMI-based double differences with double differences between ATMS and Megha-Tropiques SAPHIR data as well as single differences between observed and simulated ATMS brightness temperatures.
- Investigate impact of differences between state-of-the-art radiative transfer models on the resulting double differences. This will include both ocean emissivity models for window and/or semi-transparent water vapor channels as well as atmospheric absorption models.
- Report results to the ATMS SDR team.

PROJECT ACCOMPLISHMENTS:

Task 1: Intercalibration of NPP and NOAA-20 ATMS Window and Water Vapor Channels

Our efforts over the past fiscal year have focused on NPP and NOAA-20 intercalibration with other well-calibrated operational sensors including GPM GMI, Megha-Tropiques SAPHIR, and MHS on board the operational NOAA and MetOp satellites. Double difference comparisons with well-calibrated sensors in precessing orbits, such as GPM GMI and Megha-Tropiques SAPHIR, also provides a way to get very accurate estimates of calibration differences between ATMS sensors by differencing the double difference values. Table 1 provides an example, showing the impact of the NPP and NOAA-20 calibration changes, which were implemented operationally on the 15th of October 2019. This analysis was based on our intercalibration assessment using double differences versus GPM GMI (Berg et al. 2016) from test datasets with the updated SDR tables produced by NOAA STAR. These results indicate a significant reduction in calibration differences between the two operational ATMS instruments for high-frequency window and water vapor channels (i.e. channels 16-22). This is mainly due to updates to the NPP ATMS calibration to better align with NOAA-20 ATMS calibration corrections for an emissive reflector, etc., however, there were small changes to a few of the NOAA-20 channels as well. Assessment of the intercalibration changes after operational implementation of the calibration updates, shown in Figure 1, are consistent with the results from the test data. The estimates from Table 1 were subsequently implemented into the GPM Level 1C processing to provide consistent brightness temperatures across the October 2019 calibration change for GPM data users.

Table 1: Intercalibration of S-NPP and NOAA-20 versus GPM GMI for the period from August through October 2018 to assess the impact of SDR calibration changes. The table on the left was for the previous operational SDR datasets and the table on the right is for the SDR calibration, which was implemented in October of 2019.

Channel	S-NPP	NOAA-20	N20 - NPP
1) 23 GHz	2.38	2.13	-0.33
2) 31 GHz	1.50	1.19	-0.31
16) 88 GHz	-2.03	-0.22	1.81
17) 165 GHz	-0.53	0.42	0.95
18) 183+/-7.0 GHz	0.92	1.96	1.04
19) 183+/-4.5 GHz	-0.20	0.70	0.90
20) 183+/-3.0 GHz	-0.88	-0.09	0.79
21) 183+/-1.8 GHz	-0.93	-0.06	0.87
22) 183+/-1.0 GHz	-0.59	0.25	0.84

Channel	S-NPP	NOAA-20	N20 - NPP
1) 23 GHz	2.48	2.15	-0.33
2) 31 GHz	1.55	1.15	-0.40
16) 88 GHz	-0.86	-0.74	0.12
17) 165 GHz	0.63	0.41	-0.22
18) 183+/-7.0 GHz	2.07	1.85	-0.22
19) 183+/-4.5 GHz	0.96	0.64	-0.32
20) 183+/-3.0 GHz	0.33	-0.10	-0.43
21) 183+/-1.8 GHz	0.25	-0.05	-0.30
22) 183+/-1.0 GHz	0.59	0.24	-0.35

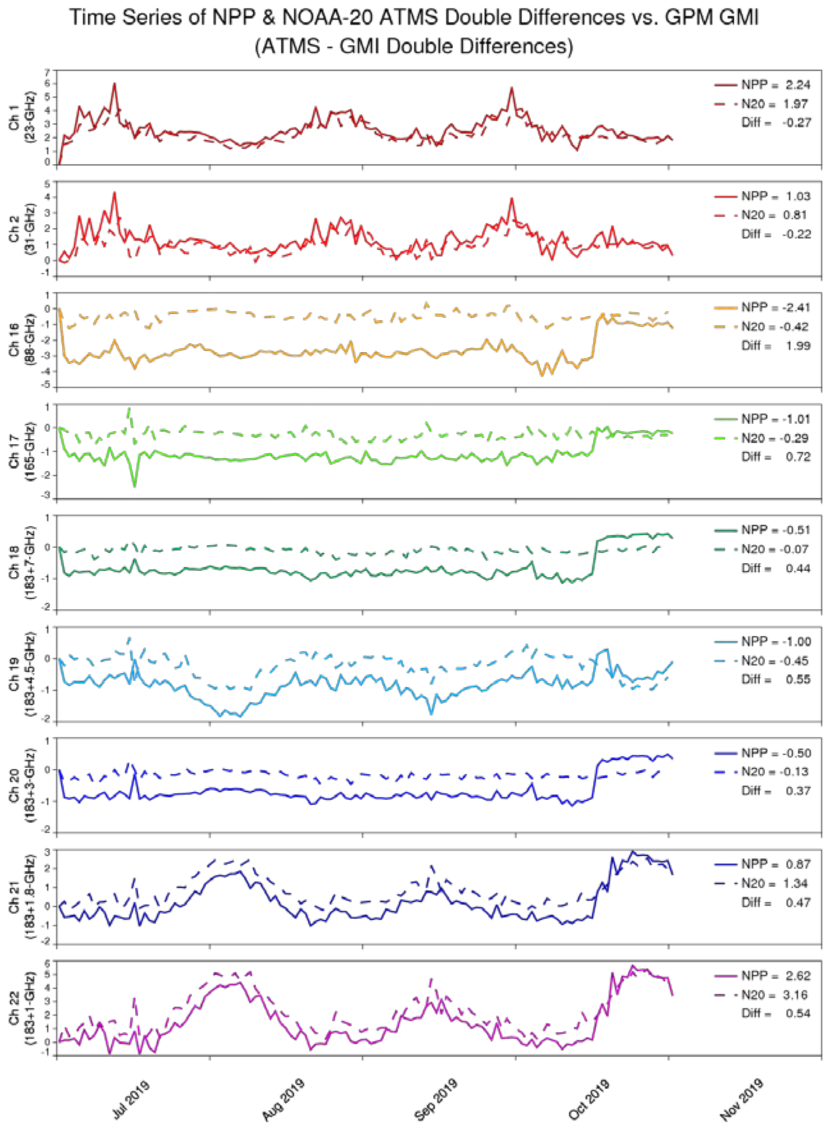


Figure 1: Daily mean simulated minus observed brightness temperature differences versus time for NPP and NOAA-20 ATMS along with the difference between the two instruments for the 9 window and water vapor channels. The impact of the calibration changes implemented in October of 2019 are evident in the double differences, and are fully consistent with the expected changes based on the analysis of the test data shown in Table 1.

The results in Table 1 are based on double difference estimates versus GPM GMI, but we also looked at double differences for the water vapor channels with Megha-Tropiques SAPHIR, which is in a low inclination precessing orbit, and by looking at simulated minus observed Tb differences, or single differences. A comparison of results from these various approaches is given in Table 2. For comparing the NPP versus NOAA-20 ATMS calibration, there is excellent consistency in the approaches. This is due to the fact that errors in the simulated Tb due to the radiative transfer model (RTM) almost entirely cancel when differenced between the two very similar ATMS instruments. As a result, assessing changes to the calibration for a single ATMS instrument versus another can be accomplished with a high degree of accuracy using a limited dataset. The single difference approach uses geophysical parameters from the NASA GEOS5 global analysis, which is obtained in near real time. The data is screened for the presence of precipitation, land, and highly variable scenes to ensure stable results. While there is significant variability in the daily mean values, the difference between NPP and NOAA-20 ATMS is quite stable and quickly approaches the higher quality double differences estimates based on coincident observations shown in Table 2. This is evident in the daily mean double difference time series shown in Figure 1, although the difference between NPP and NOAA-20 changed with the October 2019 calibration update.

Table 2: Intercalibration differences for the NPP vs. NOAA-20 ATMS window and water vapor sounding channels based on three different approaches. These include 1) single differences (i.e. observed minus simulated Tb) that are not matched in space and time, and double differences based on coincident observations for 2) GPM GMI and 3) Megha Tropiques SAPHIR.

Channel	Single Difference (Obs – Sim)	Double Difference (GMI	Double Difference (SAPHIR)	Mean Difference (N20– NPP)	Standard Deviation of Techniques
1) 23 GHz	-0.31	-0.33	N/A	**-0.32**	0.01
2) 31 GHz	-0.40	-0.40	N/A	**-0.40**	0.00
16) 88 GHz	0.19	0.12	N/A	**0.16**	0.05
17) 165 GHz	-0.18	-0.22	N/A	**-0.20**	0.03
18) 183±7.0 GHz	-0.20	-0.22	-0.21	**-0.21**	0.01
19) 183±4.5 GHz	-0.30	-0.32	-0.34	**-0.32**	0.02
20) 183±3.0 GHz	-0.42	-0.43	-0.44	**-0.43**	0.01
21) 183±1.8 GHz	-0.28	-0.30	-0.29	**-0.29**	0.01
22) 183±1.0 GHz	-0.37	-0.35	-0.38	**-0.37**	0.02

The results shown in Table 2 are based on intercalibration approaches largely developed and refined as part of the NASA Precipitation Measurement Mission (PMM) intercalibration (i.e. XCAL) working group. Dr. Berg currently leads the XCAL working group within the PMM science team and continues to provide feedback to the ATMS SDR team from ongoing efforts involving the ATMS instruments. Work is currently ongoing within the XCAL team to quantify residual uncertainties in double difference estimates between sensors such as those shown here.

Task 2: Investigating Radiative Transfer Model Errors for Improved Calibration Assessments including Cross-Track Calibration Biases

Figure 2 shows differences between observed and simulated Tb as a function of scan position for both NPP and NOAA-20 (left panel) as well as the difference between the two instruments (right panel) for the ATMS window and water vapor channels. These results are based on the latest SDR calibration implemented in October of 2019. While these changes show significant improvement in the consistency of the calibration across the scan versus the previous calibration for these two instruments, some differences remain. As shown in the left panel of Figure 2, there are significant variations in the Tb differences across the scan that are at least partly due to errors in the radiative transfer models, most likely with the ocean emissivity model (i.e. FASTEM6 from CRTM). Such variations between observed and simulated Tb are not unique to ATMS or the RTM used for these simulations. Similar results of Tb residuals from the ECMWF 4D-Var data assimilation system show similar scan-based variations. Some of the residual asymmetries in the N20-NPP scan differences, however, are likely to be due to instrument calibration and/or pointing issues as the RTMs are influenced solely by the angle from nadir.

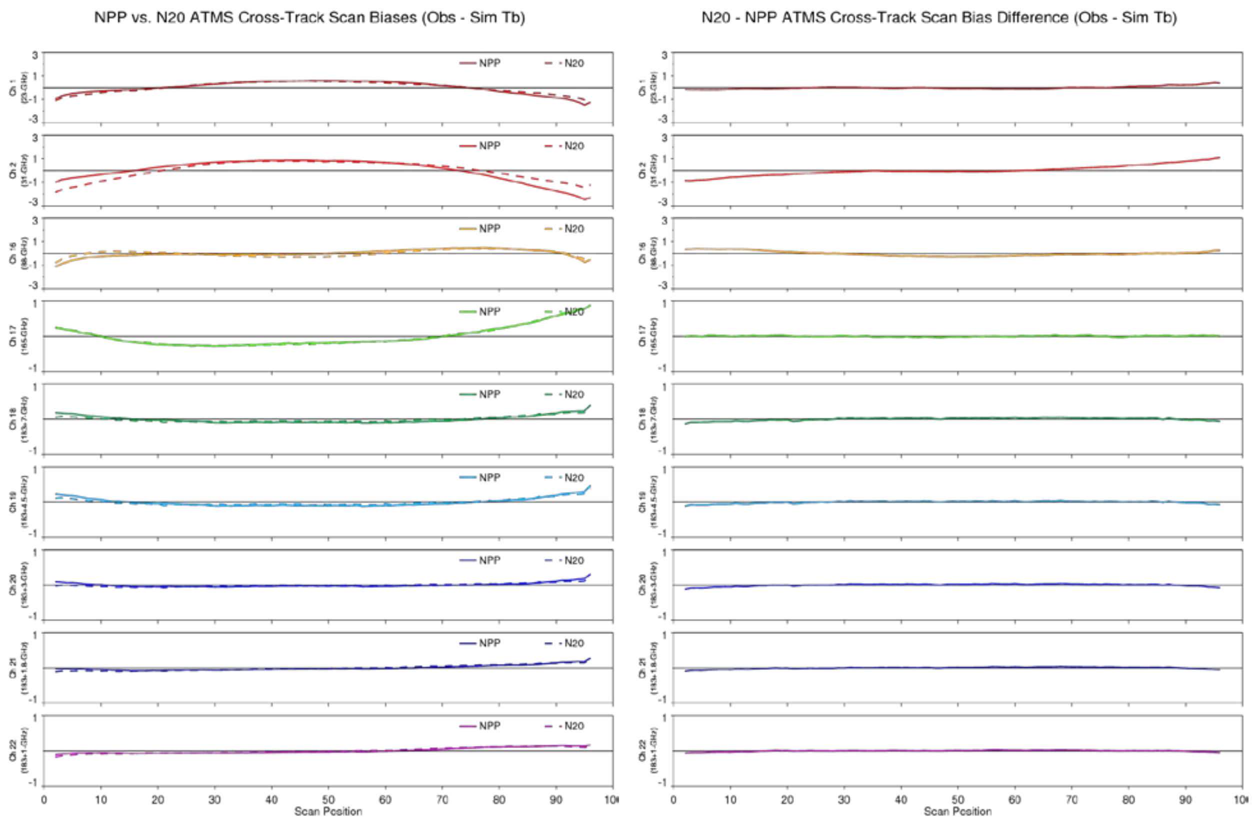


Figure 2: Comparison of Tb residuals (Observed minus simulated Tb) as a function of scan position for both NPP and NOAA-20 ATMS (left) and the difference between the two instruments (right) for the window and water vapor sounding channels.

The simulated minus observed Tb differences for the individual NPP and NOAA-20 ATMS results shown in Figure 1 suggest significant simulation errors, particularly for channel 16 (i.e. 88 GHz) which shows mean differences of 4-6 K. As noted above these errors largely cancel when comparing NPP and NOAA-20 results, however, as the results in Figure 2 indicate, they can be a factor in assessing and understanding the root causes of calibration errors. Ultimately, residual differences due to simulation errors, such as shown in the cross-scan biases in the left panel of Figure 2, may be due to a combination of factors, including instrument calibration issues, pointing errors, ocean emissivity model errors, imperfect screening for precipitation, and inhomogeneity effects related to the significant field-of-view changes across the scan.

In addition to comparing cross-scan biases between ATMS instruments and with well-calibrated instruments like MHS, we have also been investigating these errors using a unique new dataset from the TEMPEST-D CubeSat mission. Like ATMS, TEMPEST-D is a cross-scan radiometer with similar spatial resolution, although TEMPEST-D has only 5 channels centered near 87, 163, 178, 184 and 181 GHz. We have collected and are continuing to collect TEMPEST-D observations from a series of maneuvers where the spacecraft was yawed by 92 degrees, thus providing along-track scanning during portions of the descending scan. This provides a dataset with multiple observations of a given point on the Earth from a wide range of view angles. Figure 3 shows the global coverage from TEMPEST-D during one of these recent maneuvers, which took place 25-27 January 2020.

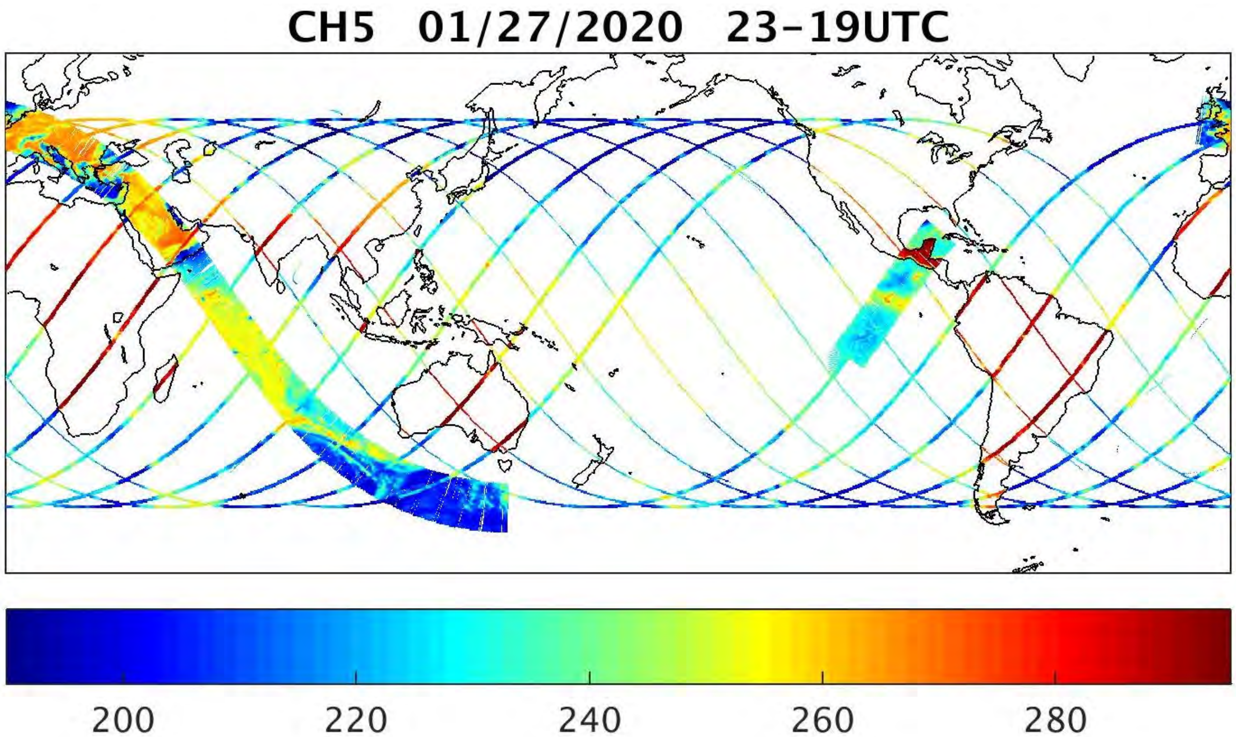


Figure 3: A quick look image of the 87 GHz channel on TEMPEST-D for almost one day showing the transition to along-track scanning as well as multiple orbits with the instrument in the yawed orientation. A yaw angle of 92 degrees is used to optimize for along-track scanning during descending passes in the midlatitude regions. The deviation from 90 degrees is needed to account for the east-west motion due to the Earth's rotation.

An analysis of some of this unique TEMPEST-D along-track scanning data is detailed in Schulte et al. (2020). Figure 9 from that paper is shown below. This figure shows a retrieval of total precipitable water from the TEMPEST-D radiometer for a non-precipitating ocean scene during the along-track scanning. The panel on the left shows the initial TPW retrieval, based on a modified version of the 1D-Var retrieval by Duncan and Kummerow (2016), while the panel on the right shows the retrieved TPW after the mean simulated minus observed Tb differences, similar to those shown for ATMS in the left-hand panel of Figure 2, have been removed. Although the atmospheric path viewed by the instrument varies with scan angle, for homogenious, clear-sky scenes the retrieved TPW should be relatively consistent regardless of view angle or EIA. The fact that we have to remove scan-dependent calibration biases to get consistent results across the scan is likely due to a combination of RTM and instrument calibration errors. We are currently investigating these cross-scan biases to understand the contribution of scan-angle dependent errors in the ocean emissivity model (i.e. FASTEM6 from CRTM) on the simulated Tb.

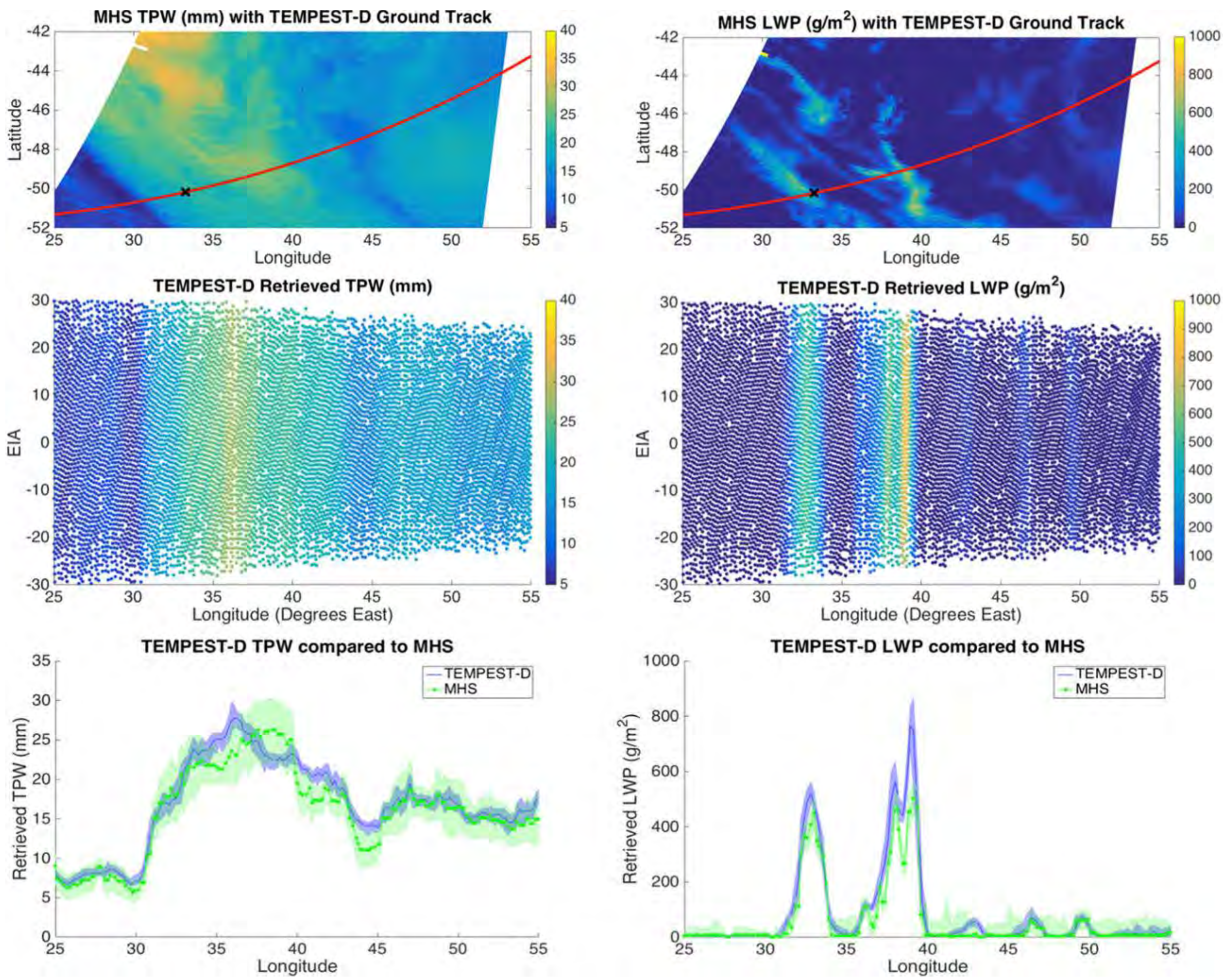


Figure 9 from Shulte et al. (2020): (top left) TPW and (top right) LWP retrieved by the CSU 1DVAR algorithm for an MHS overpass from MetOp-B over the Southern Ocean on 30 Jan 2019 around 0600 UTC. The red line shows the ground track of a coincident TEMPEST-D overpass while the TEMPEST-D satellite was in along-track scanning mode. The black X shows the location of the MHS pixel used as a comparison point. All of the TEMPEST-D pixels within 10 km of the TEMPEST-D ground track, plotted with respect to longitude and EIA. The color of each dot represents the magnitude of (left) TPWor (right) LWP retrieved. (bottom left) TPW and (bottom right) LWP (solid blue lines) retrieved by TEMPEST-D at nadir along the ground track, with the shading showing the full range of values retrieved for the corresponding pixel at all view angles. The green line is the value retrieved at the closest MHS pixel, with shading representing 61 standard deviation, as reported by the posterior covariance matrix.

PROJECT PUBLICATIONS:

Berg, W., R. Kroodsma, C. D. Kummerow and D. S. McKague, 2018: Fundamental Climate Data Records of Microwave Brightness Temperatures, Remote Sensing, Vol. 10, 1306, doi: 10.3390/rs10081306.

Berg, W., “Calibration of Microwave Radiometers from GPM to CubeSats”, presented at the International Geoscience and Remote Sensing Symposium (IGARSS), 22-27 July 2018, Valencia, Spain.

Berg, W., “A 31+ Year Record of Intercalibrated Brightness Temperatures from Satellite Passive Microwave Sensors Developed for Global Precipitation Retrievals, presented at the American Geophysical Union (AGU) Fall Meeting, 10-14 December 2018, Washington, D.C.

Duncan, D. and C. D. Kummerow, 2016: A 1DVAR Retrieval Applied to GMI: Algorithm Description, Validation, and Sensitivities. *J. Geophys. Res.: Atmospheres*, **121**, 7415-7429.

Schulte, R. M., C. D. Kummerow, W. Berg and S. C. Reising, 2020: A Passive Microwave Retrieval Algorithm with Minimal View Angle Bias: Application to the TEMPEST-D CubeSat Mission, *J. Atmos. Oceanic Technol.,* Vol. 37, pp. 197-210, doi: 10.1175/JTECH-D-19-0163.1.

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting and Training

PRINCIPAL INVESTIGATOR: Steven Miller

Project #	GOESR- Risk Reduction Project - Titles
1	**Developing an Environmental Awareness Repertoire of ABI Imagery (‘*DEAR-ABII’*) to Advise the Operational Weather Forecaster**
2	**GOES-R ABI channel differencing used to reveal cloud-free zones of ‘precursors of convective initiation’.**
3	**ProbSevere: Upgrades and Adaptation to Offshore Thunderstorms**
4	**Support of GOES-R AWG Imagery Team**
5	**Support of GOES-R AWG Cloud Team**

PROJECT TITLE: Developing an Environmental Awareness Repertoire of ABI Imagery (‘*DEAR-ABII’*) to Advise the Operational Weather Forecaster

PRINCIPAL INVESTIGATOR**:** Steve Miller

RESEARCH TEAM: Curtis Seaman, Yoo-Jeong Noh, Jeremy Solbrig, Jason Apke, Kyle Hilburn, Matthew Rogers, Natalie Tourville

NOAA TECHNICAL CONTACT: Dan Lindsey NOAA/NESDIS/GOESR

NOAA RESEARCH TEAM: Don Hillger and Deb Molenar NOAA/NESDIS/STAR/RAMMB

PROJECT OBJECTIVES:

The Himawari-8 Advanced Himawari Imagery (AHI) has provided a golden opportunity to develop multispectral and data-fusion imagery products tailored to an assortment of operational forecaster situational awareness needs in advance of GOES-R. Value-added applications such as Rayleigh-corrected true color, GeoColor (a data fusion product), fire temperature, 'blue-light' and background-reduced dust, snow/ice, and other enhancements have been crafted to provide context and a sanity check for the suite of quantitative (Level-2) products supported by the ABI. Several of these applications have followed the natural progression from polar-orbiting platforms (based on the MODerate-resolution Imaging Spectroradiometer (MODIS) leading into the Visible/Infrared Imaging Radiometer Suite (VIIRS). With GOES-16 and GOES-17 both operational, focus of this DEAR ABII project was on transitioning, further refining, and demonstrating through established Satellite Proving Ground channels all imagery products developed over the past years. The products were made available to operational centers and National Weather Service (NWS) forecasters in the AWIPS-II display environment.

PROJECT ACCOMPLISHMENTS SUMMARY:

<u>Milestone 1</u>: Continued near-real-time demonstration of core products in AWIPS/NAWIPS and on the web. Conduct validations of products against independent observations.

Demonstrated were the following GOESR Core Products: GeoColor, Snow/Cloud Discriminator and the Snow/Cloud Layer products, Fire Temperature RGB and Natural Color-Fire products, DEBRA Dust Product, Optical Flow.

- GOES-16/17 GeoColor imagery is examined daily and monitored for performance. When there is a downtime, we hear about it from external users. (Figure 1).

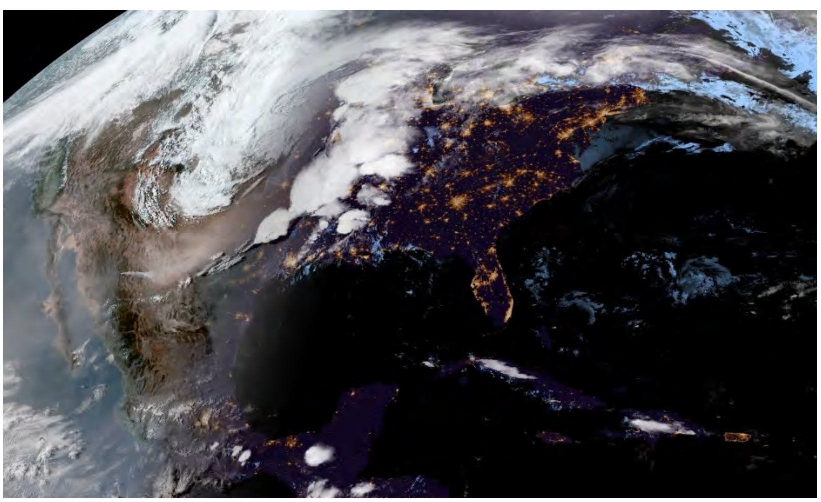


Figure 1: Figure: GOES-16 ABI GeoColor imagery from 14 April 2018 at 0002Z depicts a powerful Springtime midlatitude cyclone with pre-frontal severe thunderstorms over the central U.S., with lofted dust over Texas, a biomass smoke plume over north/central Mexico. Meanwhile, the eastern U.S. enjoys relatively quiescent conditions as city lights shine under the clear, early evening skies.

- Instructions to ingest and display the products in AWIPS2 D2D have been sent to requesting WFOs (distributed via the Regional Headquarters).

- The GOES-R Program Office continues to use CIRA's GeoColor imagery products daily:
- GeoColor is available on the NESDIS GOES-East and NESDIS GOES-West Viewer websites: https://www.star.nesdis.noaa.gov/GOES/conus.php?sat=G16 and https://www.star.nesdis.noaa.gov/GOES/conus.php?sat=G17
- Special RAMMB/CIRA GeoColor Sector was created for the NHC Media Desk.
- NOAA Managers highlighted GeoColor as part of their presentations at the 2019 Joint Satellite Meeting in Boston, 30 September – 4 October 2019:
  Stephen Volz, Louis Uccellini, Pam Sullivan, Neil Jacobs, Tim Walsh (Figure 2)

Figure 2: Stephen Volz presenting TC Dorian GOES-16 GeoColor imagery loop at the 2019 Joint Satellite Meeting in Boston, 30 September – 4 October 2019

- GeoColor was used for the 2019 CAMP2Ex and 2019 PISTON ship cruise operations—high profile NASA/DoD field campaigns: http://rammb.cira.colostate.edu/ramsdis/online/himawari-8.asp#PISTON_Experiment
- ABI and VIIRS imagery of Alaska fires provided to Congress: A congressional committee asked NASA for satellite imagery of wildfires in Alaska during the spring of 2019. CIRA provided two videos to fulfill this request: a nearly month-long loop of VIIRS Fire Temperature RGB images (25 June-17 July 2019) from both S-NPP and NOAA-20, and a 5-day loop of GOES-17 GeoColor images (6-10 July 2019).
- Steve Miller is currently serving as part of the NASA LANCE Users Working Group, which fields near real-time data (primarily NASA assets, but also Suomi-NPP and most recently, GOES-R ABI) for various purposes, including support of the NASA Disasters Program and the NASA Worldview website.
- The Snow/Cloud Layer products are running in SLIDER as well as in AWIPS2.
- Snow/Cloud Layer products are being evaluated regularly by CIRA Scientists and Operational Forecasters. NWS forecasters at WFO Buffalo (BUF) use this product regularly.
- The Fire Temp RGB products have been standardized for use in AWIPS and are easily displayed through the "on-the-fly" RGB capability available to all AWIPS users. They are Very Popular within the operational NWS/WFO forecasters (especially California!).
- Fire Temperature RGB imagery loop was presented by the Director of the NWS, Louie Uccellini, at the 2019 Joint AMS-EUMETSAT Satellite Conference in Boston, MA
- Based on discussions with Brad Pierce, at the 2019 Joint AMS/EUMETSAT Conference in Boston, CIRA's Fire Temperature RGB was used extensively by flight operations during the FIREX-AQ campaign, conducted during summer 2019 over the US.
- Transitioning the existing DEBRA code from Terascan over to IDL is now completed.
- The CIRA DEAR-ABII Team continued its work on Optical Flow in GOESR ABI. Different types of Optical Flow algorithms are currently being tested

Milestone 2: Begin near real-time demonstration of augmented core products and custom tailored products in AWIPS/NAWIPS and on the web.

- Real-time demonstration of most DEAR-ABII products happens via RAMSDIS online and on SLIDER
  http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/
  https://rammb-slider.cira.colostate.edu/
- GeoColor with Multi-Radar/Multi-Sensor (MRMS) overlay on SLIDER:
- @NOAA Satellite tweets a GeoColor nighttime image with GLM lightning overlay (25 July 2019)

Milestone 3: Continue supplying materials to satellite training partners.

- CIRA Participation in the 10th Asia-Oceania Meteorological Satellite Users' Conference (AOMSUC), held from 2-7 December 2019, in Melbourne, Australia.
- 18-29 November 2019: Paraguay and Uruguay Workshop
  Workshop report received from José Manuel Gálvez, SRG at NOAA/NWS/NCEP/WPC,
  mentions that Bernie Connell and Curtis Seaman were key to the success of the workshops.
- Extensive use of GeoColor imagery by NESDIS Public Relations:
  - GOES-R Program Office Newsletter:
    https://www.goesr.gov/downloads/multimedia/newsletters/GOESRQ32019NewsFINAL.pdf
  - GOES-R Program Office "Fact Sheets"
    https://www.goes-r.gov/resources/education.html
  - @ NOAA Satellites Twitter
    https://twitter.com/NOAASatellites
    Example: On November 18th, the @ NOAA Satellite page depicted 31 GeoColor imagery (mostly loops), 4 Snow/Cloud Layer RGB, and 5 Fire Temperature RGB imagery.

Milestone 4: Work with Satellite Liaisons to coordinate NWS recommendations to NOAA/OSPO for operation transitions.

GeoColor and other DEAR-ABII products are making their way into operations! National Centers, Regional HQs, and WFOs are using our core products.

1) AWIPS RGB telecon, 5 December 2019: (Lindsey, Foster, Gravelle, Molenar, Line, Miller):
   Chad Gravelle comment: *reviewed GeoColor, noted its widespread usage…this is the future of RGB…very powerful visualization. Could transcend satellite and change the game*.

2) From: Andy Just - NOAA Federal <andy.just@noaa.gov>
   Andrew Just, ForecastBuilder Manager, Techniques Development Meteorologist,
   NWS Central Region Headquarters SSD
   Date: Thu, Sep 26, 2019 at 9:50 AM
   Subject: Re: GeoColor data outage
   "Even though it's (*i.e. GeoColor*) not operational, in my opinion, it's far superior to any of the operational RGB products, at least for what I want to see. It would be great to see this become an operational product at some point. "

3) February 2019: Western Region Headquarters implemented LDM data access which disseminates GeoColor to individual WR NWS forecast offices. Instructions to ingest and display the product in AWIPS2 D2D were sent out as well.

4) DoD Dugway Proving Ground Meteorology Division in Dugway, UT requested access to GeoColor. LDM data access for that site was implemented in February. Instructions to ingest and display the product in AWIPS2 D2D were sent out as well.

5) NWS forecaster at NWS Buffalo, NY used SLIDER Snow/Cloud RBG for information about the ice cover on Lake Erie and Lake Ontario (called it 'breathtaking'). Also used for case studies and workshops.

6) Fire Temperature RGB was used during FIREX-AQ (see under Milestone 1, under Core Product Fire Temperature RGB). FIREX-AQ, a large field program (summer 2019) joint between NOAA and NASA, involved many flights to various fire events to study smoke and air quality impacts in situ. It turns out that the Fire Temperature RGB was one of the "go-to" products used by the forecasters.

7) GeoColor imagery was used extensively by forecasters for the CAMP2Ex Field Campaign in summer 2019 (see under Milestone 1, under Core Product GeoColor).

<u>Milestone 5: </u>Prepare/submit 1-2 publication(s) on selected DEAR-ABII products and illustrative use-cases based on Satellite Liaison and forecaster interactions.

Miller, S. D., D. T. Lindsey, C. J. Seaman, and J. E. Solbrig, 2020: GeoColor: A Blending Technique for Satellite Imagery. *J. Atmos. Ocean. Tech.*, **37**(3), 429-448, https://doi.org/10.1175/JTECH-D-19-0134.1.

Grasso, L. D., D. E. Bikos, and S. D. Miller, 2018: Observations of lower tropospheric water vapor structures in GOES-16 ABI Imagery. *JGR-Atmospheres*, **123**(24), 13,625-13,642, doi: 10.1029/2018JD029220.

<u>Other Items: GeoColor in the Media</u>

GOES-16 and GOES-17 GeoColor Imagery continues to be used <u>extensively</u> by the media and science community like, and is the undisputed "flagship product" of the GOES-R Program.

Media sources (which we know about) which used GeoColor for their postings (during July 2019 – December 2019): CNN, NPR, Washington Post, Miami Herald, Boston Globe, The Guardian, TIME Magazine, German ARD TV, news.com Australia, The Watchers, Florida Times-Union, ACCU Weather, Weather Nation, and many others.

PROJECT PUBLICATIONS:

Miller, S. D., D. T. Lindsey, C. J. Seaman, and J. E. Solbrig, 2020: GeoColor: A Blending Technique for Satellite Imagery. *J. Atmos. Ocean. Tech.*, **37**(3), 429-448, https://doi.org/10.1175/JTECH-D-19-0134.1.

Grasso, L. D., D. E. Bikos, and S. D. Miller, 2018: Observations of lower tropospheric water vapor structures in GOES-16 ABI Imagery. *JGR-Atmospheres*, **123**(24), 13,625-13,642, doi: 10.1029/2018JD029220.

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: GOES-R ABI Channel Differencing Used to Reveal Cloud-free Zones of 'Precursors of Convective Initiation'.

PRINCIPAL INVESTIGATOR**:** Lewis Grasso

RESEARCH TEAM: Jack Dostalek

NOAA TECHNICAL CONTACT: Dan Lindsey NOAA/NESDIS

NOAA RESEARCH TEAM: Don Hillger and Steve Weiss

PROJECT OBJECTIVES:

Similar to low-level precipitable water retrieval of Chesters et al. (1983), a three-channel product, bands 13, 14, and 15, which utilizes a single-layer approximation to the radiative transfer equation, was used to retrieve values of Boundary layer Precipitable Water (BPW). Chesters et al. (1983) used two infrared channels and required an approximation to the low-level air temperature. The addition of a third channel in the BPW retrieval eliminates the need for such an approximation. In addition, no NWP forecast profiles of temperature and water vapor are required for BPW, unlike the GOES-R Total Precipitable Water (TPW) baseline product. Since the weighting function of each of the three bands peaks in the boundary layer, and their differences are due primarily to low-level water vapor, retrieved values of BPW would be related to values of Convective Available Potential Energy (CAPE), which is available during convective initiation. The TPW GOES-R Baseline Product makes use of additional IR bands and forecast profiles of temperature and water vapor, but for the application in this project, we were only interested in the BPW due to the relationship between CAPE and convective morphology. Retrieving BPW is a more quantitative approach than the 10.35-12.3 µm difference alone. Initial testing of BPW began in FY17 with observed GOES-R data followed by any necessary improvements in FY18 and FY19.

PROJECT ACCOMPLISHMENTS SUMMARY:

A paper entitled, “Application of the GOES-16 Advanced Baseline Imager: Morphology of a Pre-convective Environment on 17 April 2019” by Grasso et al. has been accepted for publication in the Electronic Journal of Severe Storms Meteorology. The following is a brief outline of the paper:

Thunderstorms formed in the afternoon of 17 April 2019 over northern Mexico. Satellite data are used to highlight several features associated with convective preconditioning over portions of Coahuila, Mexico. Satellite imagery was used to identify two pre-convective features over northern Coahuila and they are (1) a relatively moist boundary layer inferred from channel differencing of imagery near 10.3 µm and 12.3 µm and (2) upward vertical motion inferred from decreasing values of brightness temperatures near 7.34 µm (low-level water vapor). Due to the approach of a trough at 500 hPa, a larger region of cooling was evident in low-level water vapor imagery. Evidence of blowing dust in imagery was used to highlight a wind-shift boundary along with a possible region of enhanced horizontal convergence. A demonstration of a time-of-arrival tracking feature is used to show a benefit to a forecaster in determining the arrival of a region of blowing dust and possible enhanced horizontal convergence and subsequent convective initiation. Assimilation of satellite data that contains key features and potential benefits to numerical weather prediction is addressed. Convective preconditioning of an environment outside of the United States, and hence a county warning area of a forecaster in the United States, is an important situation for a forecaster to monitor as subsequent convection may move into a forecaster’s region of responsibility.

A representative figure from the paper is shown below.

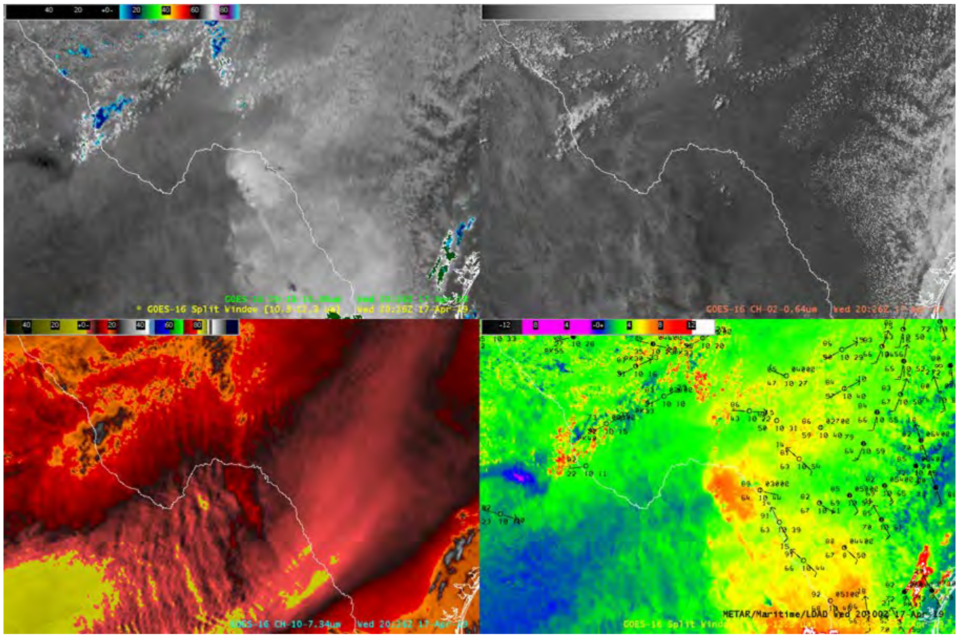


Figure 1: Four panel display of GOES-16 ABI data at 20:26 UTC 17 April 2019. Blended split window difference (grey shades) and Tbs at 10.35 um (rainbow color enhanced) are displayed in the top left. In the image, the moist boundary layer is indicated by light grey shades with the western edge of the moist layer oriented north-south from the center of the image towards the bottom of the image. Values of reflectance at 0.64 um are shown in the top right panel, which does not show the western edge of the moist layer. Tbs at 7.34 um in the lower left panel indicate the origin and downwind location of an elevated mixed layer. Also evident was a quasi linear region of cooling oriented north-south and crossing the Texas Mexico border. This region of cooling is suggestive of upward vertical motion co-located with the western edge of the moist layer. Values of the SWD are shown in the lower right panel that highlights the western edge of the moist layer over northern Mexico as orange. Also blowing dust (purple) is evident on the left side of the image.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: ProbSevere: Upgrades and Adaptation to Offshore Thunderstorms

PRINCIPAL INVESTIGATOR: Jack Dostalek

RESEARCH TEAM: N/A

NOAA TECHNICAL CONTACT: Mike Pavolonis NOAA/NESDIS/StAR

NOAA RESEARCH TEAM: Joe Sienkiewicz, Michael Folmer

PROJECT OBJECTIVES:

1) Assist in the development and validation of Offshore ProbSevere through analysis of prospective predictors and the development of validation methodologies.
2) Quantify potential impacts of SPC effective storm relative helicity on CONUS ProbTor predictions by identifying how often the SPC effective storm relative helicity is more consistent with local

storm reports than the RAP storm relative helicity (low in the absence of tornado reports, larger when tornadoes do form).

PROJECT ACCOMPLISHMENTS SUMMARY:

For both the Offshore ProbSevere (Objective 1) and ProbTor efforts (Objective 2), data have been collected and analysis begun. For the Offshore ProbSevere work, three prospective predictors from SPC's mesoanalysis fields are being considered: the derecho composite parameter, the damaging wind parameter, and the microburst composite parameter. For the ProbTor effort, a collection of severe weather events from April and May 2019 has been assembled. For these events the relative helicity field from NOAA's Rapid Refresh model is being compared to SPC's effective storm relative helicity to determine which is better for distinguishing tornadic from non-tornadic severe thunderstorms. The figure below shows the location of severe weather events included in the collection (Figure 1).

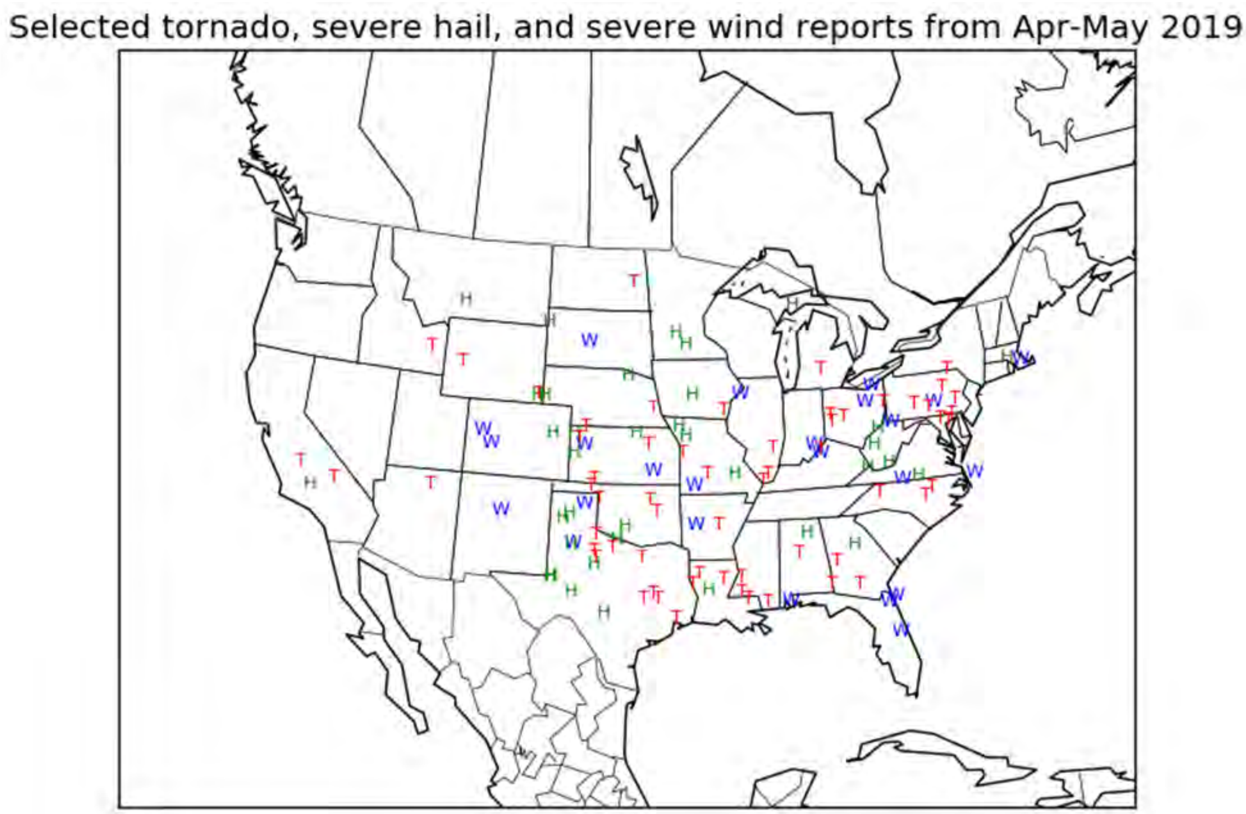


Figure 1: Location of severe weather events from April-May 2019 for which the Rapid Refresh storm relative helicity will be compared to SPC's effective relative humidity. T: tornado, W: wind ≥ 58 mph, H: hail ≥1 inch.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: GOES-R AWG Imagery Team

PRINCIPAL INVESTIGATOR**:** Steve Miller

RESEARCH TEAM: Curtis Seaman, Lewis Grasso, Jason Apke, Matt Rogers

NOAA TECHNICAL CONTACT: Tim Schmit, Jaime Daniels NOAA/NESDIS)

NOAA RESEARCH TEAM: Don Hillger, Dan Lindsey NOAA/NESDIS/STAR/RAMMB

PROJECT OBJECTIVES:

CIRA's contribution to the GOES-R AWG Imagery Team addressed the following high priority areas for ABI imagery assessment and algorithm quality assurance:

- Continue to assist with analyzing the GOES-16 and GOES-17 ABI CMI products, providing feedback to the Team Leads on any problems and/or issues encountered.
- Continue to support the science maintenance of the ABI CMI products. Level of support will be based on user-defined priorities and readiness for product consumption.
- Continue support of true color real-time production at NESDIS and in support of myriad outreach activities and both forecaster and general public consumption.

PROJECT ACCOMPLISHMENTS SUMMARY:

Milestone 1:
Continue to compare GOES-17 CMI against GOES-16 CMI for space/time-matched scenes. Leverage CIRA multispectral imagery products for CMI evaluation. Examine stitching GOES-17 and GOES-16 GeoColor imagery.

- GOES-17 ABI GeoColor (true color day, blended IR, low-cloud enhancement and city lights at night) has been running with no problems since it was first implemented in late 2018.
- GOES-16/17 GeoColor imagery is examined daily and monitored for performance.
- The consistency of the true color performance between the two ABI sensors remains excellent, meaning that GOES-17 ABI calibration adjustments (done upstream of this processing) are providing good consistency with GOES-16 ABI (Figure 1).

Figure 1: Comparison of GOES-17 (left) and GOES-16 (right) full disk GeoColor images (18:00 UTC, 5 October 2019).

Milestone 2:
Take inventory of any GOES-16 vs. GOES-17 discrepancies encountered and conduct analyses to identify the root causes, passing findings up the chain to the Imagery AWG lead and CWG as appropriate.

We continue to analyze CMI from GOES-17 for impacts related to the faulty Loop Heat Pipe (LHP) issue. The Predictive Calibration algorithm was implemented on 25 July 2019. This algorithm was developed by the Calibration Working Group in coordination with the vendor, and is designed to adjust the calibration of the IR detectors during periods when the temperature of the instrument becomes unstable. The algorithm does not eliminate all impacts of the Loop Heat Pipe issue however, as it cannot prevent detector saturation. An example from the mid-level water vapor band (7.34 micron; Band 10) is shown in Figure 2 below. This image is from 1400 UTC, 15 October 2019, a post-equinox night known to have high impacts from the Loop Heat Pipe anomaly. In contrast, Bands 13 and 14 (10.35 and 11.2 micron, respectively) did not saturate during this same event, and impacts on the imagery were minimal.

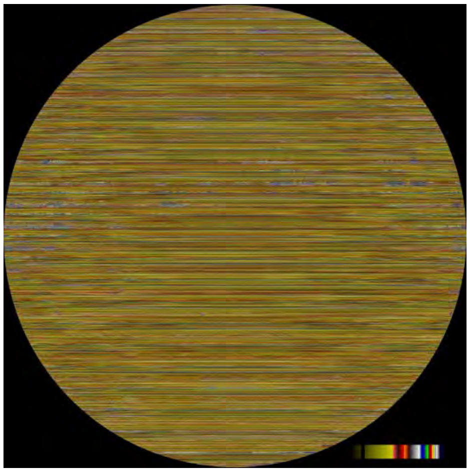


Figure 2: GOES-17 Band 10 (7.35 micron) image (1400 UTC, 15 October 2019) showing the result of detector saturation as a result of overheating.

Milestone 3:

Compare recently re-calibrated GOES-R ABI red band with VIIRS red band for simultaneous nadir overpasses of Suomi National Polar-orbiting Partnership (S-NPP) and Joint Polar Satellite System-1 (NOAA-20).

We studied examples of a near-nadir VIIRS-ABI matchup for the purpose of comparing (qualitatively) the visible band calibration differences between the two instruments. The initial comparison did not point to a significant issue, but a quantitative analysis is still pending. Work started on utilizing pass predictions to determine a S-NPP crossing near the nadir point of GOES-16, co-register the imagery, and produce a scatter plot. If obvious biases are found, then the plan is to gather additional cases and attempt to characterize it more robustly.

Milestone 4:

Assess imagery quality in context of its suitability for application to optical flow techniques for deriving Atmospheric Motion Vectors (AMV) analysis, storm top dynamics, and other environmental parameters.

The CIRA DEAR-ABII Team continued its work on **Optical Flow in GOESR ABI.** Efforts were put into validating and tuning optical flow produced with 1-min Advanced Baseline Imager data to identify atmospheric winds. Courtesy of NASA-Langley Research Center, CIRA now had access to Doppler Aerosol Wind Profiling Lidar (DAWN) data containing winds and cloud-top heights for several case study days sampled with 1-min GOES-17 data. Wind profiles were sampled around boundary layer cumulus over the Pacific Ocean for the ADM-Aeolus Cal/Val experiments on 23 April 2019. These data were within ~ 1 m s^{-1} of dropsonde winds released in the area and represent a fine-scale tool to resolve mesoscale AMV related flows.

The new modified Sun et al. (2014) optical flow algorithm and the fast, open source Farnebäck (2001) algorithm both show promising bias and mean-vector difference statistics when they were compared to the DAWN-derived cloud-top winds (Table 1).

Table 1. GOES-17 Optical Flow Validation Statistics.

Algorithm	Bias (m s^{-1})	Mean Vector Difference
Sun et al. (2013) (IR Ch-7)	1.623	4.04
Modified-Sun et al. (2013) (IR Ch-7)	-0.798	3.101
Farnebäck (2001) (Vis Imagery)	-0.597	2.447
➔ Modified 1-min (2 Pyr. Levels)	-0.114	2.272
➔ 3 min | 5 min | 10 min	-0.15 | 0.15 | -1.91	2.327 | 2.068 | 4.38
DMW's (IR Ch-7) from Daniels et al. (2018)	< |-0.5|	~2.9-4.5
DMW's (vis Ch-2) from Daniels et al. (2018)	< |0.5|	~2.8-3.7

Another important aspect of this past year's work was to test the viability of running optical flow on GOES-R CONUS (5-min) and Full Disk (10-min) imagery. Our tests currently indicate, in slow boundary layer cumulus, using longer time steps (up to 5-min) mitigates navigation and registration related errors, however using up to 10 min results in brightness constancy and tracking issues. These preliminary results imply that finer temporal resolution imagery is better even for simple-to-track slow moving scenes, and dense optical flow may not be practical for most motions with 10-min or greater image refresh rates without significant tuning. Work is currently underway to better tune these algorithms with the truth datasets and identify cloud-scenes where certain approaches may struggle for quality control.

Milestone 5:

Continue support and refinement as necessary of true color real-time production at NESDIS.

- GeoColor implementation at NESDIS is ongoing.
- Besides all 16 ABI bands, 24 additional GOES-17 ABI products are available on the CIRA Web Application, "SLIDER" (see https://rammb-slider.cira.colostate.edu/)
- GOES-16 and GOES-17 ABI GeoColor products are running at NESDIS as well as to the NWS WFOs (through the AWIPS LDM) and is also being used by the National Centers (OPC, WPC, SPC, AWC, NHC).
- GOES-16 and GOES-17 ABI GeoColor imagery, made possible in part due to this AWG work, is available on the NESDIS GOES-East and on the NESDIS GOES-West Viewer websites: https://www.star.nesdis.noaa.gov/GOES/conus.php?sat=G16 and https://www.star.nesdis.noaa.gov/GOES/conus.php?sat=G17

Milestone 6:

Provide GOES-16 and GOES-17 ABI imagery examples to NESDIS for outreach and communications purposes.

- NOAA NESDIS Homepage
  The NOAA NESDIS homepage https://www.nesdis.noaa.gov/ regularly posts GeoColor imagery of special weather events.
- NOAA Satellites on Twitter @NOAASatellites and @ NOAASatellitePA:
  GeoColor imagery continues to be routinely shared on social media through the NOAA/NESDIS Twitter account @NOAASatellites. These images come from both CIRA's real time processing and the real-time processing at NOAA/NESDIS: https://twitter.com/NOAASatellites
- GOES-R Program Office: GOES-R Quarterly Newsletters
  GOES-16 and GOES-17 GeoColor imagery is regularly used in the GOES-R Program Office GOES-R Quarterly Newsletters. The Issue (Q4, October - December 2019) can be seen here: https://www.goes-r.gov/downloads/multimedia/newsletters/GOESR4Q2019newsletterfinal.pdf
- CIRA's "ABI Loop-of-the-Day" is posted on different NESDIS webpages regularly and used by NESDIS managers for their presentations. http://rammb.cira.colostate.edu/ramsdis/online/loop_of_the_day/

Milestone 7:

If needed, assist with preparation and delivery of presentations for Peer-Stakeholder Product Validation Reviews (PS-PVR).

Six NOAA/NESDIS managers presented GeoColor imagery as part of their presentations at the 2019 AMS-EUMETSAT Joint Satellite Conference in Boston, MA (30 September - 4 October 2019).

Milestone 8:

Provide quarterly progress reports, CIRA Annual Report, and present results at a scientific meeting/conference relevant to GOES-R.

Quarterly progress reports and annual reports are being provided. For list of presentations see the end of this report.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Six NOAA/NESDIS managers presented GeoColor imagery as part of their presentations at the 2019 AMS-EUMETSAT Joint Satellite Conference in Boston, MA (30 September - 4 October 2019).

PROJECT TITLE: GOES-R AWG Cloud Team

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Yoo-Jeong Noh

NOAA TECHNICAL CONTACT: Dan Lindsey NOAA/NESDIS

NOAA RESEARCH TEAM: Don Hillger and Andy Heidinger NOAA/NESDIS

CIRA's initial AWG Cloud Team contributions (performed with FY16-18 funding) involved the ongoing development of the CGT algorithm, evaluation of CGT against CloudSat, and application of a version of the CGT algorithm to AHI data. Over the course of this work, GOES-R has launched successfully and transitioned to GOES-16. The ABI is operating nominally and is on schedule for operational transition as either GOES-E or GOES-W pending NOAA decision.

For FY19, we completed the CGT/CBH/CCL algorithm transition to GOES-17 ABI and continue to evaluate performance against multiple observations. As GOES-16 and GOES-17 ABI permanently transitioned to 10-minute full disk scan mode (Mode 6) operations, it is essential to ensure the optimal performance with the new data stream. This work includes monitoring and reporting of the algorithm performance in various configurations for both GOES-16/17 ABIs and working on an improved ABI Cloud Cover Layers (CCL) applications requested by aviation forecasters. In addition, we have formal demonstrations with users and evaluation of product performance in the NOAA operational environment.

PROJECT OBJECTIVES:

1-- Evaluation of CGT/CBH algorithm on GOES-16 and GOES-17 ABI

2-- Algorithm validation and improvement using CloudSat/CALIPSO (machine learning for improved cloud vertical structure)

3-- Interactions with key users and improvement of product demonstration

4-- Prepare reports and contribute materials to presentations as requested by Team Lead

PROJECT ACCOMPLISHMENTS SUMMARY:

We continued to evaluate the statistical CGT/ CBH algorithms for both GOES-16 and GOES-17 ABIs. The Clouds from AVHRR Extended (CLAVR-x; a testbed for NOAA AWG operational cloud algorithms) run at CIRA has been updated to adopt latest updates for NOAA cloud mask and other cloud algorithms in collaboration with CIMSS team. Cloud products from GOES-16, GOES-17, and Himawari-8 have been displayed in CIRA's SLIDER and popularly used by general and operational users. We tested CLAVR-x updates and reported NWP interpolation problems and compile issues to Andy Heidinger (NOAA Cloud Team Lead) and CLAVR-x developers.

Leveraging research efforts from CIRA's GOES-R Risk Reduction project on improvement of CCL for multi-layer clouds, a collocation method for CloudSat/CALIPSO within the ABI of view were continued. We utilized NWP humidity data and the currently cloud type information to improve multi-layer cloud scenes. The results compared with CloudSat show potential to find additional "High+Low" cloud layer pixels for middle latitudes including CONUS (Figure 1). Since this approach is not effective over tropical and high latitude regions, we continued to utilize a machine learning approach (random forest model) in parallel, focusing on historical data with both valid CloudSat and CALIPSO data (the operational data processing is under reprocessing since the new C-train orbit maneuvers). Multiple ABI bands, channel differences, and NWP humidity profiles, solar zenith angles, latitudes are trained using ground truth data from CloudSat and CALIPSO (40-day global matchups in 2017). The probability of detection of low cloud under cirrus is increased from 22% to 69% using the machine learning model.

The CIRA team regularly participated in the Cloud Team teleconferences and meetings for user-developer interactions including Aviation/Arctic Proving Ground Initiative" established on the JPSS side, and provided input materials for reviews and reports requested by NOAA Cloud Team Lead. CIRA's SLIDER is used as a supplementary data display tool to support the NOAA Alaska Demonstration of Cloud Products, together with a new experimental product website for the VIIRS Cloud Vertical Cross-sections over Alaska (http://rammb.cira.colostate.edu/ramsdis/online/npp_viirs_arctic_aviation.asp) which we developed to support the JPSS PGRR Aviation Initiative. John Haynes (CIRA) visited the Aviation Weather Center (August 1-2, 2019) for product demonstrations and collaborations with AWC researchers. Our research efforts and scientific results were presented at 2019 AMS-EUMETSAT Joint satellite conference and other science meetings. All the presentations are listed in the presentation section.

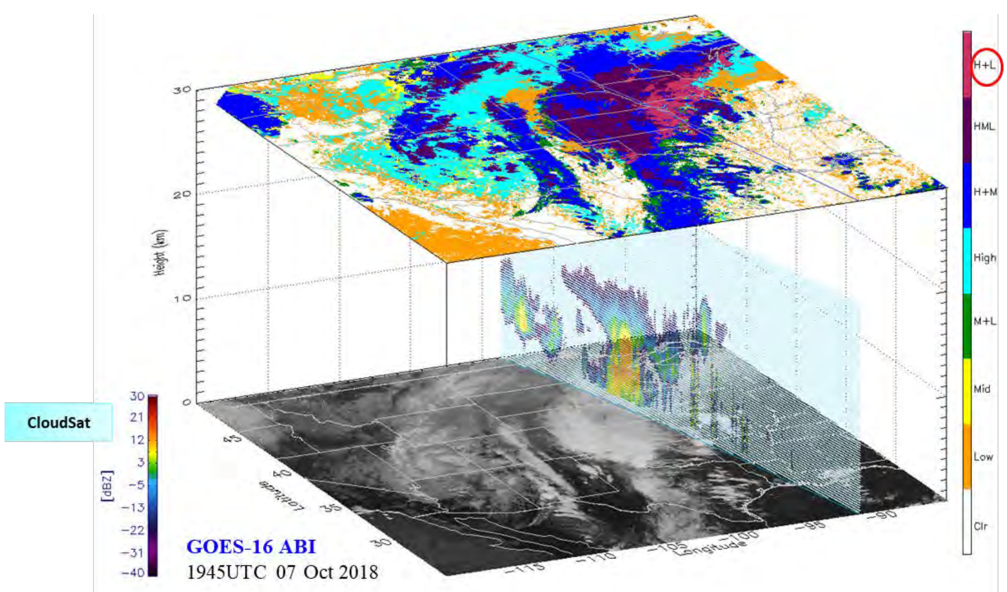


Figure 1. Sample cloud layer product including multilayer clouds (High+Low) from GOES-16 ABI with the simultaneous CloudSat radar cross-section over CONUS. The bottom IR image is from ABI 11.2 µm.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting

PRINCIPAL INVESTIGATOR: Renate Brummer

RESEARCH TEAM: Kathy Fryer

NOAA TECHNICAL CONTACT: Dan Lindsey NOAA/NESDIS

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVE:

Consistent with our long-standing Memorandum of Understanding between NOAA and Colorado State University, the CIRA GOES-R project included a budget specifically to support administrative and clerical personnel directly associated with the technical and managerial administration of this project. This support is "quid pro quo" for the reduced indirect cost rate agreed upon in the long-standing subject memoranda.

PROJECT ACCOMPLISHMENTS SUMMARY:

The CIRA/RAMMB Administrative Assistant provided communication support, assisted in the acquisition and distribution of reference materials relevant to the conception and execution of the projects, and collected reports and conference papers. In addition, the CIRA Administrative Employee also provided administrative support for the wider GOES-R program, including tracking of project progress reports and all GOESR3-List email (goesr3.list@gmail.com) communication. The CIRA Administrative Employee also provided federal travel documentation and made all of the travel arrangements for the Federal RAMMB Employees.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Support for the Generation of Multispectral Imagery Products from Metop-SG METImage

PRINCIPAL INVESTIGATORS: Curtis J. Seaman, Steven D. Miller

RESEARCH TEAM: Jorel Torres, Yoo-Jeong Noh, Matthew Rogers

NOAA TECHNICAL CONTACT: Mitch Goldberg

NOAA RESEARCH TEAM: Debra Molenar, Donald Hillger

PROJECT OBJECTIVES:

1--Continue development and refinement of VIIRS multi-spectral imagery applications and generation of materials on global phenomena.

2--Continue distribution of products and user engagement in coordination with users and Satellite Liaisons.

3--Publication of results in both technical journals and blogs and development of training materials.

4--Participate in appropriate PGI teleconferences.

5--Participate in JPSS/PGRR Annual Review and domestic science conference(s).

This work is conducted in collaboration with the Geographic Information Network of Alaska (GINA) at the University of Alaska-Fairbanks (UAF).

PROJECT ACCOMPLISHMENTS SUMMARY:

1-- One of the primary accomplishments of this project has been the development of “Polar SLIDER”: the polar-orbiting satellite analog to CIRA’s popular Satellite Loop Interactive Data Explorer in Realtime (SLIDER) website (http://rammb-slider.cira.colostate.edu). Access to Polar SLIDER is made available by selecting “JPSS” from the Satellite Menu on SLIDER or, alternately, through this URL: http://rammb-slider.cira.colostate.edu/?sat=jpss. The primary goal of Polar SLIDER is to show the most recently available VIIRS data for every location on Earth in near-real-time. This is done in two hemispheric views (Northern and Southern) in an orthographic projection (Fig. 1). This has become a new platform for the demonstration of VIIRS imagery applications at the high latitudes, where the combination of S-NPP and NOAA-20 provide quasi-geostationary coverage of the Poles. In addition, VIIRS multispectral imagery applications are also demonstrated on RAMSDIS Online (http://rammb.cira.colostate.edu/ramsdis/online/npp_viirs_arctic.asp)

2-- CIRA-developed VIIRS imagery products, including the Fire Temperature RGB and Day Land Cloud Fire RGB are being distributed by UAF/GINA to forecasters throughout the National Weather Service (NWS) Alaska Region. These products are utilized on a daily basis by the Alaska Fire Service throughout fire season. During the period covered by this report, two new RGB composites useful for snow characterization and snowmelt monitoring have been developed and are now being distributed to the NWS Alaska Region (Fig. 2). We are also in the process of transitioning the Day/Night Snow/Cloud Discriminator (the VIIRS version of the ABI Snow/Cloud-Layers product) into operations in Alaska based on user requests. We are actively collaborating with the Satellite Liaisons and the Total Operational Weather Readiness-Satellites (TOWR-S) team (a joint effort of the NWS and the GOES-R and JPSS Programs) to provide these products to NWS offices throughout CONUS as well. However, unresolved issues within AWIPS have so far stunted progress in this area. A successful visit to CIRA by GINA satellite liaison Carl Dierking led to the implementation of the JMA SO_2 RGB in AWIPS, as well as to improvements in the aviation-related cloud products and NUCAPS products produced at CIRA as part of other JPSS PGRR funded projects.

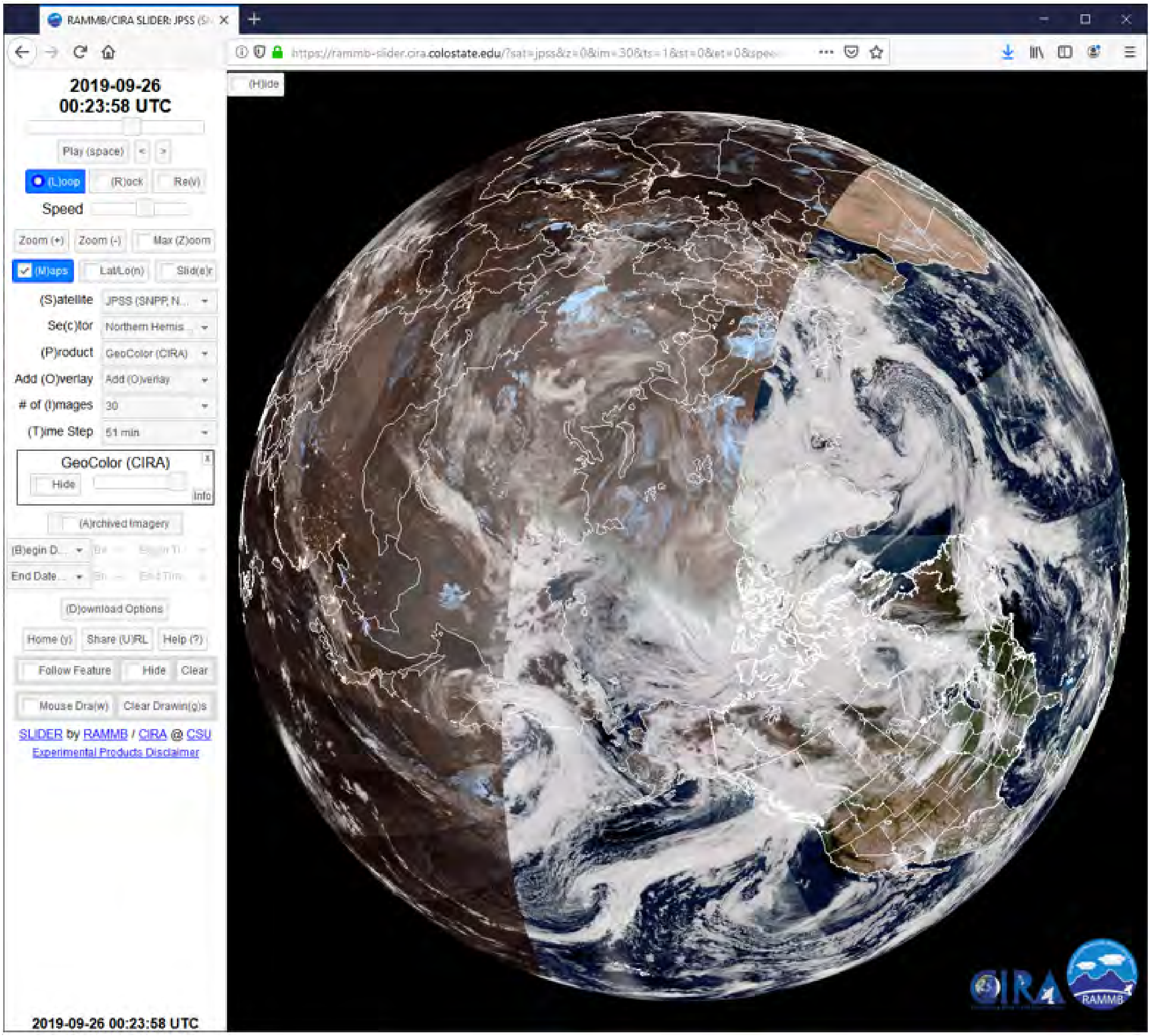


Figure 1. Example of the Northern Hemisphere sector on Polar SLIDER displaying the VIIRS version of GeoColor (26 September 2019).

3-- J. Torres, in his role as JPSS Satellite Liaison, has developed Quick Guides for the VIIRS Fire Temperature RGB, VIIRS Day Land Cloud Fire RGB, and Day/Night Snow/Cloud Discriminator. In addition, a Quick Brief (~5 min. training video) has been developed for the Day Land Cloud Fire RGB. These materials are available on the CIRA VISIT website (http://rammb.cira.colostate.edu/training/visit/) and the NOAA VLab. Training materials have also been provided to the COMET program. J. Torres and C. Seaman have combined to write 9 blog posts on three blogs demonstrating the utility of VIIRS imagery. URLs for these blogs are: http://rammb.cira.colostate.edu/training/visit/blog/; http://rammb.cira.colostate.edu/projects/npp/blog/; http://rammb.cira.colostate.edu/projects/alaska/blog/ Beginning in November 2019, J. Torres is now offering teletraining sessions for NWS forecasters, and has provided on-location training at the NWS offices in Boulder and Grand Junction. C. Seaman provided hands-on training for forecasters on the utility of SLIDER (including Polar SLIDER) at the Asia-Oceania Meteorological Satellite User's Conference (AOMSUC), in Melbourne, Australia in December.

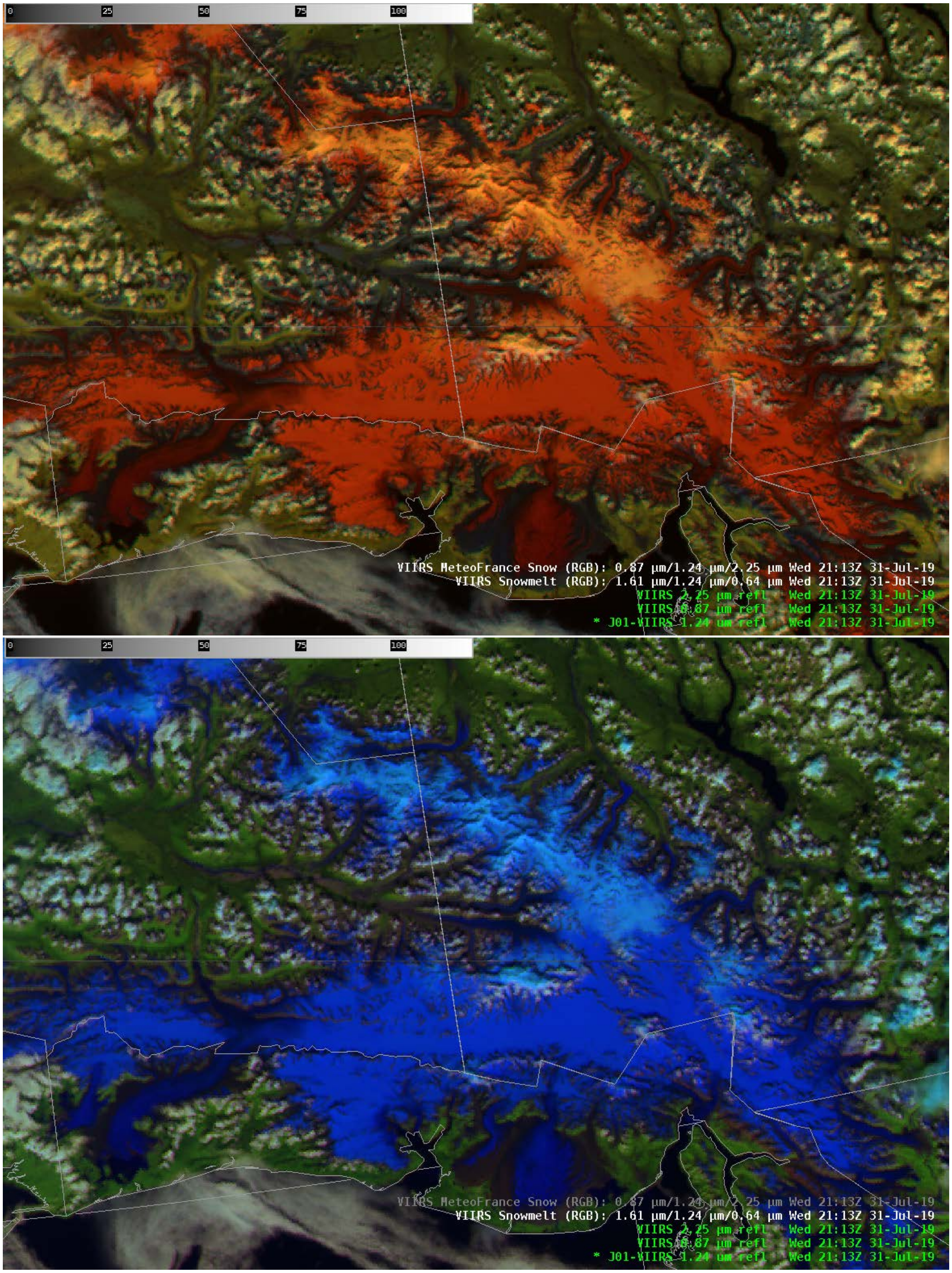


Figure 2: Top: Example of the Météo-France Snow RGB adapted for VIIRS and AWIPS. Bottom: The new VIIRS Snowmelt RGB developed at CIRA as displayed in AWIPS (31 July 2019). In both images, the coloration of the snow is related to grain size (a proxy for age) and water content. These products are currently being evaluated for use in monitoring snowmelt, flood prediction and avalanche danger.

4-- Project members have combined to participate in the majority of the JPSS Proving Ground Initiative (PGI) teleconferences, including: Arctic, Aviation, Fire and Smoke, River Ice and Flooding, NUCAPS and Training.

5-- Project members have attended a variety of domestic and international conferences during this year, including: AMS Annual Meeting, Asia-Oceania Meteorological Satellite User's Conference (AOMSUC), Joint AMS-EUMETSAT Satellite Conference, National Weather Association Meeting, and the NOAA/NASA Satellite Meteorology Summer Workshop. A list of first author presentations is included below.

PROJECT PUBLICATIONS:

Miller, S. D., W. C. Straka III, J. Yue, C. J. Seaman, S. Xu, C. D. Elvidge, L. Hoffman, and S. I. Azeem, 2018: The Dark Side of Hurricane Matthew—Unique Perspectives from the Day/Night Band. *Bull. Amer. Meteor. Soc.*, 99, 2561-2574, https://journals.ametsoc.org/doi/10.1175/BAMS-D-17-0097.1.

PROJECT PRESENTATIONS/CONFERENCES:

WFO Grand Junction Spring Workshop, Grand Junction, CO (15 May 2019)
Presenter's name: Jorel Torres
Presentation type: Remote Oral Presentation
Presentation title: JPSS Products in AWIPS and SatFC-J

2019 NOAA/NASA Satellite Meteorology Summer Workshop, Fort Collins, CO (11 July 2019)
Presenter's name: Jorel Torres
Presentation type: Oral Presentation
Presentation title: JPSS Educational Resources

National Weather Association (NWA) Annual Meeting, Huntsville, AL (7-12 September 2019)
Presenter's name: Jorel Torres, Bernie Connell, Erin Sanders and Dan Bikos
Presentation type: Poster Presentation
Presentation title: An overview of the Satellite Foundational Course for JPSS (SatFC-J)

Presenter's name: Jorel Torres, Dan Bikos and Ed Szoke
Presentation type: Poster Presentation
Presentation title: Polar-orbiting and Geostationary capabilities and observations in support of Active Fires

2019 AMS - EUMETSAT Joint Satellite Conference, Boston, MA (30 September - 4 October 2019)
Presenter's name: Jorel Torres and Janel Thomas
Presentation type: Short Course Lecture
Presentation title: Training Resources/Q&A/Course Evaluation

Presenter's name: Curtis Seaman, Kevin Micke, Yoo-Jeong Noh, Jack Dostalek, Steve Finley, Steve Miller, Dan Lindsey, Natalie Tourville and Don Hillger
Presentation type: Oral Presentation
Presentation title: Polar SLIDER: A website for the display of global polar-orbiting satellite data in near-realtime

Presenter's name: Jorel Torres**,** Bernie Connell, Dan Bikos, Erin Sanders and Steve Miller
Presentation type: Oral Presentation
Presentation title: An overview of the Satellite Foundational Course for JPSS (SatFC-J)

Presenter’s name: Steve Miller, Dan Lindsey and Curtis Seaman
Presentation type: Oral Presentation
Presentation title: GeoColor - Taking value-added satellite imagery to the next level in the GOES-R era

10th Asia-Oceania Meteorological Satellite Users’ Conference, Melbourne, Victoria, Australia (2 - 6 December 2019)
Presenter’s name: Curtis Seaman
Presentation type: Hands-on Training Activity
Presentation title: Spectral band / now-casting exercise with a short example or two using RAMMB/CIRA SLIDER

Presenter’s name: Curtis Seaman, Kevin Micke, Dan Lindsey, Steve Miller, Yoo-Jeong Noh, Natalie Tourville, Jack Dostalek, Don Hillger, Galina Chirokova and Steve Finley
Presentation type: Oral Presentation
Presentation title: SLIDER: A website for displaying geostationary and polar-orbiting satellite data in realtime

2019 AMS Annual Meeting, Boston, MA (12 - 17 January 2020)
Presenter’s name: Jorel Torres
Presentation type: Oral Presentation
Presentation title: The Utility of JPSS and GOES Fire Weather Products and Applications in the Operational Forecasting Environment

PROJECT TITLE: CIRA Support for the Hurricane Intensity and Structure Algorithm (HISA) Migration to STAR Enterprise System

PRINCIPAL INVESTIGATOR: Galina Chirokova

RESEARCH TEAM: Robert DeMaria, Alex Libardoni

NOAA TECHNICAL CONTACT: Walter Wolf NOAA/NESDIS/STAR

NOAA RESEARCH TEAM: John Knaff NESDIS/STAR

PROJECT OBJECTIVES:

Tropical cyclones (TCs) tend to develop and spend a significant portion of their lifecycle over tropical oceans, out of range of aircraft reconnaissance and where in situ observations are sparse. In these regions, meteorologists must rely on satellites to provide data to initialize atmospheric models and to monitor TC motion and intensity. Satellite microwave sounders have proven especially useful for these tasks, since they can be used in the presence of cloud cover. The Regional and Mesoscale Meteorology Branch (RAMMB) at CIRA has developed the Hurricane Intensity and Structure Algorithm [HISA, former TC Intensity (TCI) algorithm] that uses temperature profiles derived from microwave radiances measured from polar orbiting satellites in conjunction with boundary conditions from the GFS model and TC location fixes from the Automated TC Forecasting System (ATCF) to estimate TC intensity and structure. HISA intensity estimates are objective, independent of Dvorak intensity estimates, and available globally for TCs in all basins. HISA intensity and wind radii are provided to the National Hurricane Center (NHC) and Joint Typhoon warning Center via ATCF f-deck or fixes. In previous PSDI projects, HISA was upgraded to use MiRS retrievals instead of the Goldberg’s Statistical Retrievals for which the algorithm was originally developed (Demuth et al., 2004, 2006, Bessho et al. 2006). Currently, the old version of HISA, TCI, is operational at NESDIS and produces TC intensity and structure estimates from temperature profiles retrieved with Microwave Integrated Retrieval System (MiRS) from instruments on-board 5 satellites. These include the Advanced Microwave Sounding Unit (AMSU) on NOAA-18, NOAA-19, MetOp-A, and MetOp-B, and Advanced Technology Microwave Sounder (ATMS) on Suomi National Polar-orbiting Partnership (SNPP) satellite. HISA version that can also process data from NOAA-20 ATMS will be transitioned to operations later this year under a separate PSDI funding.

Specific goals this year include:
1) Collect AMSU-MiRS data v11;
2) Upgrade HISA processing to standards, including converting all existing HISA Python2 code to Python3, and to work with MetOp-B AMSU-MiRS data v11;
3) Reprocess HISA for 2017 – 2020 using AMSU-MiRS and data v11, and refit statistical model.

PROJECT ACCOMPLISHMENTS SUMMARY:

1) AMSU-MiRS data have been collected for the years 2017 – current. The AMSU-MiRS data are being acquired and archived in real-time. The real-time data are provided to CIRA from PDA, and sometimes contain data gaps due to various reasons external to CIRA (e.g. data outages or bugs in the data pushing scripts). Several large gaps in ATMS-MiRS and AMSU-MiRS data have been filled by downloading data from NOAA CLASS. Downloading large amount of data from NOAA CLASS is a very tedious and time-consuming process, because CLASS requires all orders to be placed manually and limits the number of files per order. Thus, it is not always possible or practical to fill all gaps, however, there is a continuing effort to keep the database as complete as possible.
In addition, the pass prediction code was developed to allow more efficient selection of satellite-TC overpasses for historical data. Figure 2 shows an example of all SNPP overpasses, within 1000 km from the storm center, over 2017 Hurricane Lee. Work is in progress on using the pass prediction code to find all MetOp-B, NOAA-18, NOAA-19, SNPP, and NOAA-20 overpasses over global TCs for the last 3 years. The data for these overpasses will be used to refit the statistical part of HISA.

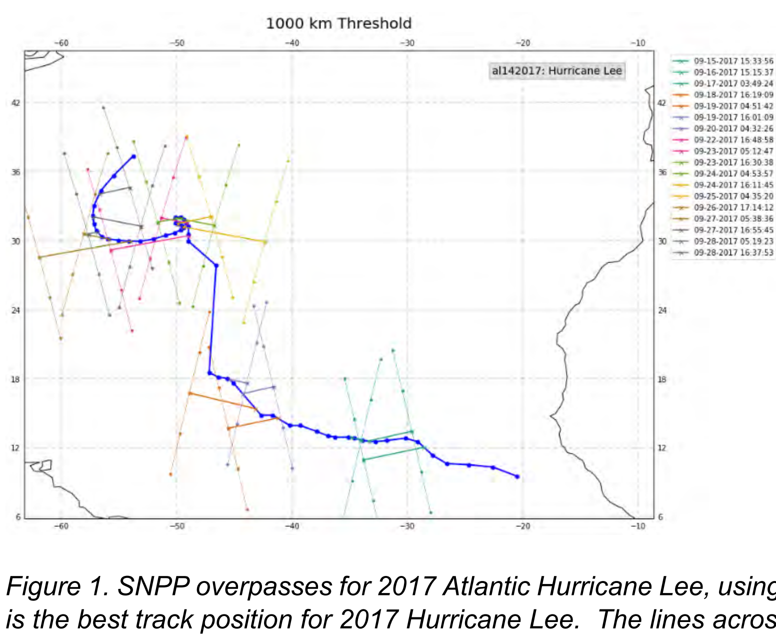


Figure 1. SNPP overpasses for 2017 Atlantic Hurricane Lee, using a 1000 km threshold. The thick blue line is the best track position for 2017 Hurricane Lee. The lines across the TC track show parts of the satellite track close to TC track.

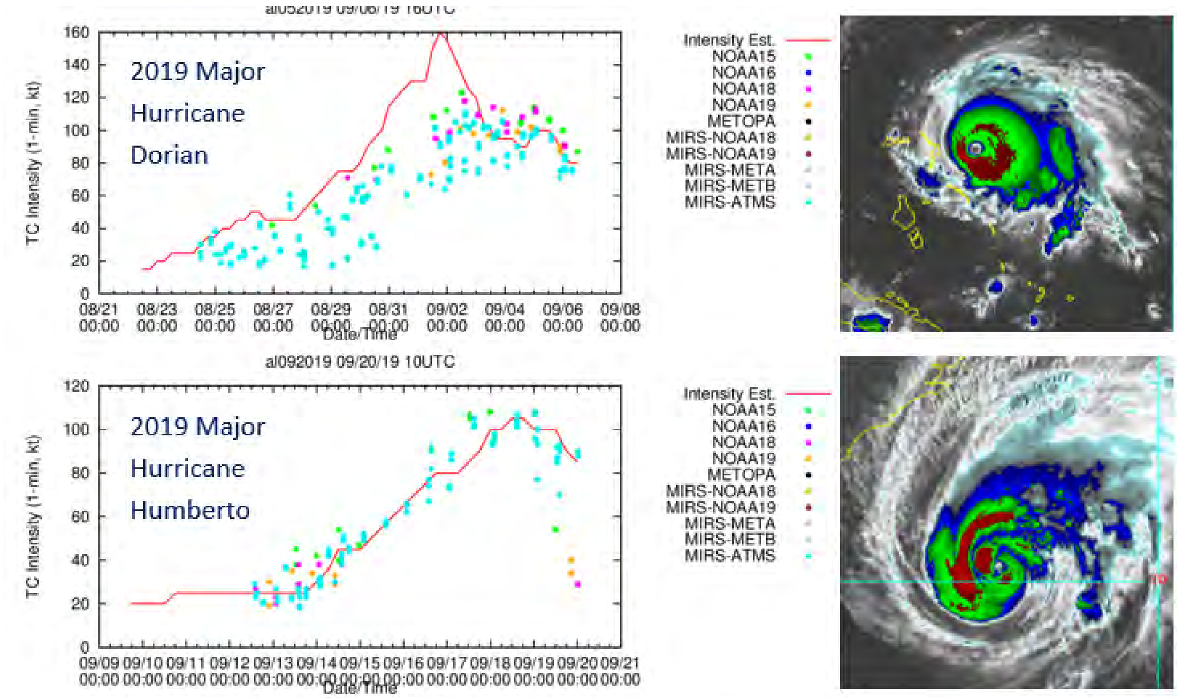


Figure 2. HISA intensity estimates for 2019 major hurricane Dorian (upper left panel) and major hurricane Humberto (lower left panel). While for Humberto the intensity estimates age generally very good, for Dorian the intensity is significantly underestimated in many cases.

2) Work is in progress on upgrading HISA processing to operational standards. The script for creating Process Control File (PCF) has been upgraded to Python3, and project scientists are working on rewriting and upgrading the main driver script, HISA.py, as well as other python scripts, including plotting scripts. Several bugs have been identified and fixed while rewriting and upgrading the code, including several known bugs in operational processing. In addition, python and Fortran code is being upgraded to use a single config file to run HISA with input from multiple instruments and satellites, including ATMS-MiRS from SNPP and NOAA-20, and AMSU from MetOp-B. The use of a single config file will allow using the same code for running HISA with input from different satellites and instruments, which should significantly simplify code maintenance. Also, as part of the update, the new version of CIRA Polar Orbiters Database (CPOD, DeMaria and Chirokova 2019) is being incorporated into processing. CPOD allows for quick and efficient selection of ATMS- and AMSU-MiRS data for each satellite-TC overpass, and the use of CPOD should result in reduced processing time for HISA.

3) Figure 3 demonstrates poor performance of the operational HISA for 2019 Atlantic Hurricane Dorian. While there might be additional reasons for poor performance, the first step in improving performance is to use the last 4 years (2017 - 2020) of SNPP and NOAA-20 ATMS-MiRS, and MetOp-B AMSU-MiRS data to re-fit the statistical part of HISA. That task is complicated by the fact that multiple versions of MiRS data will need to be used. For example, just for the 2019 there are MiRS version 11r1, 11r2, 11r3, and 11r4. In some cases, the difference between MiRS versions requires significant code adjustments. Work is in progress on identifying most common differences between versions and adding those to the config file, which should simplify processing of multiple current and future MiRS versions. Most of the differences between MiRS version have been identified, and the statistical model will be re-fit after the update of the HISA code to standards is complete. Figure 4 shows an example of the experimental HISA output for temperature and 2D winds for 2019 Hurricane Dorian.

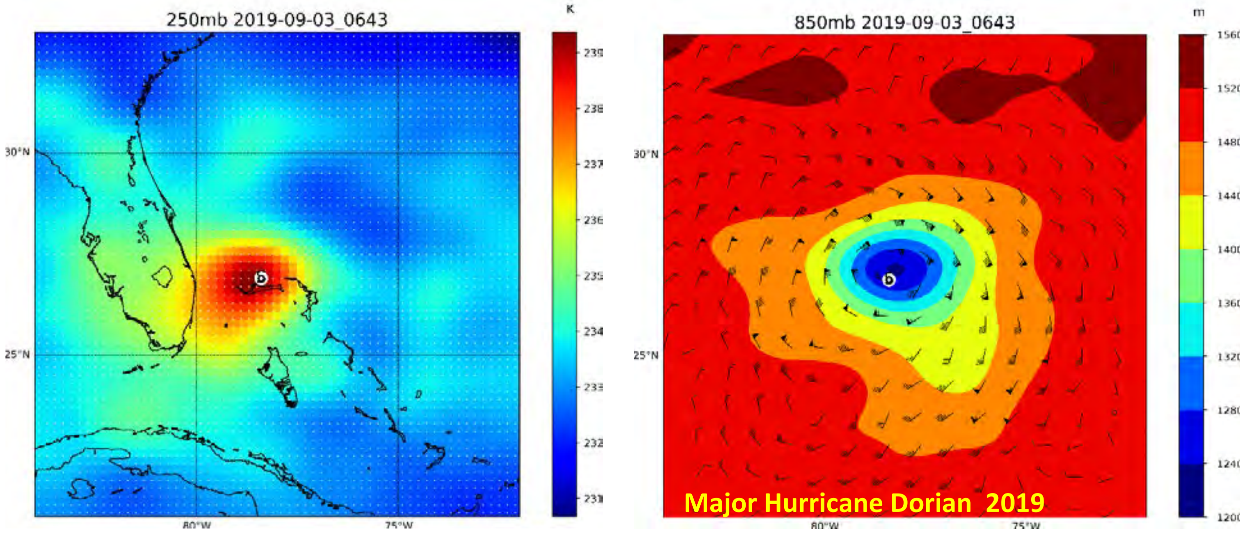


Figure 3. Example of HISA experimental output for 2019 major Hurricane Dorian. (Left) 250 hPa temperature, and (right) 850 hPa geopotential height.

PROJECT PUBLICATIONS:

DeMaria, R.T. and G. Chirokova, 2019: CIRA Polar Orbiters Database Software (CPOD): Python Software to Make Searching Polar Orbiting Satellite Data Fast and Easy. 99^{th} AMS Annual Meeting, Ninth Symposium on Advances in Modeling and Analysis Using Python, Phoenix, Arizona, 6-10 January, 2019. https://ams.confex.com/ams/2019Annual/mediafile/Manuscript/Paper351455/287_cpod_robert_ demaria_ams_2019_ poster_extended_abstract.pdf

PROJECT PRESENTATIONS/CONFERENCES:

Chirokova G., J. Knaff, A. Libardoni, L. Rivoire and C. Grassotti, 2020: How JPSS data can improve operational TC analysis and forecasting. JPSS/GOES-R Proving Ground / Risk Reduction Summit. 24 – 28 February 2020, College Park, MD.

Herndon D. and G. Chirokova, 2020: Level 2 TROPICS Tropical Cyclone Intensity Products. 2nd TROPICS Applications Workshop. 19 -20 February 2020, Miami, FL

Chirokova G., 2020: How JPSS Data can improve operational tropical cyclones analysis and intensity forecasting? Invited presentation at the JPSS Science Seminar, 27 January 2020, online.

Grassotti C., S. Liu, R. Honeyager, Y. Lee, Q. Liu, J. M. Forsythe, and G. Chirokova, 2019: Noaa's Microwave Integrated Retrieval System (MiRS): Operational Update, Applications, and Recent Scientific Progress. 2019 AMS Joint EUMETSAT/AMS Satellite Conference, Boston, MA, 28-September – 04 October 2019.

Knaff, J, C. Sampson, G. Chirokova, K. Musgrave and C. Slocum, 2019: CIRA/RAMMB Satellite and Forecast Tools, Products and Updates. 2019 Joint INDOPACOM Theater METOC Summit and Tropical Cyclone Conference, Honolulu, HI, 9-12 April 2019.

PROJECT TITLE: CIRA Support for Upgrade to the Multi-Platform Satellite Tropical Cyclone Surface Wind Analysis Product

PRINCIPAL INVESTIGATOR: Jack Dostalek

RESEARCH TEAM: N/A

NOAA TECHNICAL CONTACT: John Knaff

NOAA RESEARCH TEAM: Peter Keehn

PROJECT OBJECTIVES:

1) Validate the operational output by comparing it with the parallel output from CIRA. Work with NESDIS programmers to account for and/or fix differences.
2) Complete necessary documentation required by NESDIS.
3) Prepare for and present materials for teleconference reviews required by NESDIS for transition of the MTCSWA product to operations, such as the Algorithm Readiness Review, Operational Readiness Review, and the SPSRB briefing.
4) Coordinate and assist the Algorithm Scientific Software Integration and System Transition Team (ASSISTT) personnel transitioning the code to NESDIS operations.

PROJECT ACCOMPLISHMENTS SUMMARY:

Objective 4 is a general task covering all objectives 1-3. Discussions with the NESDIS team have begun on the issue of validation (Objective 1). A draft Algorithm Theoretical Basis Document has been written (Objective 2). The Algorithm Readiness Review was conducted in February 2020 (Objective 3). Sample output from the MTCSWA algorithm is shown below.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

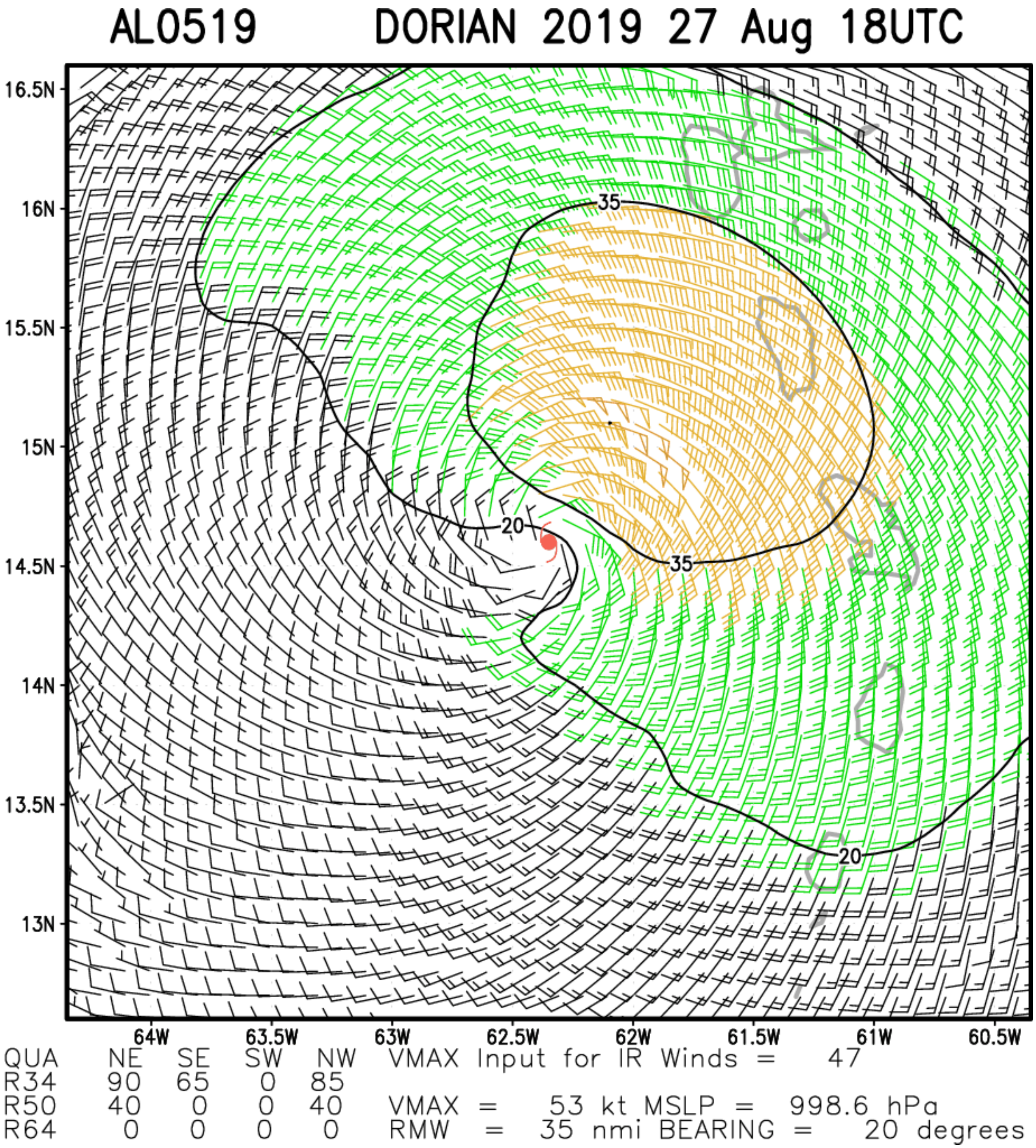


Figure: MTCSWA output for Hurricane Dorian, 1800 UTC 27 August 2019, as it moved into the Caribbean Sea after passing the Lesser Antilles.

PROJECT TITLE: A GOES-R Proving Ground for National Weather Service Forecaster Readiness and Training

PRINCIPAL INVESTIGATORS: Steve Miller

RESEARCH TEAM: Steve Miller, Jason Apke, Dan Bikos, Rosemary Borger, Renate Brummer, Galina Chirokova, Bernadette Connell, Erin Dagg, Robert DeMaria, Jack Dostalek, John Forsythe, Louie Grasso, John Haynes, Kyle Hilburn, Scott Longmore, Kevin Micke, Yoo-Jeong Noh, Andrea Schumacher, Curtis Seaman, Stephanie Stevenson, Jorel Torres, Natalie Tourville, Ed Szoke.

NOAA TECHNICAL CONTACT: Dan Lindsey NOAA/NEDSIS

NOAA RESEARCH TEAM: Donald Hillger, John Knaff, Dan Lindsey, Deb Molenar NOAA/NESDIS/StAR Kevin Scharfenberg NOAA/NWS

PROJECT OBJECTIVES:

Since its inception in 2007, NOAA's GOES-R Satellite Proving Ground (PG) program has played a central role in familiarizing forecasters and operational users of GOES-16/17 data with the new capabilities of the Advanced Baseline Imager (ABI) and the Geostationary Lightning Mapper (GLM). The PG has provided a powerful conduit for coupling NOAA's research and operational communities. In addition to establishing familiarity with GOES-R, this Proving Ground has established a human interface and rapport that will serve the program for years to come.

After GOES-R and GOES-S were launched successfully, GOES-16 and GOES-17 first-light data have been demonstrated to the community, and the various sensor data have progressed through calibration/validation, CIRA's contributions in the GOES-R Proving Ground focus changed to the direct support of NWS Weather Forecast Offices and National Centers with the display and interpretation of the GOES-16 /17 baseline products and derived products. Some of these products are "Day 2" variety (not part of the baseline "Day 1" product suite, but highly desired by forecasters) such as GeoColor. These will be referred to as Decision Aids.

Emphasis of CIRA's FY19 Proving Ground activities was placed on:

1) Close collaboration with the GOES-R Satellite Liaisons and operational forecasters
2) Transitioning of all products developed for GOES-16 to GOES-17
3) Demonstrating GOES-16/17 products within AWIPS II, within N-AWIPS where appropriate, and CIRA's SLIDER as a back-up solution,

As part of a nationally distributed team of PG algorithm developers and subject matter experts, CIRA continued to work in close collaboration with the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison, the NASA Short-term Prediction Research and Transition (SPoRT) Center located in Huntsville, Alabama, the National Weather Service Operations Proving Ground (OPG), the National Weather Service Aviation Weather Center (AWC), and a large number of operational forecasting partners involved in Proving Ground product usage and evaluation.

Nearly all CIRA PG products are made available in real-time on the CIRA web page at http://rammb.cira.colostate.edu/ramsdis/online/goes-r_proving_ground.asp. Real-time CIRA products are also available on CIRA's web application SLIDER at: http://rammb-slider.cira.colostate.edu/
This annual GOES-R Proving Ground and Training report covers CIRA Proving Ground activities conducted in the following areas:

1- GOES-R Proving Ground Activities -- CIRA Meteorological Satellite Application Group

2- GOES-R Proving Ground Activities -- CIRA Tropical Cyclone Group
3- GOES-R Proving Ground Activities -- CIRA Training Team

Project Objectives and Special Project Achievements by Project:

Project 1: GOES-R Proving Ground Activities -- CIRA Meteorological Satellite Application Group

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: (CIRA/CSU): Curtis Seaman, Yoo-Jeong Noh, John Forsythe, Louie Grasso, Kyle Hilburn, John Haynes, Jack Dostalek

NOAA TECHNICAL CONTACT: Dan Lindsey (NOAA/NEDSIS)

NOAA RESEARCH TEAM: Don Hillger, John Knaff and Deb Molenar

PROJECT OBJECTIVES:

- Continue to demonstrate GeoColor at individual WFOs and collect forecaster feedback. Make GeoColor available for NAWIPS display. Support evaluation studies to potentially make this product a “baseline” product.
- Demonstrated, and evaluate the Snow/Cloud Discrimination product at WFOs affected by winter storms. Make product available in NAWIPS to be used at AWC and other National Centers.
- Work on refinements to the DEBRA algorithm for GOES-16 and GOES-17. Transition DEBRA to AWIPS and NAWIPS.
- Develop a new color table for the ABI Split Window Difference Product and make the product available in NAWIPS.
- Evaluate the Boundary Layer PW product.
- Visit AWC, assist AWC with the evaluation of the Cloud Cover & Layers Product, make product available in NAWIPS.
- Support evaluation and demonstration of ABI-Infused Blended Total Precipitable Water Product during the HWT. Support evaluation of the ALPW product during hurricane season.
- Continue creating Synthetic Satellite Imagery from NWP in near-real time and providing it to the NWS (used in daily operations for model quality control).
- Continue evaluation of GLM performance.
- Support High-Latitude GOES-17 product demonstrations for Alaska.

PROJECT ACCOMPLISHMENTS SUMMARY:

GeoColor has gained widespread use at the NWS WFOs, as well as at the Ocean Prediction Center (OPC), National Hurricane Center (NHC), Aviation Weather Center (AWC) and the Center Weather Service Units (CWSUs). GeoColor imagery is regularly featured in materials shared by these groups on social media (Fig. 1). This product is available in AWIPS-II and NAWIPS displays. Forecaster feedback has been overwhelmingly positive. Based on a user request sent to the Satellite Product and Services Review Board (SPSRB) at NOAA/NESDIS from WFO Boulder, GeoColor is now being transitioned into operations as a “baseline” GOES-R product. The SPSRB has given a “green light” for this transition to take place. We are currently coordinating with NOAA/NESDIS and the GOES-R Program Office to determine the best path forward. The primary question is whether the algorithm will be under the responsibility of STAR or OSPO at NOAA/NESDIS.

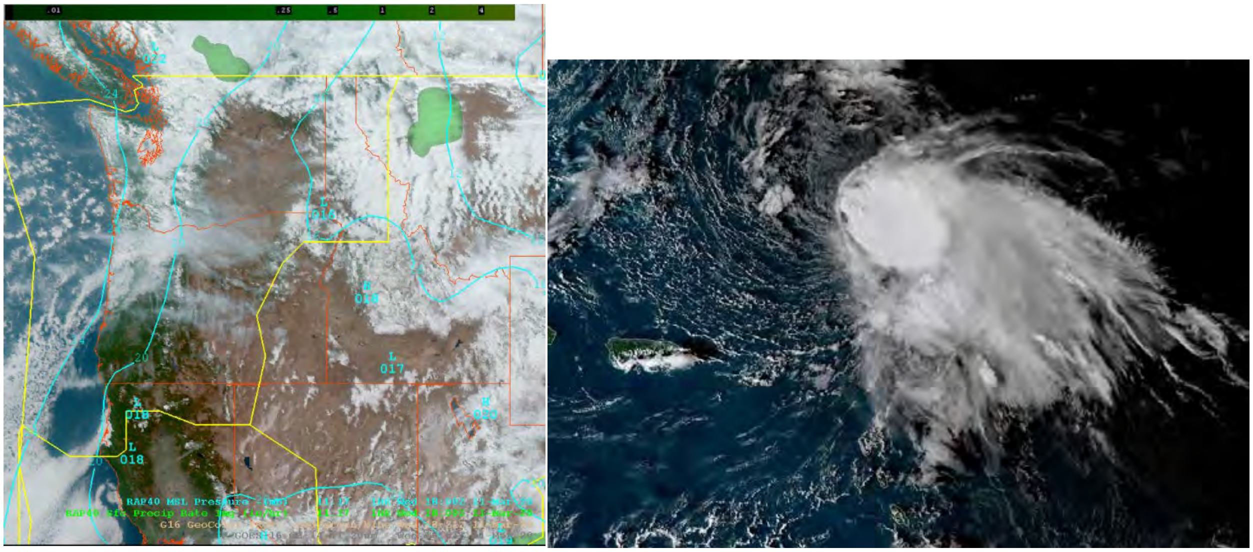


Figure 1. Left: An image shared on social media (11 March 2020) by the NWS CWSU in Seattle using GeoColor as the base with model data overlaid. Right: a GeoColor image shared on social media by NHC in an update on Tropical Storm Sebastien (20 November 2019).

On 5 December 2019, Chad Gravelle made the following comment during an AWIPS RGB telecon with Lindsey, Foster, Gravelle, Molenar, Line, Miller: "*reviewed GeoColor, noted its widespread usage…this is the future of RGB…very powerful visualization. Could transcend satellite and change the game*."

At the 2019 Joint Satellite Meeting in Boston, 30 September – 4 October 2019, six NOAA Managers highlight GeoColor as part of their presentations. These were: Stephen Volz, Louis Uccellini, Pam Sullivan, Neil Jacobs, Tim Walsh, and Lori Brown.

GeoColor was used for preparation and during the field campaign of the 2019 CAMP2Ex and 2019 PISTON ship cruise operations (20 August – 10 October 2019). These were high profile NASA/DoD field campaigns. https://espo.nasa.gov/camp2ex/content/CAMP2Ex
The CIRA team, with help from Dan Lindsey (NOAA/NESDIS), supplied a special sector for CAMP2Ex and PISTON. GeoColor imagery was used extensively by many of the forecasters for the field campaign as part of their regular forecast duties.

The Snow/Cloud Discrimination product has been re-branded as "Snow/Cloud-Layers" as it is transitioning into operational use. This product highlights snow and ice in white, low clouds in yellow, mid-level clouds in orange and high clouds in magenta (Fig. 2). CIRA is now delivering this product to NWS WFOs and National Centers via the AWIPS Local Data Manager (LDM). The Snow/Cloud-Layers product has become a favorite of the WFO in Buffalo, NY, where it is used to monitor lake effect snow events, and has been made available to all WFOs with an interest in winter weather.

Figure 2. Example of the Snow/Cloud-Layers Product shared on social media (27 February 2020).

During the reporting period, work continued on a new overlay product that combines GeoColor with dust-detection (either via the traditional split-window "12-11 micron BTD" or the DEBRA product) through a technique referred to in the Miller et al. (JTECH GeoColor paper) as "signal imprinting."
Miller, S. D., D. T. Lindsey, C. J. Seaman, and J. E. Solbrig, 2020: GeoColor: A Blending Technique for Satellite Imagery. *J. Atmos. Ocean. Tech.*, 37(3), 429-448, https://doi.org/10.1175/JTECH-D-19-0134.1.

Transitioning the existing DEBRA code from Terascan over to IDL is now completed. This transition will expedite future revisions, debugging, and innovations on DEBRA by coupling it to the powerful IDL toolkit.

The Split Window Difference Product is now available for GOES-16 and GOES-17 ABI and Himawari AHI using a standard color table (Fig. 3). Imagery for all sectors from GOES-16/17 and full disk images from Himawari are now available on the Satellite Loop Interactive Data Explorer in Realtime (SLIDER) website: http://rammb-slider.cira.colostate.edu. Transition to NAWIPS is ongoing.

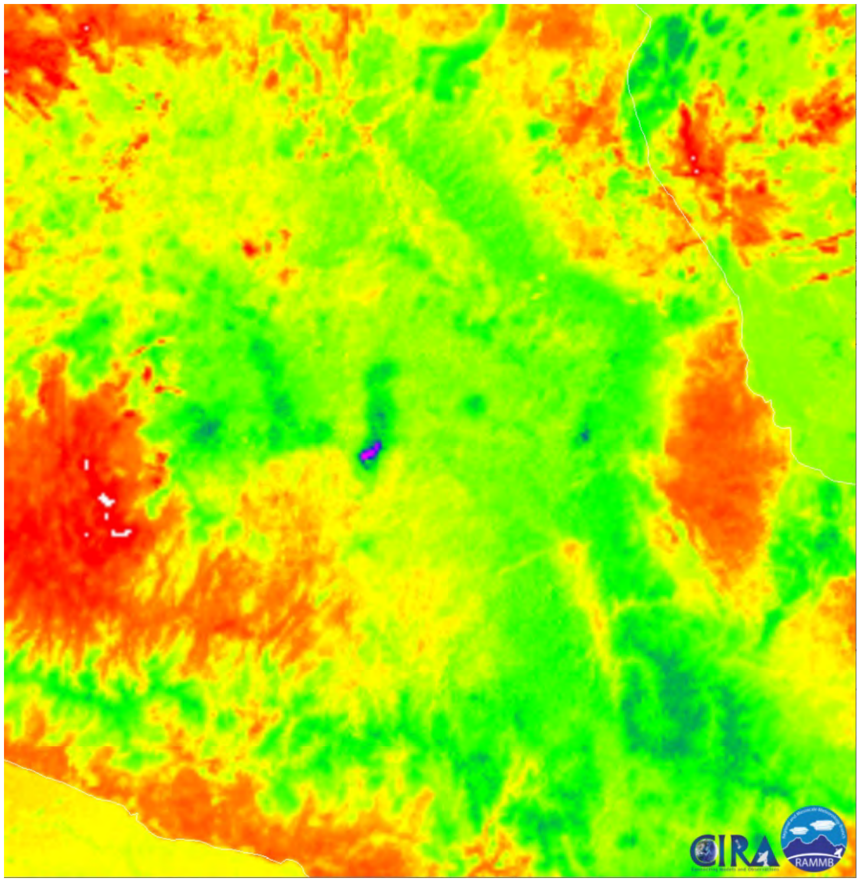


Figure 3. Example of the GOES-16 ABI Split Window Difference product. The purple spot near the center of the image is a puff of volcanic ash from the Popocatepetl volcano near Mexico City (15:21 UTC, 12 March 2020).

CIRA has developed a technique to measure low-level water vapor from the GOES ABI channels at 10.35 µm, 11.2 µm, and 12.3 µm. The product, called the Boundary Precipitable Water (BPW) product has advantages over the simple two-channel split window technique in that it retrieves an actual amount of integrated water vapor, measured in mm. In order to evaluate the BPW product, it was compared to 338 radiosondes launched over the continental United States during the summer and fall of 2019. The integrated water vapor from the radiosondes was measured from the surface to the level at which it equaled the BPW value, and the height of that level recorded. Figure 4 indicates that the lowest root mean squared error between the integrated water vapor from the radiosondes and the BPW product is 3.8 mm and occurs at 1450 m. This result is in good agreement with the hypothesis that, given the low-altitude peaks of the weighting functions of the split window channels, the product is measuring integrated water vapor in a near-surface layer.

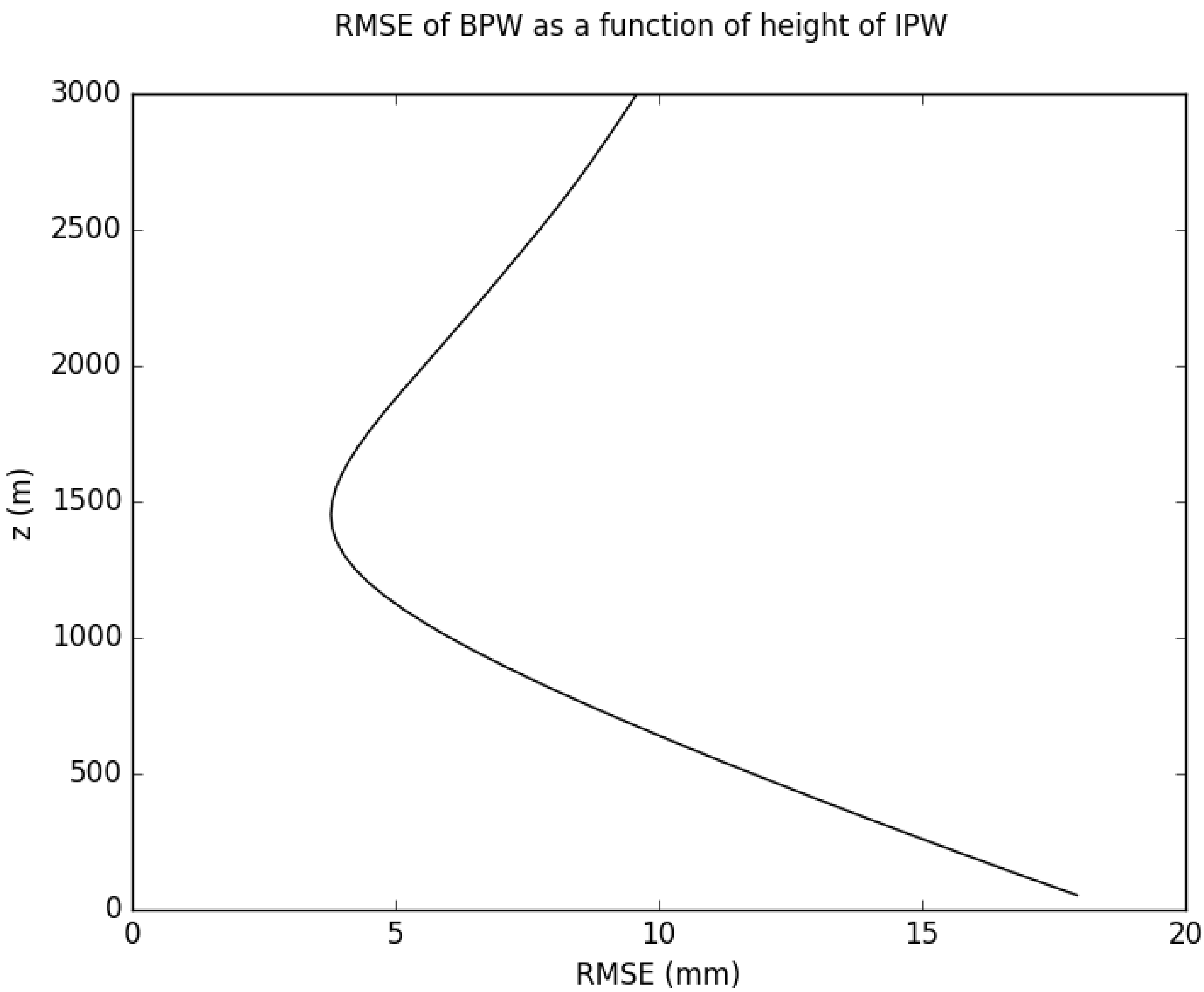


Figure 4: Root mean squared error between BPW and the integrated water vapor from 338 radiosonde launches over the United States during the summer and fall of 2019.

John Haynes visited AWC in Kansas City, Missouri, in August 2019, to discuss various aspects of this project, gather user input, and further development of an NAWIPS interface for the cloud cover layers (CCL) product. Extremely valuable insight emerged from this visit during interactions with operational forecasters, particularly with regards to how forecasters use cloud information from the ABI to aid in evaluating and forecasting aviation-related hazards, as well as how forecasters would use high-quality layered cloud information if it were available to them. Further interaction (and a visit, travel-permitting) are planned for 2020, particularly with regard to development of an NAWIPS interface for the product. In conjunction with NOAA employees at CIRA, we have developed an initial NAWIPS display for the product (Figure 5). Having now determined how to setup a data feed of this product to AWC via LDM, we are ready to engage with AWC in the best way to proceed with evaluation of this product in the first half of 2020.

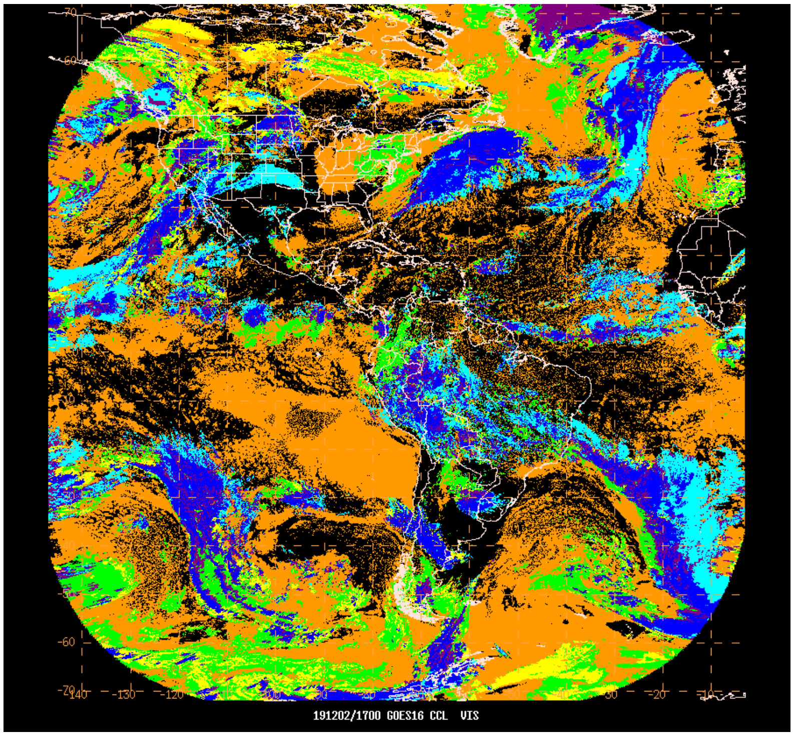


Figure 5: Initial test version of an N-AWIPS product display for CCL. Colors represent different combination of high (H), mid (M), and low (L) cloud layers.

A major project milestone was participation in the Hazardous Weather Testbed – Experimental Warning Program (6 weeks; April – June 2019) at NSSL and the Flash Flood and Intense Rainfall (FFaIR) experiment (4 weeks – June-July 2019) at WPC. At both of these experiments, near-realtime Merged Total Precipitable Water (TPW) data was provided in AWIPS-2 format, served via the CIRA LDM. Deb Molenar (RAMMB) is acknowledged for valuable technical assistance with this delivery.

A near-realtime advectively blended TPW product has been created, and is available hourly for both CONUS and fulldisk domains at http://cat.cira.colostate.edu/abi_tpw/ (CONUS) and http://cat.cira.colostate.edu/ABI_TPW_FD/ (Full disk). Advected microwave-derived TPW data from polar orbiters is first mapped onto the output grid. Then GOES-16 TPW is overlaid where clear. It is noteworthy that seams or gradients between these two datasets are not usually large, which would cause distracting artifacts and result in poor forecaster reviews. This approach allows a dominant role in the merged TPW product for GOES-R data.

At HWT and FFaIR, forecasters were posed these three questions:

1. Did the new Merged TPW product perform better than the operational blended TPW?
2. Is hourly temporal resolution sufficient?
3. Would you like a TPW product that is completely independent of model moisture fields?

A summary of the answers to these questions are shown in Figure 6. Each experiment had a different forecast application (severe weather versus flash flooding). Between 68 and 70% of forecasters rated the Merged TPW product as better than the current operational NOAA blended TPW product. It should be noted that Merged TPW currently only uses 4 polar orbiters while operational blended TPW uses 7 spacecraft. And MTPW does not avail itself of highly accurate surface-based GPS data. In the future, the advected MIMIC TPW product from CIMSS will replace the CIRA implementation of MIMIC. The next major upgrade to operational blended TPW will include the MIMIC TPW with GOES-16 augmentation. It is encouraging that a version without full utilization of the data outscores the current operational blended TPW product.

Question	2019 HWT (severe wx experiment)	2019 FFaIR (flash flood experiment)
1. Did the new Merged TPW product perform better than the operational blended TPW?	(responses = 79) 68% YES 32% NO	(responses = 80) 70% - much better 12% - better 14% - same 4% - worse
2. Is hourly temporal resolution sufficient?	(responses = 35) 60 % Yes 40 % No	responses = 25) 68% Yes 12 % No (20 % N/A)
3. Would you like a TPW product that is completely independent of model moisture fields?	(responses = 35) Yes, but - 45% No, but - 40% No definitive answer - 15%	(responses = 15) Yes - 60% No - 7% Yes and No - 7% No position - 26%

Figure 6: Summary of user comments about Merged TPW from the HWT and FFaIR experiments.

Work progressed on creating simulated GOES-16/17 channel 9 radiance simulations. The hypothesis is that cloud-free simulated radiance imagery can be created from the Advected Layer Precipitable Water (ALPW) product. ALPW is created only from polar orbiter microwave data and allows sensing of water vapor profiles in cloudy regions. The difference between measured and simulated GOES water vapor channel radiance is hypothesized to provide information on cirrus clouds. This unmasks regions where high clouds obscure the water vapor signal for forecasters and yield a “cirrus masking dry” product. An initial target application is tropical cyclone forecasting and sensing dry air in the storm environment. An example of the utility of this product for detecting the cirrus outflow around a hurricane is shown in Fig. 7.

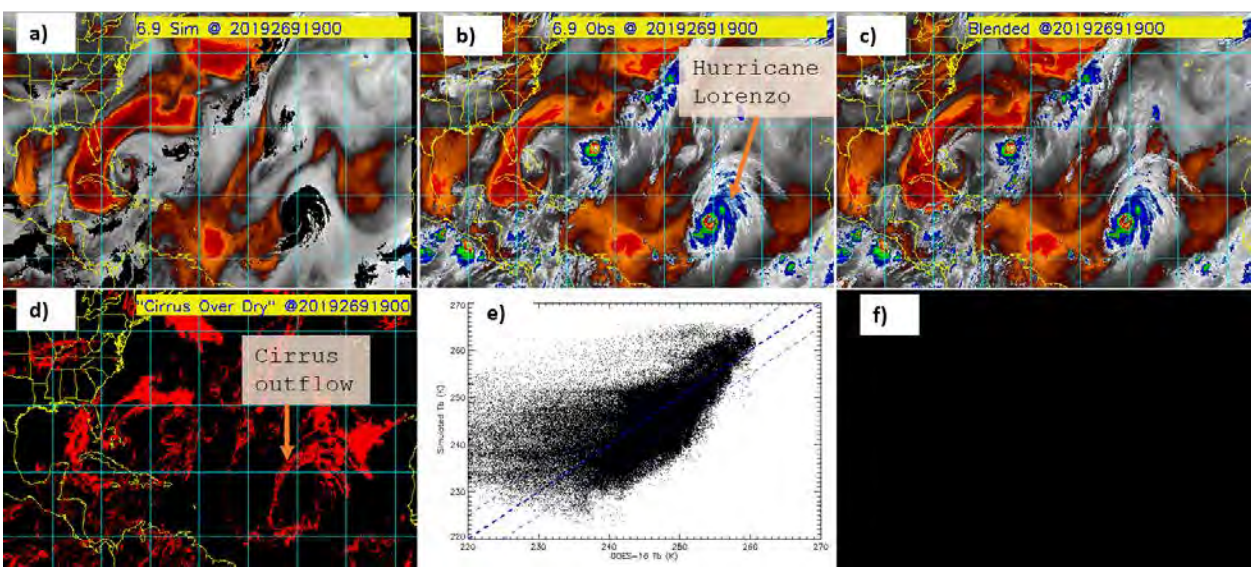


Figure 7: 6-panel plot of simulated and observed GOES-16 Channel 9 data from 1900 UTC 26 Sept. 2019. a) Simulated cloud-free brightness temperature. b) Observed brightness temperature. c) Prototype merged product, using observed but adding simulated according to the “cirrus over dry” mask

in d). Note cirrus outflow ring around Hurricane Lorenzo. e) Scatter plot of observed (x-axis) and simulated (y-axis) brightness temperatures. Tails leading to the left are cloud-impacted radiances. f) Reserved for future use.

Generation of forecast synthetic imagery from the NSSL 4 km WRF-ARW continues to provide support to forecasters. Imagery is generated each night with data from NSSL. All processing is controlled by automated routines to ensure timely output, which is displayed on-line for easy access to forecasters. Due to the success of forecast satellite imagery, CIRA has been providing forecast satellite imagery for the past nine years and will do so in the future.

We have continued our evaluation of GLM flash detection capabilities relative to Lightning Mapping Array observations, in collaboration with Steve Rutledge's group at CSU. We have found a dependence of detection efficiency on the ice water path above the flash, which is a robust result regardless of whether the estimate is based on MRMS radar profiles or ABI cloud water path retrievals. The work is in its final stages of preparation for a paper to be submitted to JGR-Atmospheres shortly for the upcoming GLM Special Collection.

GOES-17 imagery is now available to all WFOs within the Alaska Region. GOES-17 imagery is used heavily by both WFO Anchorage and WFO Juneau. Alaska Region forecasters have been involved with comparing VIIRS and GOES-17 ABI imagery related to fire detection and monitoring. Feedback received from forecasters indicates that both imagers have value - ABI for high-temporal frequency updates and VIIRS for high spatial resolution. Carl Dierking, a satellite liaison with the Geographic Information Network of Alaska (GINA) at the University of Alaska-Fairbanks, visited CIRA in July 2019. As a result of this visit, C. Dierking received training on the SO_2 RGB, which is useful for monitoring volcanic eruptions. C. Dierking assisted in the transition of the SO_2 RGB into AWIPS for the Alaska Region (Fig. 8). This RGB is now available for ABI and MODIS at all Alaska Region WFOs (it is not available for VIIRS as it requires water vapor bands) and is used by the Alaska Aviation Weather Unit (AAWU). We are currently coordinating with the NWS Alaska Region to deliver the GOES-17 Snow/Cloud-Layers product to the WFOs.

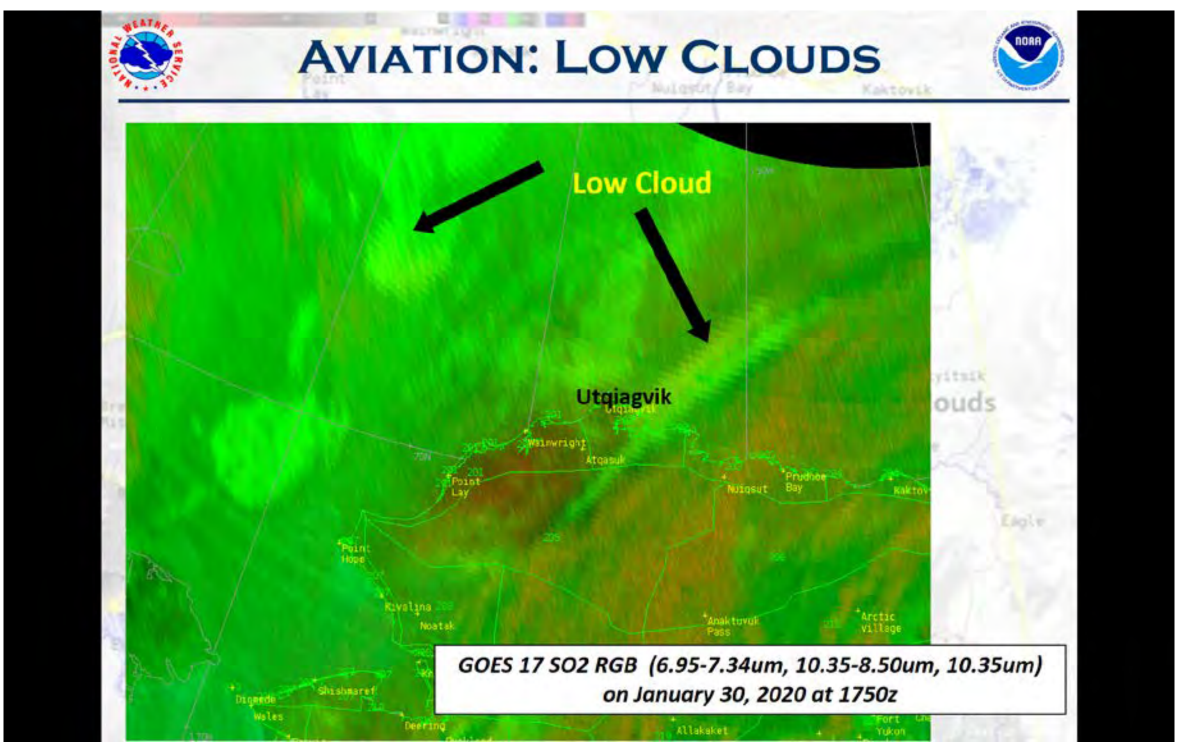


Figure 8. Example of the GOES-17 SO_2 RGB in AWIPS. Image courtesy Melissa Kreller (WFO Fairbanks).

PROJECT PUBLICATIONS:

Miller, S. D., D. T. Lindsey, C. J. Seaman, and J. E. Solbrig (2020): GeoColor: A Blending Technique for Satellite Imagery. Journal of Atmospheric and Oceanic Technology, 37(3), 429-448, doi: 10.1175/JTECH-D-19-0134.1.

Grasso, L., D. Bikos, J. Dostalek, T.-C. Wu, K. Hilburn, E. Szoke, J. Torres, J. W. Zeitler, W. E. Line, and A. E. Cohen, 2020 (in press): Application of the GOES-16 Advanced Baseline Imager: Morphology of a Pre-convective Environment on 17 April 2019. Electronic Journal of Severe Storms Meteorology.

PROJECT PRESENTATIONS/CONFERENCES:

Curtis Seaman, C. J. 2019: *SLIDER:* A website for viewing global, full-resolution satellite imagery in real-time. 10th AOMSUC, Melbourne, Australia, 2-7 December 2019.

Miller, S. D., C. J. Seaman, D. T. Lindsey, Y.-J. Noh, J. Apke, J. E. Solbrig, 2019: GOES-R ABI Research and Applications Development: Lessons Learned from Himawari-8 AHI and Practical Benefits to the Weather Forecasting Community. *Invited seminar at the Korean Meteorological Administration*, Seoul, South Korea, 15 November 2019.

Dostalek, J., L. Grasso, Y.J. Noh and D. Lindsey (2019): A Three Channel, Split Window Retrieval of Low-level Water Vapor for Convective Nowcasting. Talk, AMS 2019 Joint Satellite Conference, 29 September – 4 October 2019, Boston.

Haynes, J., Y.J. Noh, S. Miller, A. Heidinger and J. Forsythe (2019): Cloud Boundary Detection in Multilayer Scenes with the GOES ABI. Talk, AMS 2019 Joint Satellite Conference, 29 September – 4 October 2019, Boston.

Miller, S.D., D.T. Lindsey and C.J. Seaman (2019): GeoColor - Taking value-added satellite imagery to the next level in the GOES-R era, Joint AMS-EUMETSAT Meteorological Satellite Conference, 30 September-4 October 2019, Boston, MA.

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Tores and C. Seaman, 2019: An Update on CIRA's GOES-16/17 Proving Ground Efforts. Poster, 44th National Weather Association (NWA) Annual Meeting, 9-12 September 2019, Huntsville, Alabama.

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Tores and C. Seaman, 2019: Some Lessons Learned from the CIRA GOES-R Proving Ground Effort. Talk, AMS 2019 Joint Satellite Conference, 29 September – 4 October 2019, Boston.

Tourville, N., 2019: CIRA Specialized Satellite Data Products and Visualization Tools for GOES, JPSS and Himawari. AMS 2019 Joint Satellite Conference, 29 September – 4 October 2019, Boston.

PROJECT 2: GOES-R Proving Ground Activities - CIRA Tropical Cyclone Group

PRINCIPAL INVESTIGATOR: Galina Chirokova

RESEARCH TEAM: Robert DeMaria, Stephanie Stevenson

NOAA TECHNICAL CONTACT: Dan Lindsey NOAA/NESDIS/STAR

NOAA RESEARCH TEAM: John Knaff NESDIS/STAR

PROJECT OBJECTIVES:

1) Continue to make lightning-based TC Rapid Intensification Index (RII) available for the 2019 NHC PG demonstration.

2) Investigate the possibility of using channels less affected by GOES-17 heating issues to provide a version of ProxyVisible Imagery during the times when GOES-17 channels become saturated and ProxyVisible imagery is not available;

3) Adapt ProxyVisible imagery to work with 5-minute CONUS and/or 1-minute mesoscale sector for NHC PG demonstration;

4) Prepare for publication manuscript on ProxyVisible imagery.

PROJECT ACCOMPLISHMENTS SUMMARY:

1) CIRA scientists are currently in the process of re-running the lightning-based RII using WWLLN data for 2019, which is being used in complementary risk-reduction research to develop GLM-based RI predictors. ELDN data was also provided to NHC in real-time during the 2019 season at their request for comparison with GLM data.

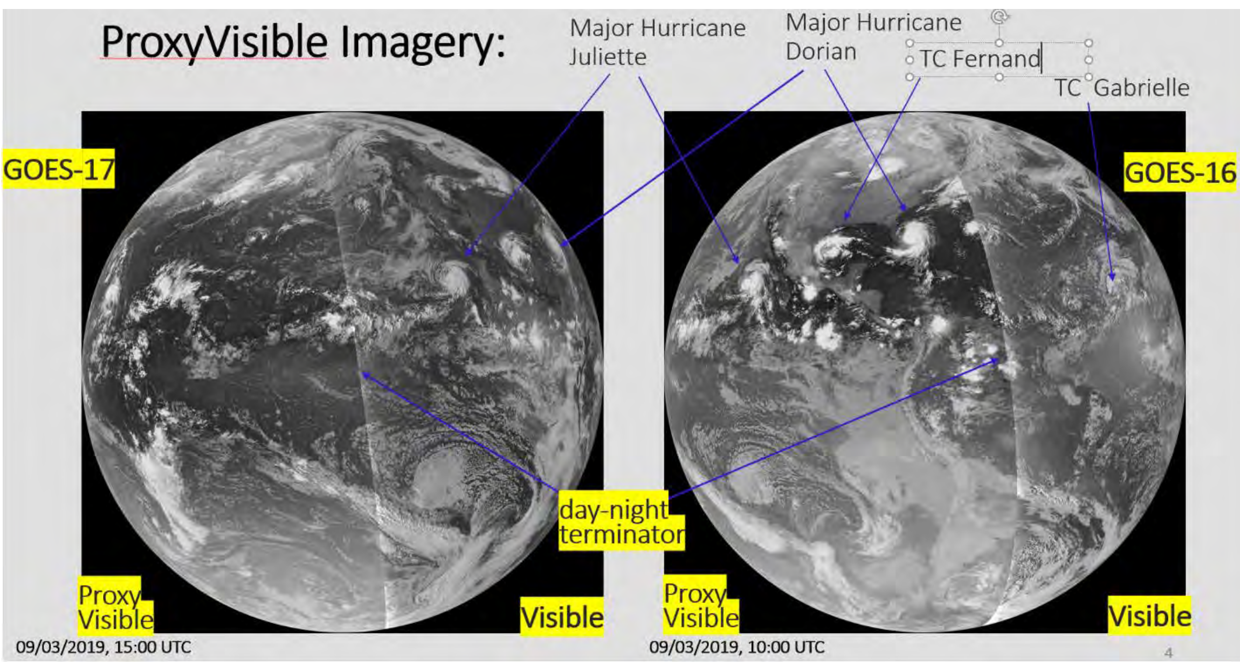


Figure 1. Example of (left) GOES-17 and (right) GOES-17 ProxyVisible imagery on 03 September 2019, at the time when there were multiple TCs in both Atlantic and east Pacific basins, including Major Hurricane Juliette, Major Hurricane Dorian, TC Fernand, and TC Gabrielle.

2) The GOES-17 version of ProxyVisible imagery has been provided to NHC by CIRA since the beginning of 2019 hurricane season, and has been used by NHC extensively, together with the GOES-16 ProxyVisible imagery. An example of GOES-16/-17 ProxyVisible imagery for 03 September 2019 is provided in Figure 1. A special version of ProxyVisible imagery that works when GOES-17 is affected by heat loop pipe issues was developed and tested on the internal version of RAMMB/CIRA SLIDER (https://rammb-slider.cira.colostate.edu). Work is in progress on making a single GOES-17 product that will use full ProxyVisible algorithm and switch to the special version when the satellite is affected by heat loop pipe issues, based on the temperature of detectors.

3) Additions to the ISATSS software, which is now used by multiple National Forecast Centers, have been developed to allow using ISATSS for display of derived ABI-based products, in addition to single ABI channels. The software was tested with GOES-16 and GOES-17 versions of ProxyVisible imagery and provided to NHC. CIRA is currently working with NHC on implementing that software on their local ISATSS machines. The ProxyVisible algorithm was optimized for ISATSS processing and display in AWIPS2. The updated version can now work with CONUS and mesoscale sectors, in addition to full disk. ProxyVisible for CONUS and mesoscale sectors will be implements at NHC after the testing and implementation of full-disk ISATSS AWIPS2 version is completed.

4) Manuscript on ProxyVisible imagery was prepared for publication and will be submitted in April 2020, after the internal review at CIRA and NHC is completed:
Chirokova, G., J. Knaff, M. J. Brennan, R. T. DeMaria, D. T. Lindsey, and D. Hillger 2020: Proxy-visible Satellite Imagery*. In preparation.*

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Chirokova G., J. Knaff, M. J. Brennan, S. Stevenson, D. T. Lindsey, S. D. Miller, R. T. DeMaria, D. W. Hillger, and D. A. Molenar, 2019: Proxy Visible Imagery and Beyond. *2019 AMS Joint EUMETSAT/AMS Satellite Conference, Boston, MA, 28-September – 04 October 2019.*

Knaff, J, C. Sampson, G. Chirokova, K. Musgrave and C. Slocum, 2019: CIRA/RAMMB Satellite and Forecast Tools, Products and Updates. *2019 Joint INDOPACOM Theater METOC Summit and Tropical Cyclone Conference, Honolulu, HI, 9-12 April 2019.*

Project 3: GOESR Proving Ground Activities -- CIRA Training Team

PRINCIPAL INVESTIGATOR: Bernadette Connell

RESEARCH TEAM: Ed Szoke, Dan Bikos, Jorel Torres, Erin Sanders

NOAA TECHNICAL CONTACT: Dan Lindsey NOAA/NESDIS

NOAA RESEARCH TEAM: Donald Hillger, John Knaff, Dan Lindsey, Deb Molena NOAA/NESDIS/StAR
Kevin Scharfenberg NOAA/NWS

PROJECT OBJECTIVES:

1--Continue close collaborations with local partner WFOs Boulder and Cheyenne

2--Continue general support of participating WFOs that receive CIRA PG products

3--Continue to collect and evaluate forecaster product feedback

4--Continue to refine and improve PG products as a result of forecaster feedback

5--Introduce potential new PG products through interaction with our WFO partners, assure that any necessary training is readily available and coordinate activities with SSD Chiefs.

PROJECT ACCOMPLISHMENTS SUMMARY:

The CIRA Training Group continued its close collaboration with nearby WFOs, particularly the Boulder WFO, which is co-located with NOAA/ESRL. In particular, Ed Szoke frequently visits the office to interact with the forecasters and answer any questions about GOES-16/17 imagery and products, both CIRA experimental products and other baseline products and RGBs. Ed also works occasional forecast shifts and presents updates at the twice yearly Boulder WFO forecaster workshops. This past year we also made a visit and workshop presentation at the Grand Junction WFO and at the Cheyenne WFO.

We also support a number of WFOs and National Centers across the nation that use one or more of the CIRA experimental products. By far the most used of these has been GeoColor, which is now at most WFOs and all the National Centers and is considered a mature product, although still not an official baseline product. GeoColor is very popular with WFOs and often used to share satellite information with the public through official WFO tweets, etc. In fact, one statistic compiled by the NOAA/NESDIS/STAR group noted that GeoColor imagery makes up 95% of the satellite web and download traffic from the public on the official NOAA satellite web page (Brown, L. et al., 2019, Poster at the AMS 2019 Joint Satellite Conference, Boston).

The other main product that is distributed to a more limited number of WFOs is the CIRA Snow/Cloud Layer Product, which discriminates snow on the ground from clouds (separated into lower (liquid) and higher (ice) clouds). During this past year baseline RGBs that also discriminate snow on the ground from clouds were found to be able to detect blowing snow. Some of the WFOs where blowing snow is a common forecast problem are also using the CIRA Snow/Cloud Layer Product in a similar manner, particularly the Cheyenne, Wyoming WFO and some of the WFOs in the Dakotas.

We interact with WFOs who are using the CIRA products both to support the product distribution to their AWIPS workstations and to gather any feedback that they may have on using the experimental products. Sometimes the use of the products is shared with other WFOs through approximate bi-monthly live webinars, which are typically led by a forecaster or forecasters at a WFO. The training group uses two blog sites to highlight the application of new satellite data and products in different weather scenarios. The blogs supporting our CIRA Proving Ground Training Activities are at:
http://rammb.cira.colostate.edu/research/goes-r/proving_ground/blog/
http://rammb.cira.colostate.edu/training/visit/blog/

The group actively participates in the Satellite Training Team weekly conference call, as well as occasional special meetings on training. The group actively participates in appropriate conferences, such as the National Weather Association's Annual Meeting, which typically attracts a large number of operational forecasters. This past year the group also had presentations at the AMS 2019 Joint Satellite Conference, held in October 2019 in Boston (see photo below).

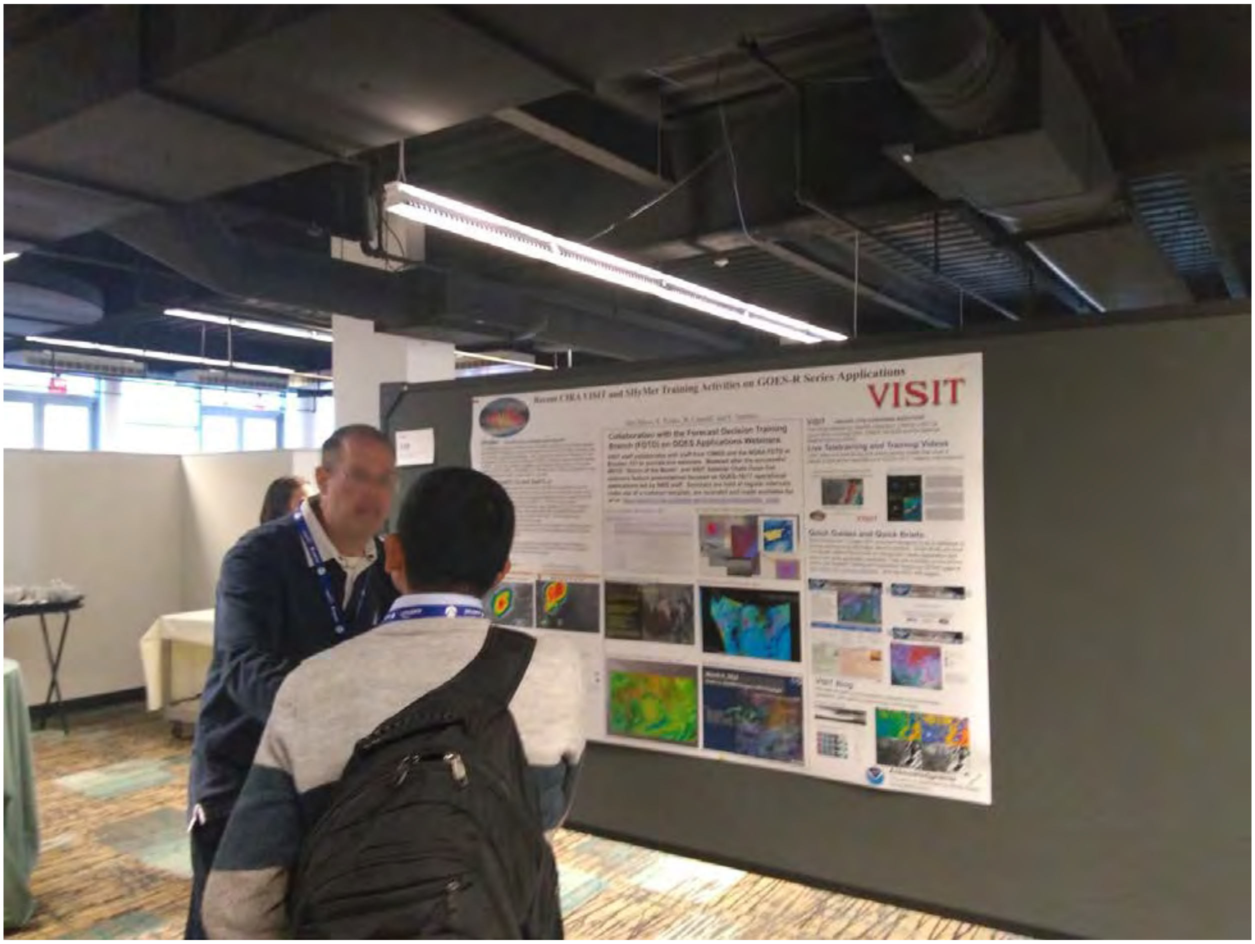


Figure 1: Dan Bikos (CIRA Training Team) presenting a research poster at the AMS/EUMETSAT 2019 Joint Satellite Conference, held in October 2019 in Boston, MA.

PROJECT PUBLICATIONS:

Grasso, L., D. Bikos, J. Dostalek, T.-C. Wu, K. Hilburn, E. Szoke, J. Torres, J. W. Zeitler, W. E. Line, and A. E. Cohen, 2020: Application of the GOES-16 Advanced Baseline Imager: Morphology of a Pre-convective Environment on 17 April 2019. Electronic Journal of Severe Storms Meteorology. *In press*

PROJECT PRESENTATIONS/CONFERENCES:

Bikos, D., E. Szoke, B. Connell, and E. Sanders 2019: Recent CIRA VISIT and SHyMet Training Activities on GOES-R Series Applications. Poster, *2019 AMS Joint EUMETSAT/AMS Satellite Conference, Boston, MA, 28-September – 04 October 2019.*

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Tores and C. Seaman, 2019: Some Lessons Learned from the CIRA GOES-R Proving Ground Effort. Talk, *2019 AMS Joint EUMETSAT/AMS Satellite Conference, Boston, MA, 28-September – 04 October 2019.*

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Tores and C. Seaman, 2019: An Update on CIRA's GOES-16/17 Proving Ground Efforts. Poster, 44th *National Weather Association (NWA) Annual Meeting, 9-12 September 2019, Huntsville, Alabama.*

PROJECT TITLE: CIRA support to ATMS Precipitable Water Algorithms and Products (MIRS)

PRINCIPAL INVESTIGATORS: John Forsythe

RESEARCH TEAM: Stan Kidder, Andy Jones

NOAA TECHNICAL CONTACT: Lihang Zhou (NESDIS/OSPO), Limin Zhao (NOAA/NESDIS/OSPO)

NOAA RESEARCH TEAM: Limin Zhao (NOAA/NESDIS/OSPO), Ralph Ferraro (NOAA/NESDIS/STAR)

PROJECT OBJECTIVES:

This project began in August 2016 with yearly renewals and has the goals of monitoring and validating the NESDIS operational blended rain rate (BRR) and blended total precipitable water (TPW) and TPW anomaly products. In this year, the focus has been on NOAA-20 products, but the blended products use many satellite sensors (SNPP, GCOM-W, NOAA-19, MetOp-A/B, GPM), blended rain rate also uses DMSP F-17/18. Surface-based GPS data from roughly 500 sites / hour is used over CONUS. Therefore the final blended products are also monitored as a whole, as this is what forecasters see. Supporting NESDIS to ensure timely delivery of high-quality blended satellite hydrometeorology products to forecasters is the overall goal of the project.

PROJECT ACCOMPLISHMENTS SUMMARY:

The team supported the NOAA-20 Operational Readiness Review (ORR) in May 2020, and NOAA-20 products were approved and added to the operational system. To support ORR, validation of NOAA-20 TPW against surface-based GPS and novel ocean TPW measurements from the NASA Orbiting Carbon Observatory-2 (OCO-2) were performed. The NOAA-20 performance looked very similar to SNPP which was expected. The Algorithm Theoretical Basis Documents (ATBDs) for operational blended rain rate and blended TPW were updated by CIRA and delivered to OSPO in July 2019. The team explored different quality flagging options, striking a balance between overall accuracy and missing data. Monthly telecons with the NESDIS management team occurred to allow troubleshooting of any issues and discussion of future blended product improvements.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Forsythe, J. M., S. Q. Kidder, S. Kusselson, A. Jones, D. Bikos, E. Szoke, 2019: Improving Blended Total Precipitable Water Products for Forecasters Via Advection and Inclusion of GOES-R. Oral presentation at AMS / EUMETSAT Joint Satellite Conference. Boston, MA, Oct. 2019.

PROJECT TITLE: CIRA Support to Connecting GOES-R with Rapid-Update Numerical Forecast Models for Advanced Short-Term Prediction and Data Fusion Capabilities Connecting GOES-R High Resolution Temporal Information with Rapid Updating Models

PRINCIPAL INVESTIGATORS: Chris Kummerow

RESEARCH TEAM: Kyle Hilburn, Steven D. Miller

NOAA TECHNICAL CONTACT: Satya Kalluri, Steve Goodman

NOAA RESEARCH TEAM: Dan Lindsey, Stephen Weygandt, Curtis Alexander

PROJECT OBJECTIVES:

The main objective of our project is to use the high-resolution temporal information from the Advanced Baseline Imager (ABI) and Geostationary Lightning Mapper (GLM) on the GOES-R Series to improve short-term forecasts of high impact weather hazards. During the last year, machine learning (ML) techniques have taken center stage in this project as we have come to realize their power and understand their proper usage. In fact, it turns out that ML is absolutely *essential* for this application: visible and infrared radiance information content saturates in precipitating scenes and this has been the historical roadblock for using these observations in data assimilation or precipitation applications. Moreover, we have demonstrated that convolutional neural network (CNN) architectures provide not just incremental, but *breakthrough* improvement in the skill of GOES-R for precipitating scene characterization. Using a novel analysis methodology, we have been able to open the "black box" that is our ML algorithm and demonstrate that GOES-R skill comes from using information in infrared image gradients and the presence of lightning. We want to acknowledge that Imme Ebert-Uphoff from CSU Department of Electrical and Computer Engineering joined CIRA to promote the usage of machine learning (ML) techniques applied to satellite and model data. While she is not technically part of this project, we have had many stimulating discussions with her that have provided new insights and inspirations for this work.

PROJECT ACCOMPLISHMENTS SUMMARY:

There are two primary strategies for assimilating satellite information in numerical weather prediction (NWP) models:

- **Radiance assimilation** is physically based (easy to interpret), but individual pixel information content saturates around optical depths of 160(8) during day(night), which corresponds to composite reflectivity (REFC) of 20-25(0-5) dBZ. Radiance assimilation is not capable of handling lightning information.
- **Machine learning** is statistically based (harder to interpret), but image gradients and spatial context provide reliable information to about 45 dBZ and it provides framework for using lightning information (data fusion).
-

The Rapid Refresh Forecast System (RRFS) that encompasses RAP and HRRR has long used radar reflectivity to estimate latent heating in order to spin-up convection in the models. (*Benjamin et al., 2016*). Thus, our strategy has been to transform GOES observations into radar reflectivity fields, from which latent heating (that is consistent with RAP/HRRR microphysics) is inferred using the existing GSD cloud analysis package in the WRF/GSI code.

During daytime, *Hilburn et al. (2018)* has demonstrated that the channels going into the Day Cloud Microphysics product (visible 0.64 µm, near-IR 2.2 µm, and longwave IR 10.3 µm) provide the most skill for precipitation applications. Unfortunately, the Nighttime Microphysics product has suboptimal performance, which we believe may be due to use of the split window difference in the Red Component and longwave-shortwave difference in the Green Component, leading to noisy red/yellow speckle over large areas of thunderstorm anvils. Since we seek a unified Day-Night algorithm, we are using the Advanced Baseline Imager (ABI) channels:

- Channel 7, 3.9-micron, shortwave infrared window
- Channel 9, 6.9-micron, mid-level water vapor (~442 mb)
- Channel 13, 10.3-micron, clean longwave infrared window

From GOES-16 Geostationary Lightning Mapper (GLM), we are using the group extent density accumulated over 15-minutes because it provides more “filled in” maps than using flashes. The GOES data are trained to the Multi-Radar Multi-Sensor (MRMS) Quality-Controlled Composite Reflectivity. All fields are resampled to 3-km Lambert Conformal Conic HRRR grid.

Figure 1 (left panel) provides a depiction of our model architecture, which is a sequential structure based on the U-Net. Unlike a U-Net, skip connections are turned off: they provide only very small improvements but complicate model visualization. The model has 3 encoding and decoding layers, and we found that deeper networks produce overfitting. Note that overfitting is a function of region size, number of samples, and depth of network. The network width has a constant 32 filters per layer, doubling filters among layers did not provide additional useful skill. Using fewer filters (16) does nearly as well in the overall statistics but gives noticeably blurrier output. We used convolutional blocks of the form CP, because CCP blocks doubles the number of parameters making overfitting more likely. Training with 100 epochs yields the validation statistics: RMSD = 5.29 dBZ and R^2 = 0.738.

An important consideration in training the NN is the loss function since radar reflectivity fields suffer from a class imbalance issue. The standard unweighted MSE loss function has sub-optimal performance at high REFC (**Figure 1, right panel**). High radar reflectivity values are relatively less common: if *y* represents the scaled radar reflectivity (scaling 0-60 dBZ linearly into the range 0-1), then the probability density function closely follow $P(y) \propto e^{-5y}$s. We developed a novel method of using a performance diagram to select loss function weights that produce the minimum categorical bias. While minimizing the categorical bias does not guarantee that the results will also have maximal critical success index, we found that in practice this was the case. This approach is related to using the Area-Under-the-Curve as a loss function but avoids the problem of derivatives not existing for a discontinuous function. Our approach also acts as a global constraint on realism of the resulting fields. We define loss function weights according to a generalized exponential: $Wt = e^{by^c}$ and then vary *b* and *c* in a grid search to find the optimal values. In order to get reliable results, we also train several versions of the model (20 versions) that differ only in their random seeds. While the intuitive 1/PDF weights would give *b*=5 and *c*=1, we find the minimum categorical bias weights are *b*=5 and *c*=4 for the MSE (mean-square-error) loss and *b*=5 and *c*=3 for the MAE (mean-absolute-error) loss. This suggests there is a way to choose coefficients from first principals based on the PDF but note that the best results require a much heavier weighting of the high values than would be implied by direct usage of the inverse of the PDF.

Figure 2 compares MRMS with the NN prediction using GOES for a validation sample not used in training. The NN does an excellent job of reproducing the structure of the REFC field and is able to accurately locate convective core features. Traditional infrared retrievals of precipitation have not shown such skill, and so these results raise the question of exactly how can a NN perform so well? After all, the information content in infrared radiances (individual pixels) saturates around a REFC value of about 25 dBZ. So, using different experiments (channel withholding, 1x1 filters, and synthetic inputs) along with attribution methods (such as layer-wise relevance propagation), we were able to determine that gradients in infrared radiances provide a great deal of information about high REFC values. Lightning is also key in pinpointing high REFC values, and additionally we found that lightning information changed how the NN interpreted the radiance gradients, giving more clues to the NN about where to look and how to interpret the gradients.

References

Benjamin, S. G., and others, 2016: A North American hourly assimilation and model forecast cycle: The Rapid Refresh. *Mon. Wea. Rev.*, **144**, 1669-1694, doi: 10.1175/MWR-D-15-0242.1.

Hilburn, K., M. Marchand, Y. Lee, C. Kummerow, and C. Alexander, 2018: Using GOES-16 to improve short term forecasts. American Meteorological Society 98th Annual Meeting, Austin, TX.

PROJECT PUBLICATIONS:

Hilburn, K. A., S. D. Miller, and I. Ebert-Uphoff, 2020: Using machine learning to derive synthetic radar reflectivity from GOES-R Series Advanced Baseline Imager (ABI) and Geostationary Lightning Mapper (GLM) for convective scale forecasting applications. *J. Appl. Meteor. Climatol.*, *in preparation*, to be submitted by 31-March-2020 for inclusion in the NOAA ML Special Collection.

PROJECT PRESENTATIONS/CONFERENCES:

Hilburn, K., S. Miller, M. Marchand, and A. Libardoni, 2019: Using High-Resolution Observations from GOES-16 to Improve Operational Short-Range Forecasting. *AMS/EUMETSAT/NOAA Joint Satellite Conference*, Boston, MA, 2-Oct.

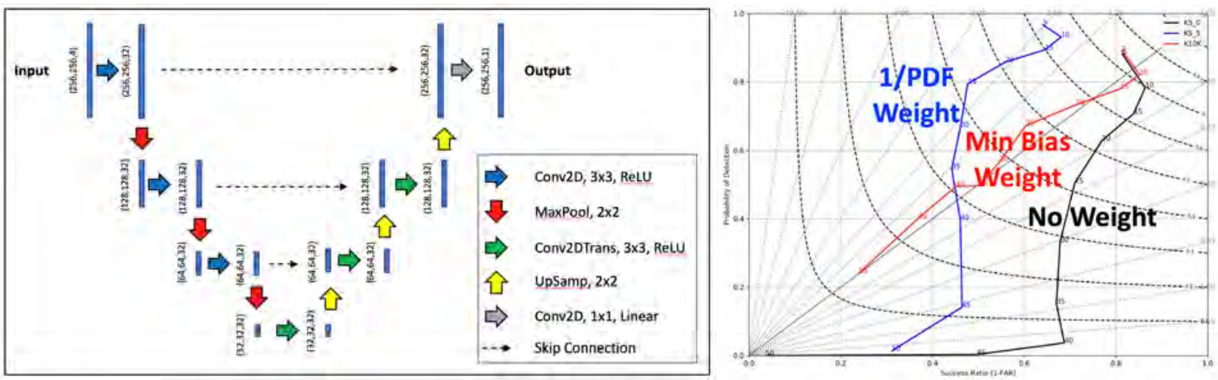


Figure 1. (Left) Our U-Net architecture has 47,457 trainable parameters. **(Right)** Performance diagram for a standard MSE loss function (black), 1/PDF weighted MSE loss (blue), and the minimum categorical bias weighted MSE loss (red) for 0, 5, 10, …, 50 dBZ categories.

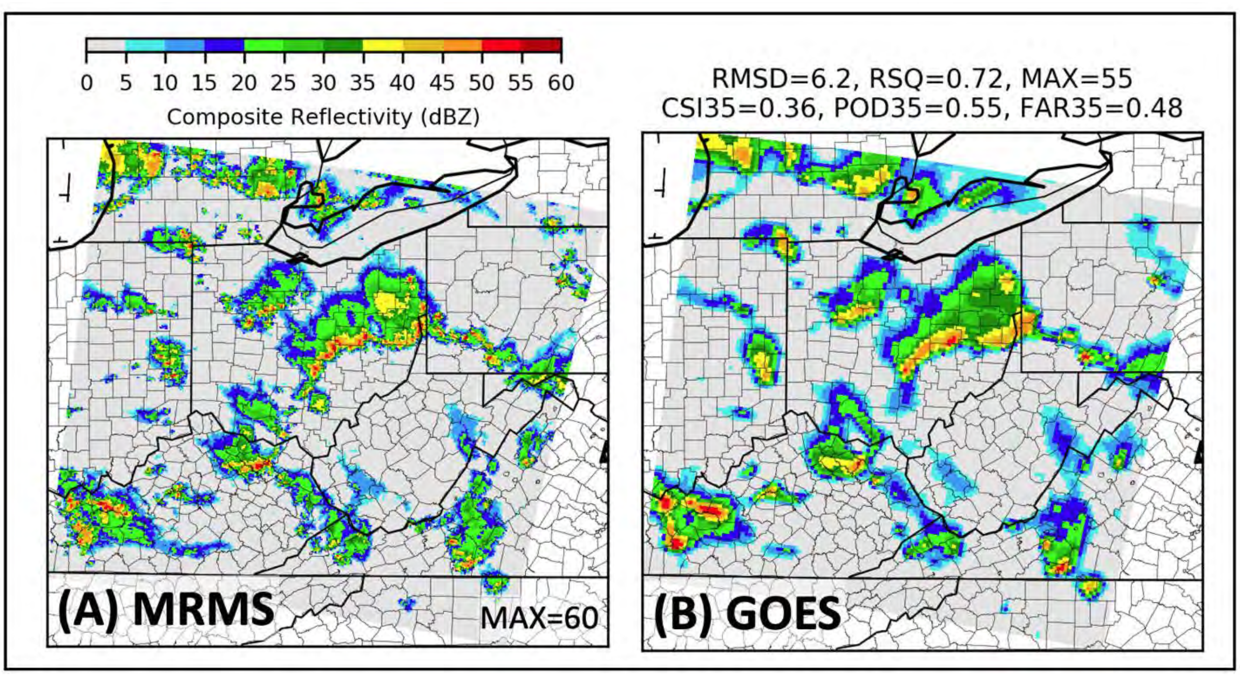


Figure 2. Validation sample (2019-07-02 23:30Z) comparing **(A)** MRMS composite reflectivity with **(B)** machine learning prediction from GOES. The title for panel **(B)** gives the statistics: root-mean-square-difference (dBZ), coefficient of determination R^2, maximum REFC (dBZ), 35-dBZ critical success index, 35-dBZ probability of detection, and 35-dBZ false alarm rate.

PROJECT TITLE: CIRA Support to Connecting GOES-R with Rapid-Update Numerical Forecast Models for Advanced Short-Term Prediction and Data Fusion Capabilities

PRINCIPAL INVESTIGATOR: Christian Kummerow

RESEARCH TEAM: Kate Musgrave, Chris Slocum, Alex Libardoni

NOAA TECHNICAL CONTACT: Dan Lindsey

NOAA RESEARCH TEAM: John Knaff

PROJECT OBJECTIVES:

In Year 3, we will expand upon the research done in Year 1 and Year 2 by working on numerical model representation of tropical cyclones and developing enhanced tropical cyclone oriented statistical-dynamical forecasting aids using GOES-R products.

- Examine the initial spin-up and spin-down during the first 24 hours in HWRF short-term forecasts and the effects of the initialization.
- Continue work on assimilation of various GOES-R TC-related products into numerical models to better initialize the primary TC vortex. Leverage and contribute to tropical cyclone work conducted at our sister cooperative institutes.
- Explore the development of a version of the RII that refreshes more frequently (3-hourly, hourly).
- Assess if the techniques developed for the midlatitude project can be applied to HWRF in connection to landfalling TCs to better forecast the exact locations where strong convective elements may superimpose on the TC flow.

PROJECT ACCOMPLISHMENTS SUMMARY:

HWRF data assimilation and vortex initialization:

- HWRF experiments in TC vortex initialization using the MTCSWA derived surface wind field and TC evolution over initial 24 hours being conducted
  - **HWRF DA Experiments (see Figure 1):**
    - *Control*
    - *MTCSWA wind 0 to 750 km*
    - *MTCSWA wind 250 to 750 km*
    - *MTCSWA central pressure only*
    - *MTCSWA wind 250 to 750 km plus central pressure*
  - **Verification:**
    - *Best-track track & intensity*
    - *Wind field to TCWA and SAR wind data from IFREMER*

SHIPS-R2I2:

- Update GOES predictors on an hourly basis to catch sudden changes in the TC

SHIPS-RII:

- GLM-based lightning SHIPS-RII
  - In collaboration with Stephanie Stevenson
  - Code to be transitioned to NHC in early-May

Large ice signature:

- Paper quantifying the large ice signature in overshooting tops

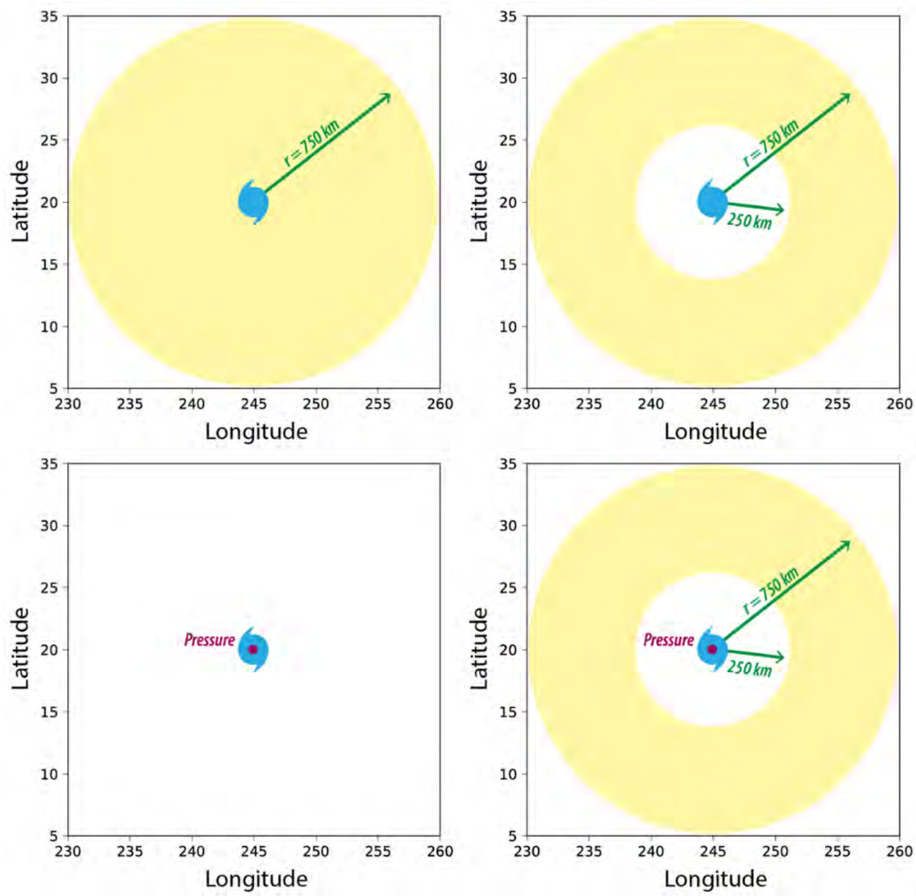


Figure 1. Schematic for experimental design for testing TC vortex initialization with MTCSWA in HWRF.

PROJECT PUBLICATIONS:

Slocum, C. J. and J. A. Knaff, 2019: Is GOES-R seeing "hottish" convective towers in hurricanes? *Bull. Amer. Met. Soc.*, 100, 733.

Slocum, C. J. and J. A. Knaff, 2020: Are the large ice crystals at cloud top the signatures of "hottish" convective towers? *In prep.*

Slocum, C. J. and S. Stevenson, 2020: SHIPS-RII using GLM data. *In Prep.*

PROJECT PRESENTATIONS/CONFERENCES:

Slocum, C. J. and J. A. Knaff, 2019: What Are the Cloud-Top Microphysical Properties of Tropical Cyclones Telling Us about Intensification? AMS Joint Satellite Conference. Boston, MA. 16B.5.

PROJECT TITLE: CIRA support to Metop-C Readiness for Blended Hydrometeorological Products

PRINCIPAL INVESTIGATOR: Andrew Jones

RESEARCH TEAM: Stan Kidder and John Forsythe

NOAA TECHNICAL CONTACT: Limin Zhao

NOAA RESEARCH TEAM: Limin Zhao, Walter Wolf, Ralph Ferraro, and others

PROJECT OBJECTIVE:

Update the operational Blended Total Precipitable Water (TPW) and Rain Rate (RR) products with Metop-C capabilities in real time at ESPC. Blended TPW and RR products will be operationally generated at ESPC via the CSU BTPW and BRR “Blended-Hydro” system. This work will add the new NOAA Metop-C Microwave Integrated Retrieval System (MiRS) products as additional inputs to the CSU Blended-Hydro product suite to enable use of the new Metop-C capabilities. The MiRS system ingests passive microwave radiances from a variety of sensors and retrieves atmospheric moisture, temperature and hydrometeor profiles. Among many retrieved atmospheric variables, MiRS-derived total precipitable water (TPW) and rain rate (RR) are used in multisatellite blended products to create analysis fields for National Weather Service (NWS) forecasters. This work assimilates the new Metop-C MiRS products as inputs into the operational multi-satellite CSU Blended-Hydro products.

This project is Year 2 of a 2-Year Project, whose first year started in 2018 under the old NOAA CIRA Cooperative Agreement. Year 2 is in the new NOAA CIRA Cooperative Agreement. Only objectives and accomplishments for the Year 2 reporting period are shown below.

PROJECT ACCOMPLISHMENTS SUMMARY:

Completed CIRA general tasks and milestones by objective for this performance period (1-Jan-2019 – 31-Dec-2020):

- Jul 19: Development Phase Continues
  - ✓ Jul 19: First Metop-C MiRS test data available.
  - ✓ Aug 19: Test software for processing near real-time Metop-C data at CIRA.
  - ✓ Sep 19: Near-realtime ingest of Metop-C MiRS experimental data completed at CIRA
  - ✓ Oct 19: Test case processed for TPW and RR
  - ✓ Nov 19: Initial comparison of Metop-C with other blended products
  - ✓ Dec 19: Recommend any additional readiness modifications for Metop-C.

Future project objectives and milestones for the next annual reporting period:

- Jul 19: Development Phase Continues (continues list from above)
  - ✓ Jan 20: Movement of CIRA blended products to use the new operational Metop-C MiRS data flows, as NDE system is ready to receive the new algorithms (this task was expedited with the use of OSPO-based testing of CIRA delivered software).
  - ✓ Jan 20: Code is prepared for implementation & Software code review held, with final DAP deliverable forwarded to the NDE implementation team
  - – Feb 20: Operational and backup processing defined
  - – Mar 20: Continue to support the NDE implementation team with technical telecon support (in progress)

- Jan 20: Pre-Operational Phase Begins

- Jan 20: Operational and backup processing capabilities in place
- Feb 20: Pre-operational product output evaluated & tested
- Mar 20: Code transitions to operations; all documentation is complete (e.g., ATBD updated)
- Apr 20: Operational and backup capabilities reach ops status
- May 20: Operational Readiness Review (check list review)*
- Jun 20: Brief OSPO, capability is ready for operation

*Actual operational dates are subject to NOAA review, approvals, and scheduling needs.

- Jun 20: Operational Phase Begins
  - Jun 20: SPSRB manager and secretaries notified update/upgrade went into operation
    - SPSRB Secretaries/manager update the SPSRB product metrics web pages
    - OSD updates Satellite Products database

* Pending Metop-C MiRS products operational status

We coordinate with the OSPO team on schedules, code reviews, and data issues during our monthly telecons.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Support to the JPSS STAR Science Program: S-NPP/NOAA-20/JPSS VIIRS EDR Imagery Algorithm and Validation Activities and S-NPP/NOAA-20/JPSS VIIRS Cloud Validation

PRINCIPAL INVESTIGATOR**:** Steve Miller

RESEARCH TEAM: Yoo-Jeong Noh, Curtis Seaman, Matt Rogers, Louie Grasso, Galina Chirokova, Steve Finley, Natalie Tourville, John Forsythe, Jorel Torres

NOAA TECHNICAL CONTACT: Satya Kalluri, Andy Heidinger (NOAA/NESDIS/StAR)

NOAA RESEARCH TEAM: Don Hillger, Bill Line, Deb Molenar, Andy Heidinger - (NOAA/NESDIS/StAR)

PROJECT OBJECTIVES:

The Suomi National Polar-orbiting Partnership (S-NPP) mission, a risk-reduction mission to the Joint Polar Satellite System (JPSS), was launched successfully on 28 October 2011. The first in the follow-on JPSS-series was launched on 19 November 2017 as NOAA-20. The Visible/Infrared Imager/Radiometer Suite (VIIRS) on board S-NPP and NOAA-20 provides atmospheric, cloud, and surface imagery for both weather and climate applications. Evaluation of VIIRS imagery and retrieved cloud product performance vis-à-vis mission stated requirements for those parameters is the emphasis of this work.

This Annual Report covers two JPSS Cal/Val projects:

Project I: The S-NPP/NOAA-20/JPSS VIIRS EDR Imagery Algorithm and Validation Activities, and
Project II: The S-NPP/NOAA-20/JPSS VIIRS Cloud Validation Activities.

These JPSS VIIRS cal/val projects directly addressed NOAA's *Weather and Wate*r goal, which seeks to serve society's various needs for weather and water information. This research falls within the NOAA-defined CIRA thematic area of *Satellite Algorithm Development, Training and Education*, as cal/val is an integral and critical first step in the algorithm performance evaluation process. Outcomes of the current research may in some cases lead to modifications to the original algorithms to correct any issues discovered along the way.

This research is part of a larger S-NPP / JPSS-1 / NOAA-20 VIIRS program coordinated within NESDIS/StAR. Results of this research will be presented at annual scientific conferences in partnership and coordination with the JPSS/VIIRS Calibration/Validation Teams. In addition, the CIRA Team achievements will be summarized in technical reports which will be delivered to NOAA and which will also be available on-line.

Project I: Support of the VIIRS Imagery Validation Activities

During FY19, CIRA continued its work on tasks which began successfully in the previous year. The utilization of VIIRS Imagery, as a Key Performance Parameter (KPP), is critical to S-NPP/NOAA-20 success. With VIIRS data being received in near real-time, operational-phase validation activities are important measures of successful utilization of the VIIRS data stream. NOAA-20 data validation was conducted now that the satellite had been launched and the first data became available to the EDR Imagery Team.

Research Objectives:

CIRA's FY19 subtasks focused on supporting the EDR Lead for Imagery checkout activities.

1) Analyze and report on the VIIRS Imagery EDR software, Imagery, and products produced from imagery, providing interesting Imagery examples on a quasi-monthly basis and occasional additions to CIRA's VIIRS blogs. *(Jul 2019 – Jun 2020)*

2) Document any EDR software and Imagery issues encountered during analyses, whether in the image data, or products derived from that imagery and/or SDRs. *(Jul 2019 – Jun 2020)*

3) Continue to contribute to StAR Long Term Monitoring (LTM) website, with Imagery products over either CONUS or Alaska. *(Jul 2019 – Jun 2020)*

4) Support the work on completion of the NOAA-20: Gain Value Versus Scene Solar Elevation (GVVSSE; or "Goosey") and Gain Value Versus Scene Lunar Elevation (GVVSLE) Look-up Tables (LUT), used in the Near-Constant Contrast (NCC) imagery product derived from the VIIRS Day/Night Band. *(Jul 2019 – Jun 2020)*

5) Support work toward completion of the Terrain Correction (TC) geo-locations for Imagery EDRs. Evaluate performance and make recommendation on ancillary data (e.g., angle information) conformance to the TC dataset. *(Jul 2019 – Jun 2020)*

6) Enable on-site (CIRA) implementation of Government Resources for Algorithm Verification, Independent Test and Evaluation (GRAVITE) Algorithm Development Library (ADL).
(Jul 2019 – Jun 2020)

7) Continue to contribute to the cal/val checkout and display of VIIRS imagery and multispectral, using Polar SLIDER: http://rammb-slider.cira.colostate.edu/?sat=jpss *(Jul 2019 – Jun 2020)*

8) Present research results at annual JPSS Science meetings and national/international conferences, publish results in refereed journals. *(Aug 2019 – Jun 2020)*

9) Provide monthly reports on the VIIRS Imagery EDR Team activities. *(Jul 2019 – Jun 2020)*

Achievements:

1) The JPSS EDR Imagery Team holds regular monthly meetings/teleconferences and discusses the VIIRS Imagery EDR software. These meetings involve all available project participants from CIRA, NOAA/NESDIS/StAR, CIMSS, NCEI, NRL, NGAS, and Aerospace. The purpose of these meetings is to discuss recent Team activities, updates from the JPSS Program Office including changes to the operational software, recent anomalies with the VIIRS instrument or upcoming planned data outages (if any), and coordinate calibration and validation activities with the VIIRS SDR Team. Imagery Team Lead is D. Hillger.

   VIIRS Imagery blogs are regularly produced by CIRA Team Members C. Seaman and J. Torres.
   Postings can be found on the CIRA-RAMMB SNPP blog page:
   http://rammb.cira.colostate.edu/projects/npp/blog/
   and on the CIRA-RAMMB Alaska blog page at:
   http://rammb.cira.colostate.edu/projects/alaska/blog/
   There were 5 CIRA-RAMMB SNPP postings over the last year
   20 Feb 2020: "Ice behavior in the Arctic"
   4 Feb 2020: "Effect of Gough Island on lee waves seen in the clouds"
   18 Nov 2019: "Australia on Fire"
   15 August 2019: "Ross Island – Antarctica"
   28 March 2019: "Tropical Cyclone Idai"
   There was also one VIIRS Arctic blog on 29 May 2019: "A four-birds-eye view of fires in Alberta.

   In addition, Bill Line is posting very regular Satellite Liaison blogs at https://satelliteliaisonblog.com/

2) Imagery issues encountered during analyses are being discussed in detail during the monthly meetings. Imagery examples, highlighting the problem, are being examined. Imagery Team Lead D. Hillger submits weekly and quarterly reports to the JPSS Program Office on Team activities.

3) "Image of the Month" examples continue to be provided for the JPSS StAR website. VIIRS Imagery blogs highlighting special imagery are regularly produced (see item # 1 above). Interesting VIIRS Imagery continues to be provided regularly to NOAA social media outlets. Alaska DNB Imagery for the StAR Long Term Monitoring (LTM) website is now being run directly at NCWCP.

4) NOAA-20 Gain Value Versus Scene Solar Elevation (GVVSSE; or "Goosey") and Gain Value Versus Scene Lunar Elevation (GVVSLE) Look-up Tables (LUT) are under development to replace the S-NPP equivalents, which are used to generate NOAA-20 NCC Imagery. The investigation will determine if changes in the LUTs are needed and the significance of those changes NOAA-20 NCC Imagery.

5) The VIIRS Imagery Team led by D. Hillger created a Terrain Correction (TC) Imagery-Geolocation Working Group involving members of the EDR Imagery Team, SDR Geolocation Team, and Raytheon. As a result of the combined efforts of the Working Group members, TC code changes were developed and tested and then delivered to the JPSS Program for operational implementation in FY20.

6) On-site (CIRA) implementation of Government Resources for Algorithm Verification, Independent Test and Evaluation (GRAVITE) Algorithm Development Library (ADL) software is being updated/improved in order to facilitate the pre-delivery testing of code and LUT changes, as anticipated in future work of the Team.

7) Polar-SLIDER turned out to be huge success over the entire past year. It is being used by science institutions, operational forecasters, and JPSS Managers.

Polar SLIDER allows for the display of
All 22 VIIRS bands
<u>-Multispectral Imagery Products:</u>
CIRA's VIIRS GeoColor product   (see Figure 1 below)
<u>-Multispectral RGB Composites:</u>
Natural Color (EUMETSAT)
<u>-Cloud Products:</u>
Cloud Top Height (NOAA)
Cloud Geometric Thickness (CIRA/NOAA)
Cloud Optical Depth (NOAA)
Cloud-Top Effective Particle Size (NOAA)
Cloud Top Altitude (NOAA)
Cloud Base Altitude (CIRA/NOAA)
Cloud Phase (NOAA)
Flight Level-Based Cloud Layers RGB (CIRA/NOAA)
<u>-Retrieval Products:</u>
NUCAPS Cold Air Aloft (CIRA

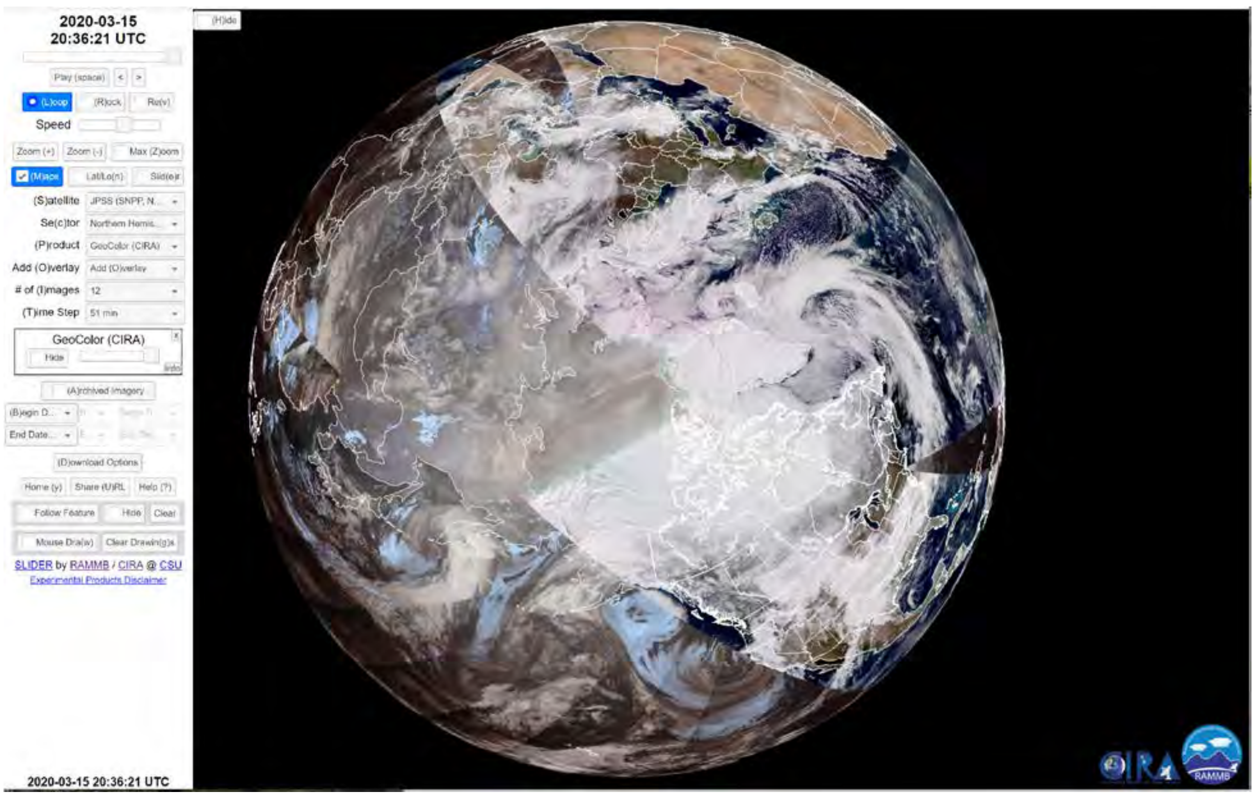


Figure 1: Polar-SLIDER display of the Northern Hemisphere VIIRS GeoColor product on 15 March 2020 at 20:36 UTC.

8) Results of this research were presented at numerous science conferences and meetings like for example:
- WFO Grand Junction Spring Workshop, Grand Junction, CO (15 May 2019)
- 2019 NOAA/NASA Satellite Meteorology Summer Workshop, Fort Collins, CO (11 July 2019)
- National Weather Association (NWA) Annual Meeting, Huntsville, AL (7-12 September 2019)
- 2019 AMS - EUMETSAT Joint Satellite Conference, Boston, MA (30 September - 4 October 2019)

- 10th Asia-Oceania Meteorological Satellite Users' Conference, Melbourne, Victoria, Australia (2 - 6 December 2019)
- 2020 AMS Annual Meeting, Boston, MA (12 - 17 January 2020)

A detailed list of presentations can be found at the end of this report.

9) Imagery Team Lead D. Hillger submits weekly and quarterly reports to the JPSS Program Office.

Project II: S-NPP/JPSS VIIRS Cloud Validation

Research Objectives:

For FY19, CIRA's contributions to this project continued to support the developing needs of the NOAA-led Cloud Cal/Val Team. Our focus was on monitoring, applications, and continuous enhancement of the Cloud Base Height (CBH) and CCL (Cloud Cover layers) algorithms, leveraging the current GOES-R research efforts. Both S-NPP and NOAA-20 products were evaluated against observations. The CIRA Team participated in JPSS Proving Ground Initiatives and interactions with operational users led by Cloud Team Lead. Feedback from key users have been incorporated in improvements of the algorithm and public demonstration of products. We presented research results at JPSS meetings, AMS, and other conferences.

1-- Continue validation of our CBH/CCL retrieval algorithms.

2-- Extend to evaluation on both S-NPP and NOAA-20 for consistency and long-term monitoring.

3-- Improve demonstrations for AWC and aviation forecasters based on user feedback, participating in JPSS Proving Ground Initiatives.

4-- Continue CBH/CCL algorithm improvements.

5-- Prepare reports, contribute materials to presentations, and participate in scientific conferences.

Achievements:

1-- We continued to compare the operational NDE CBH and CIRA's local CLAVR-x output for the product evaluation. As shown in Figure 1, CBH is highly dependent on CTH, which means that CTH updates in CLAVR-x directly impact on the CBH output. To examine the algorithm performance, we also used CALIPSO data particularly for optically thin clouds. We compared 864,494 matchup points between NOAA-20 VIIRS and CALIPSO for March 2019 cases (VIIRS 4977 granules and CALIPSO 162 granules). The mean absolute error (MAE) for optically thin clouds (COT < 1) was 0.4 km and RMSE was 1.5 km beyond meeting the requirement spec (L1RD Threshold = 3.0 km for thin clouds) when CTH is within an accurate range (2-km error range against CALIPSO). Throughout examining multiple months, we confirmed that the NDE Enterprise CBH algorithm with NOAA-20 VIIRS v2r0 algorithm integration is working nominally without serious problems, as long as the upstream cloud retrievals and supplementary data are valid.

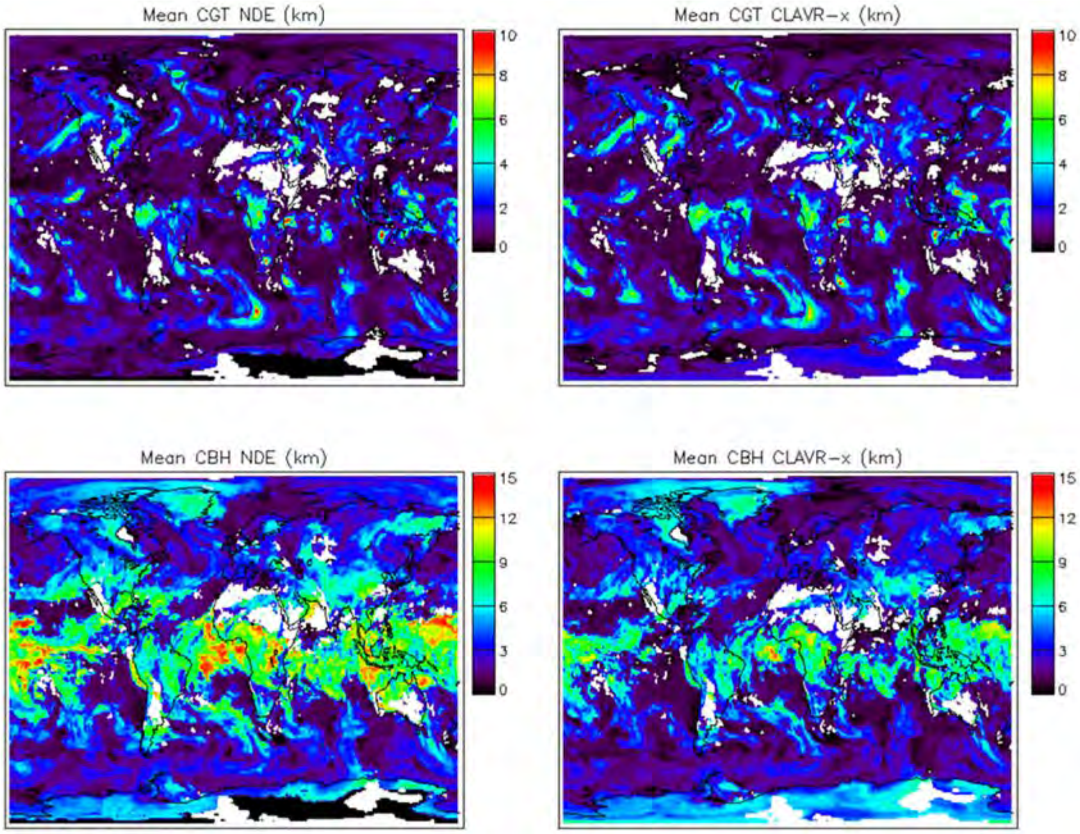


Figure 1. Comparison of global mean cloud geometric thickness (CGT) and cloud base height (CBH) using 934 VIIRS granules on 07 April 2019 (gridded in 1ºx1º) from NOAA-20 VIIRS (NDE v2r0) and CIRA's CLAVR-x. The CBH output is highly dependent on CTH changes, but the main part of the CBH algorithm obtaining CGT is consistent in both systems.

We also used ground observations such as ARM site measurements for validation. Figure 2 shows a sample comparison of CBHs (NOAA-20 NDE) and ARM NSA measurements for March - April 2019 (33 matchup cases). Precipitation cases were excluded using surface observations (MET). The results from the operational algorithm show a general agreement. 79% of the output compared against lidar (MPL) and 96% against ceilometer (Ceil) meet the 2-km L1RD spec. We will continue the product evaluations for day and night cases with updated CBH and CCL algorithms over an extended period.

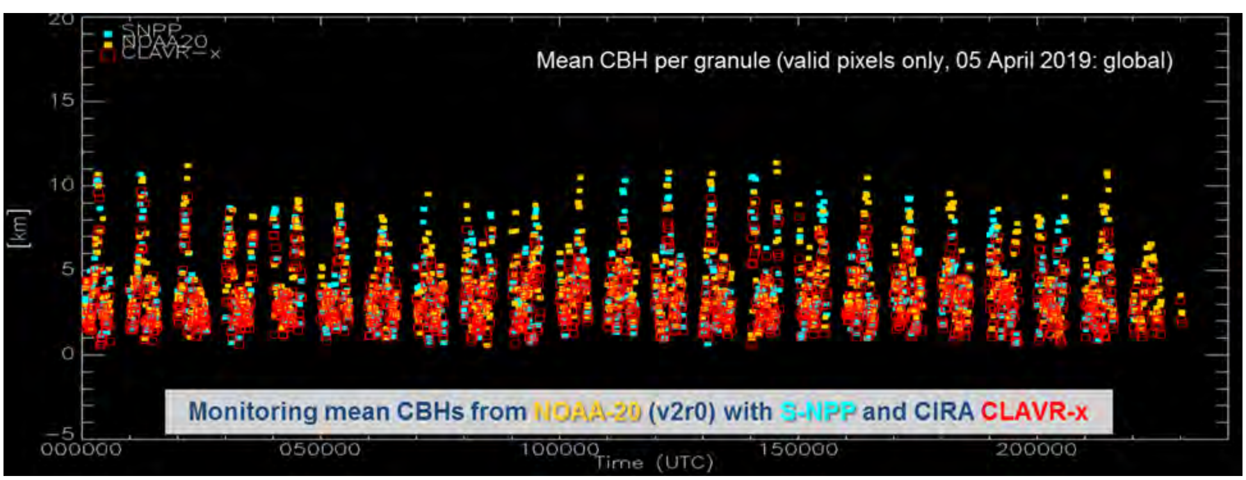


Figure 2. Global time series of VIIRS CBHs averaged over the individual granules from S-NPP and NOAA-20 operational output (v2r0) and CIRA's CLAVR-x run to monitor the algorithm consistency.

2-- We evaluated the newly operational NOAA-20 VIIRS algorithms against S-NPP. The individual granules, regional and global means have been examined to identify specific issues in the algorithm operation and consistency checking (Figure 3). NOAA-20 VIIRS cloud product validated maturity review was completed, and the results and issues were reported (May 16, 2019).

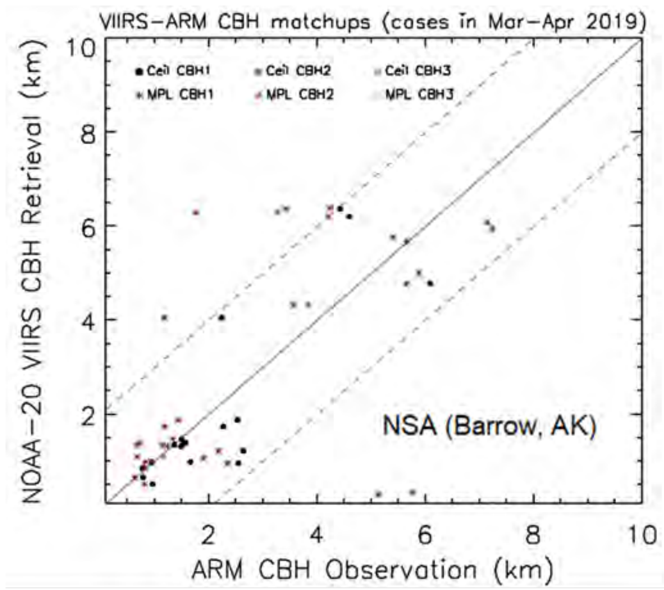


Figure 3. Comparisons of NOAA-20 operational CBH output and ground-based measurements from lidar and ceilometer (ARM NSA site in Barrow, AK) for March-April 2019. Black/gray circles are ceilometer data (Ceil), and brown/red asterisks represent lidar data (MPL).

3-- Global cloud products from both S-NPP and NOAA-20 have been publically available with all imagery in CIRA's Polar SLIDER (http://rammb-slider.cira.colostate.edu/?sat=jpss) and popularly used by general and operational users. Supporting the JPSS Cloud Product Alaska Demonstration (part of the JPSS PGRR Aviation Initiative effort), we developed an experimental product website for the VIIRS Cloud Vertical Cross-sections over Alaska (http://rammb.cira.colostate.edu/ramsdis/online/npp_viirs_arctic_aviation.asp). The cloud vertical cross-sections along selected flight routes over Alaska are available in near real time here. This effort was very successful, and we have been updating the product and user documents through intensive user-developer interactions. An example of a pilot report (PIREP) between Fairbanks and Barrow is shown in Figure 4, which was reported by an operational user (Gail Weaver, ZAN Center Weather Service Unit, Anchorage, AK) for the product evaluation. We also began interactions with AWC researches (John Haynes' visit in August 1-2, 2019) for the product demonstration and future improvement.

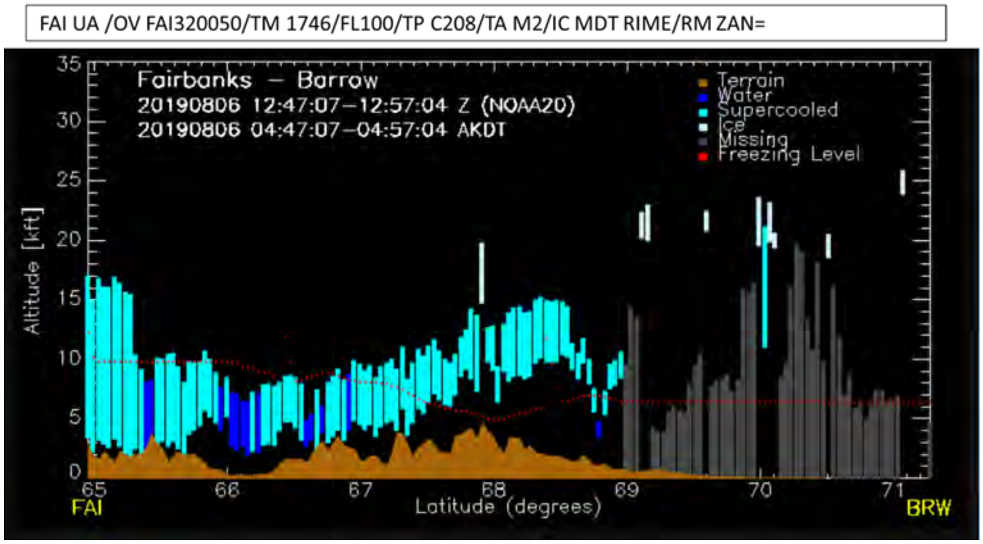


Figure 4. Sample of user-engaged validation efforts for the VIIRS cloud cross-section product. PIREP (top) reported by Gail Weaver (ZAN Center Weather Service Unit, Anchorage, AK) between Fairbanks and Barrow, Alaska for the selected cross-section.

4-- We continue to incorporate CBH/CCL impartments for nighttime clouds and multilayer scenes, leveraging CIRA's JPSS and GOES-R PGRR research. We have been working on improvement of multi-layered clouds ('High + Low' cloud layer category) by adopting a machine learning approach. Data training has been done using multiple bands, and channel differences, and NWP data, and the results are promising. We will implement this approach for the algorithm improvement and evaluate the output. For improved nighttime retrievals, we are using the Nighttime Lunar Cloud Optical and Microphysical Properties (NLCOMP) algorithm utilizing VIIRS DNB as well as NWP data. To use MiRS ATMS together with NLCOMP, NWP, and IR data, we also attempting a machine learning model (Random Forest). Early results were presented at 2019 AMS-EUMETSAT Joint satellite conference.

5-- The CIRA team regularly participated in the VIIRS Cal/Val and JPSS Initiative teleconferences (Aviation and Arctic) and NOAA-20 VIIRS cloud product validated maturity review. We regularly contributed input materials to Jeff Weinrich (JPSS Aviation Initiative) and Andy Heidinger (NOAA Cloud Team Lead) for team reviews and reports to support the JPSS VIIRS Cloud Cal/Val Team. CIRA's Polar SLIDER display of VIIRS imagery and cloud products is used as a supplementary data display tool to support the JPSS Cloud Product Alaska Demonstration (summer and fall 2019) which was initiated from JPSS Aviation Initiative. The results were presented at the AMS/EUMETSAT joint satellite conference (Boston, MA, 28 Sep - 4 Oct 2019) and various science conferences. All the presentation titles with detailed information are listed below.

PROJECT PUBLICATIONS:

Noh, Y.-J., L. D. Grasso, S. D. Miller, 2019: Toward Improvement of Nighttime Cloud Detection Over US Coastal Zones: Observations and Numerical Simulations". In preparation.

Yue, J., S. Perwitasari, S. Xu, Y. Hozumi, T. Nakamura, T. Sakanoi, A. Saito, S. D. Miller, W. C. Straka III, and P. Rong, 2020: Preliminary dual-satellite observations of atmospheric gravity waves in airglow. *Atmosphere*, in press, 2020.

Miller, S. D., D. T. Lindsey, C. J. Seaman, and J. E. Solbrig, 2020: GeoColor: A Blending Technique for Satellite Imagery. *J. Atmos. Ocean. Tech.*, 37(3), 429-448, https://doi.org/10.1175/JTECH-D-19-0134.1.

Noh, Y. J., S. D. Miller, A. Heidinger, G. Mace, A. Protat, and S. Alexander, 2019: Satellite-based detection of daytime supercooled liquid-topped mixed-phase clouds over the Southern Ocean using the Advanced Himawari Imager. J. Geophys. Res., 124(5), 2677-2701, doi:10.1029/2018JD029524.

Solbrig, J. E., S. D. Miller, J. Zhang, L. D. Grasso, and A. Kliewer, 2019: Assessing the Stability of Surface Lights for use in Retrievals of Nocturnal Atmospheric Parameters. *Atmos. Meas. Tech.*, https://doi.org/10.5194/amt-2019-103, Accepted.

Levin, N., C. C. Kyba, Q. Zhang, A. Sánchez de Miguel, M. O. Román, X. Li, B. A. Portnov, A. L. Molthan, A. Jechow, S. D. Miller, Z. Wang, R. M. Shrestha, and C. D. Elvidge, 2019: Remote sensing of night lights: a review and an outlook for the future. Remote Sensing of Environment, 237, 111443. https://doi.org/10.1016/j.rse.2019.111443.

Zhang, J., S. L. Jaker, J. S. Reid, S. D. Miller, J. E. Solbrig, and T. D. Toth, 2018: Characterization and application of artificial light sources for nighttime aerosol optical depth retrievals using the Visible Infrared Imager Radiometer Suite (VIIRS) Day/Night Band. Atmospheric Measurement Techniques, 12(6), 3209-3222, https://doi.org/10.5194/amt-12-3209-2019.

Xu, S., J. Yue, X. Xue, S. L. Vadas, S. D. Miller, I. Azeem, W. C. Straka III, L. Hoffman, and S. Zhang, 2019: Dynamical Coupling Between Hurricane Matthew and the Middle to Upper Atmosphere via Gravity Waves. J. Geophys.Res.: Space Physics, 124(5), 3589-3608, https://doi.org/10.1029/2018JA026453.

PROJECT PRESENTATIONS/CONFERENCES:

Hillger, D., and Imagery Team, 2020: Imagery - Global coverage product generation and distribution. *JPSS/GOES-R Summit*, College Park, MD, 24-28 February 2020. (panel presentation and discussion).

Noh, Y. J., S. D. Miller, J. M. Haynes, C. J. Seaman, J. M. Forsythe, A. Heidinger, Y. Li, S. Wanzong, and W. Straka, 2019: Cloud Base and Cloud Cover/Layers. *JPSS/GOES-R Summit*, College Park, MD, 24-28 February 2020.

Hillger, D., T. Kopp, G. Lin, A. Griffin, J. Dellomo, D. Stuhmer, W. Chen, S. Finley, C. Seaman, and J. Evans, 2020: Terrain-Correction for VIIRS EDR Imagery in Preparation for JPSS-2. *2019 AMS Annual Meeting,* Boston, MA, 12 - 17 January 2020.

Torres, J., 2020: The Utility of JPSS and GOES Fire Weather Products and Applications in the Operational Forecasting Environment. *2019 AMS Annual Meeting,* Boston, MA, 12 - 17 January 2020.

Seaman, C. J., K. Micke, D. T. Lindsey, S. D. Miller, Y.-J. Noh, N. Tourville, J. Dostalek, D. Hillger, G. Chirokova and S. Finley, 2019: SLIDER: A website for displaying geostationary and polar-orbiting satellite data in realtime. *10th Asia-Oceania Meteorological Satellite Users' Conference, Melbourne, Victoria, Australia (2 - 6 December 2019)*

Seaman, C. J., 2019: Spectral band / now-casting exercise with a short example or two using RAMMB/CIRA SLIDER. *10th Asia-Oceania Meteorological Satellite Users' Conference, Melbourne, Victoria, Australia (2 - 6 December 2019)*

Miller, S. D., C. J. Seaman, Y.-J. Noh, L. Grasso, and W. Straka, III, 2019: Unlocking the Potential of the Day/Night Band for Nocturnal Environmental Characterization. *Invited seminar at Seoul National University*, Seoul, S. Korea, 15 November 2019.

Noh, Y. J., 2019: Improvement of Satellite Cloud Cover/Layer Products and Aviation Weather Applications. Colloquium, School of Earth & Environ. Sci./Seoul Nat'l University, Oct. 15, 2019. South Korea.

Miller, S. D., W. C. Straka III, C. J. Seaman, Y.-J. Noh, and L. D. Grasso, 2019: *The Power of the Dark Side:* Visible Applications in Dark Environments, Revisited (VADER). *2019 Joint AMS EUMETSAT Satellite Conference*, Boston, MA., 28 September - 04 October 2019.

Noh, Y. J., S. D. Miller, J. M. Haynes, J. M. Forsythe, C. J. Seaman, A. Heidinger, A. Walther, and Y. Li, 2019: Improvement of Nighttime Cloud Geometric Thickness Retrieval Integrating Multi-Sensor Observations and Numerical Model Simulations. *2019 Joint AMS EUMETSAT Satellite Conference*, Boston, MA., 28 September - 04 October 2019.

Haynes, J. M., Y. J. Noh, S. D. Miller, A. Heidinger, and J. M. Forsythe, 2019: Cloud Boundary Detection in Multilayer Scenes with the GOES ABI. *2019 Joint AMS EUMETSAT Satellite Conference*, Boston, MA., 28 September - 04 October 2019.

Seaman, C. J., K. Micke, Y.-J. Noh, J. Dostalek, S. Finley, S. Miller, D. T. Lindsey, N. Tourville and D. Hillger, 2019: Polar SLIDER: A website for the display of global polar-orbiting satellite data in near-realtime. *2019 Joint AMS EUMETSAT Satellite Conference*, Boston, MA., 28 September - 04 October 2019.

Torres, J., B. Connell, E. Sanders and D. Bikos, 2019: An overview of the Satellite Foundational Course for JPSS (SatFC-J). *2019 Joint AMS EUMETSAT Satellite Conference*, Boston, MA., 28 September - 04 October 2019.

Torres, J., and J. Thomas, 2019: Training Resources/Q&A/Course Evaluation. *2019 Joint AMS EUMETSAT Satellite Conference*, Boston, MA, 28 September - 04 October 2019.

Miller, S. D., W. C. Straka III, C. J. Seaman, Y.-J. Noh, and L. D. Grasso, 2019: *The Power of the Dark Side*: Visible Applications in Dark Environments, Revisited (VADER). *JPSS-PGRR Seminar Series*, 18 September 2019, remote.

Torres, J., B. Connell, E. Sanders and D. Bikos, 2019: An overview of the Satellite Foundational Course for JPSS (SatFC-J). *National Weather Association (NWA) Annual Meeting,* Huntsville, AL, 7-12 September 2019.

Torres, J., D. Bikos, E. Szoke, 2019: Polar-orbiting and Geostationary capabilities and observations in support of Active Fires. *National Weather Association (NWA) Annual Meeting,* Huntsville, AL, 7-12 September 2019.

Torres, J., 2019: JPSS Educational Resources. *NOAA/NASA Satellite Summer Workshop*, Ft. Collins, CO, 11 July 2019.

Miller, S. D., 2019: Observing the Night with the VIIRS Day/Night Band. Invited Presentation: *NOAA/NASA Satellite Summer Workshop*, Ft. Collins, CO, 11 July 2019.

Torres, J., 2019: JPSS Products in AWIPS and SatFC-J. *WFO Grand Junction Spring Workshop,* Grand Junction, CO, 15 May 2019

Noh, Y. J., 2019: CIRA's satellite products, COMET Weather Analysis and Forecasting course for Korea Meteorological Administration forecasters. 14 May 2019, Boulder, CO.

PROJECT TITLE: CIRA Support to the Time-Resolved Observations of Precipitation structure and storm intensity with a Constellation of Smallsats (TROPICS)

PRINCIPAL INVESTIGATOR: Galina Chirokova

RESEARCH TEAM: Alex Libardoni

NOAA TECHNICAL CONTACT: Robert Rogers NOAA/AOML/HRD

NOAA RESEARCH TEAM: John Knaff NESDIS/STAR

PROJECT OBJECTIVES:

Adapt the CIRA Hurricane Intensity and Structure Algorithm (HISA) to work with TROPICS temperature and moisture retrievals.

PROJECT ACCOMPLISHMENTS SUMMARY:

The HISA code was adapted to TROPICS requirements and prepared for delivery to CIMSS Data Processing Center. In addition, the major changes that will need to be done to HISA to make it work with TROPICS data have been identified. The TROPICS Radiometer has 12 channels, in 91 GHz – 2015 GHz range, compared to ATMS that has 22 channels in the 23 GHz – 191 GHz range. There are several advantages in running HISA on TROPICS, compared to ATMS and AMSU that are currently used as input data. Those include the improved temporal resolution, less contribution from surface emissivity, which can lead to better overland retrievals, and improved ice-scattering correction using 205 GHz channel not available on ATMS or AMSU. At the same time, with TROPICS data it might be more difficult to detect warm core in the lower troposphere due to higher frequency band used for temperature sounding, and use of TROPICS data will involve higher uncertainties in the cloud liquid water (CLW) estimates that are used to correct for attenuation.

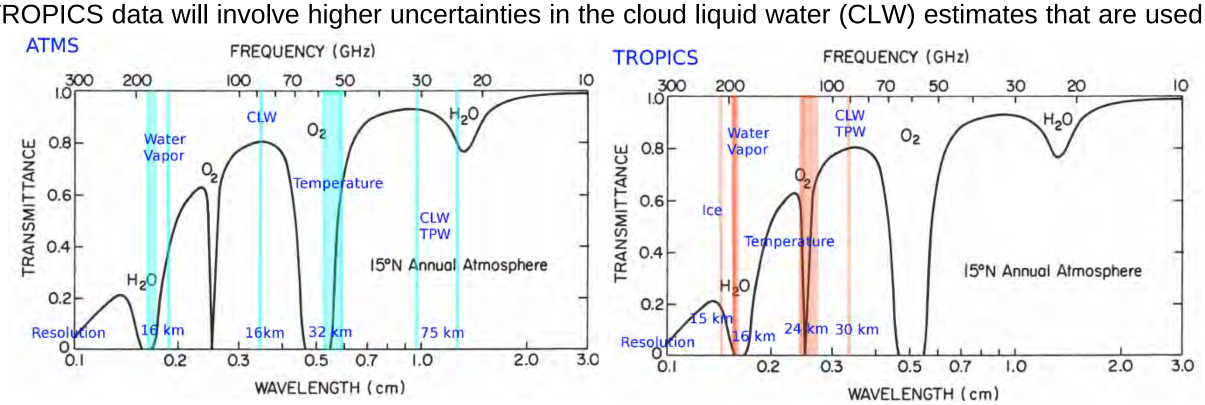


Figure 1. Comparison of channels available on ATMS and on TROPICS Radiometers.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Herndon D. and G. Chirokova, 2020: *Level 2 TROPICS Tropical Cyclone Intensity Products*. 2nd TROPICS Applications Workshop. 19 -20 February 2020, Miami, FL

Chirokova G., 2020: How JPSS Data can improve operational tropical cyclones analysis and intensity forecasting? Invited presentation at the JPSS Science Seminar, 27 January 2020, online.

Blackwell W. J., R. V. Leslie, S. a. Braun, R. Bennartz, C. S. Velden, T. Greenwald, D. Herndon, m. Demaria, G. Chirokova, R. Atlas, J. Dunion, F. Marks, R. Rogers, H. Christophersen, B. Annane, B. A. Dahl, 2020: Mission Preparation for the NASA TROPICS Hurricane Constellation Observatory. AMS 100th Annual Meeting, 12-16 January 2020, Boston, MA

Leslie R., V., MIT Lincoln Laboratory, Lexington, MA; and W. J. Blackwell, S. A. Braun, R. Bennartz, G. Chirokova, M. DeMaria, T. Greenwald, L. E. Gumley, D. C. Herndon, C. Kidd, T. Matsui, and C. S. Velde: NASA Tropics Earth Venture Mission: Payload Characteristics and Data Products. 2019 AMS Joint EUMETSAT/AMS Satellite Conference, Boston, MA, 28-September – 04 October 2019.

Blackwell, W. J, R. V. Leslie, S. A. Braun, R. Bennartz, C. S. Velden, T. Greenwald, D. C. Herndon, M. DeMaria, G. Chirokova, R. Atlas, J. P. Dunion, F. D. Marks, R. Rogers, H. Christophersen, B. Annane, B. A. Dahl, 2019: Microwave Atmospheric Sounding CubeSats: From MicroMAS-2 to TROPICS and Beyond. 99th AMS Annual Meeting, Phoenix, Arizona, 6-10 January 2019. https://ams.confex.com/ams/2019Annual/recordingredirect.cgi/oid/Recording51058/paper352453_1. mp4

PROJECT TITLE: CIRA Support to Upgrade the Tropical Cyclone Formation Probability (TCFP) Product

PRINCIPAL INVESTIGATORS: Chris Slocum, Alan Brammer

RESEARCH TEAM: Chris Slocum, Alan Brammer

NOAA TECHNICAL CONTACT: John Knaff NOAA/NESDIS/STAR

NOAA RESEARCH TEAM: Priyanka Roy, Peter Keehn, Veena Jose, NOAA/NESDIS/SMCD; Liqun Ma, NOAA/NESDIS/OSPO

PROJECT OBJECTIVE:

Incorporation of Himawari-8, Meteosat-8, & GOES-R series satellite water vapor data

PROJECT ACCOMPLISHMENTS SUMMARY:

The NESDIS Office of Satellite Data Processing and Distribution Tropical Cyclone Formation Probability (TCFP) product provides real-time, objective guidance for the 24- and 48-hour probability of tropical cyclone (TC) formation using input from geostationary environmental satellites and NCEP global model forecasts. This work updates key input data functionality for the TCFP product to sustain continued operations in support of the National Hurricane Center, Central Pacific Hurricane Center, and Joint Typhoon Warning Center user community. The TCFP product now includes updated output options that increase accessibility across forecast agencies.

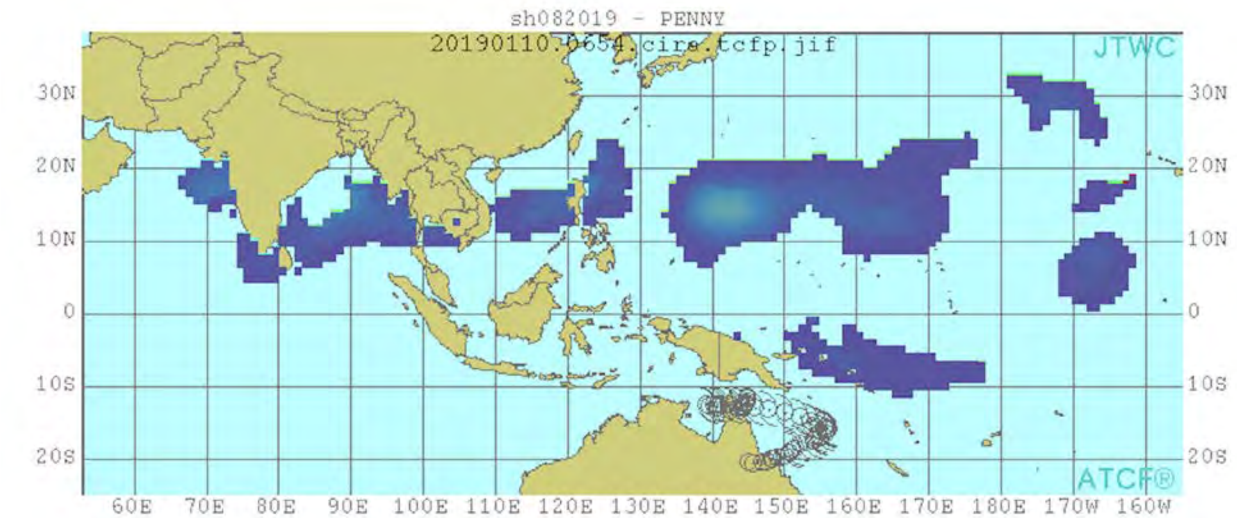


Figure 1. A METOCTIFF of the Tropical Cyclone Formation Probability product version 4.0 displayed within ATCF over the N. Western Pacific, Indian Ocean, and Southern Hemisphere basins for 18 UTC 20 Sept 2019.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: COLMA CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting

PRINCIPAL INVESTIGATORS: Steven A. Rutledge

RESEARCH TEAM: Adam Clayton, Kyle Hilburn, Steven Miller

NOAA TECHNICAL CONTACT: Dan Lindsey

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVE:

Evaluate lightning detection from the Geostationary Lightning Mapper on GOES-R and GOES-S

PROJECT ACCOMPLISHMENTS SUMMARY:

This current year focused on analysis of multiple case studies, interacting with GLM Science team colleagues, and working on a manuscript for publication. Numerous storms were analyzed from Colorado, Alabama and W. Texas, where Lightning Mapping Arrays are in place. These LMA networks provide a state of the art estimate for flash rate. By comparing GLM flash rates to LMA flash rates on a storm-by-storm basis, the instrument detection efficiency can be determined. Meteorological factors that contribute to DE can be investigated. The main finding is that high flash rates storms with anomalous charge structures have much lower DE than normal polarity, lower flash rate storms. We attribute the lower DE in anomalous storms to optical scattering by cloud water and ice particles, not precipitation-sized particles.

Anomalous storms contain large cloud water contents in comparison to normal polarity storms. We demonstrated that DE decreases with increasing cloud water path (CWP), which has been estimated from GOES ABI data. Interestingly the DE vs. CWP plot for CO us shifted (lower) for CO storms compared to AL storms. This shift is consistent with the fact that DE decreases with increasing zenith angle. It is difficult to de-convolve the effects of cloud water scattering and geometry on detection efficiency. Detection efficiencies in CO are roughly 20%. DE's in AL are higher but still below the instrument spec for many events. This award also provides support for operating and maintaining the Northeast Colorado Lightning Mapping Array.

PROJECT PUBLICATIONS:

Evaluating Geostationary Lightning Mapper flash rates within intense convective storms. S. A. Rutledge, K. Hilburn, A. Clayton, B. Fuchs and S. Miller. To be submitted to *J. Geophys. Res., Atmospheres* (GLM Special Issue)

PROJECT PRESENTATIONS/CONFERENCES:

Detection Efficiency in intense storms. Presented (virtually) at the GLM Workshop, Huntsville, AL (September 2019) S. A. Rutledge

PROJECT TITLE: Comparison of Model versus Observationally-Driven Water Vapor Profiles for Forecasting Heavy Precipitation Events

PRINCIPAL INVESTIGATOR: John Forsythe

RESEARCH TEAM: Stan Kidder, Andy Jones, Dan Bikos, Steve Fletcher, Ed Szoke

NOAA TECHNICAL CONTACT: Jim Nelson NOAA WPC

NOAA RESEARCH TEAM: Jim Nelson (WPC), Mark Klein (WPC), Andrew Orrison (WPC), Sarah Trojniak (WPC)

PROJECT OBJECTIVES:

This project began in July 2017 with a goal of testing the hypothesis that water vapor profile differences of the CIRA Advected Layer Precipitable Water (ALPW) product and derived model layer precipitable water vapor could be useful to diagnose model initialization for heavy precipitation events. ALPW is independent of forecast models, so differences of water vapor against the model in four layers (surface-850 mb, 850-700 mb, 700-500 mb and 500-300 mb) should indicate major differences in model water vapor initialization.

PROJECT ACCOMPLISHMENTS SUMMARY:

Near-realtime comparisons versus the Global Forecast System FV3 model and High Resolution Rapid Refresh (HRRR) model have been created. The difference maps are available at http://cat.cira.colostate.edu/HMT/FFaIR_Main.htm. Difference maps of the 3-hour forecast from GFS are available every six hours, while HRRR differences are available every hour. These difference maps are being delivered to the NOAA Weather Prediction Center (WPC) in AWIPS-2 format for forecaster evaluation. These maps show where the model is drier / moister than the satellite derived ALPW product in four atmospheric layers. A major accomplishment of the project was participation in for the second year in the Flash Flood and Intense Rainfall (FFaIR) experiment in June and July of 2019. Forecasters evaluated the difference product and found potential for forecasting and also recommended feedback to model developers. A forthcoming journal paper will document systematic differences between the products.

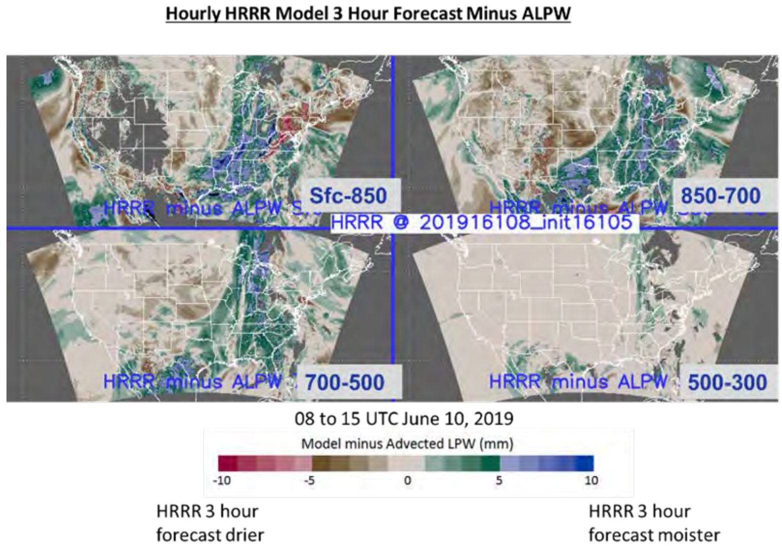


Figure 3: H*RRR minus ALPW model difference product for the four pressure layers at 15 UTC on 15 June 2019.*

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Forsythe, J. M., S. Kidder, A. Jones, D. Bikos, S. J. Fletcher, E. Szoke, 2019: Applications of Layer Precipitable Water Products from Microwave Satellite Retrievals and Forecast Model Integration. *Joint AMS / Eumetsat Satellite Conference*, October 2019, Boston MA.

Forsythe, J. M., S. Kidder, A. Jones, D. Bikos, S. J. Fletcher, E. Szoke, 2019: Improving Blended Total Precipitable Water Products for Forecasters Via Advection and Inclusion of GOES-R. *Joint AMS / Eumetsat Satellite Conferenc*e, October 2019, Boston MA.

Kusselson, S., J. M. Forsythe, S. Kidder, A. Jones, D. Bikos, 2019: The CIRA Advected Layer Precipitable Water Product and Applications to Help Forecast Hazardous Precipitation. National Weather Association Annual Meeting, Huntsville, AL, Sept. 2019.

PROJECT TITLE: DA of GLM in HWRF/GSI CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting

PRINCIPAL INVESTIGATOR: Milija Zupanski

RESEARCH TEAM: Ting-Chi Wu (CIRA), Milija Zupanski (CIRA)

NOAA TECHNICAL CONTACT: Dan Lindsey (NESDIS), Andrew Heidinger (NESDIS)

NOAA RESEARCH TEAM: Avichal Mehra (NCEP/EMC), Mark DeMaria (NCEP/NHC)

PROJECT OBJECTIVE(S): (1) Develop HWRF lightning forecast operator, (2) Verify HWRF lightning forecast against GLM observations.

PROJECT ACCOMPLISHMENTS SUMMARY:

1 - Develop HWRF lightning forecast operator

In addition to developing HWRF lightning *observation* operator, we also focus on developing HWRF lightning *forecast* operator for GLM observations. We considered several lightning operators: (1) Lightning threat operator (e.g., McCaul et al. 2009), (2) vertically integrated rimed hydrometeors (e.g., ice, snow, hail, graupel), and (3) Artificial Intelligence (AI) operator. The first two operators are generally based on (linear) regressions between lightning flash rate and cloud hydrometeors, while the third operator is an attempt to use AI in developing relevant regressions between HWRF model variables and lightning flash rate. The operator (1) was originally developed for quantifying lightning threat over land, but it proved to be inadequate for quantifying lightning over ocean, in tropical cyclone environment. Most likely reason seems to be the insufficient frozen hydrometeors in hurricanes that produce almost negligible vertical graupel flux. The operator (2) is derived from operator (1) by keeping the vertically integrated frozen hydrometeors and then further adjusting the parameters used in calculation. This operator shows a better fit to GLM observations than operator (1). A common characteristic of operator (1) and (2) is that they have been originally developed by CIRA team as lightning *observation* operators that are used in HWRF data assimilation system. However, since the developed HWRF lightning data assimilation includes an estimation of empirical parameters, these observation operators can be in principle used as HWRF *forecast* operators. Our current estimate is that they can be useful up to 36-hour forecast after data assimilation.

Development of AI operator(s) was specifically geared towards the HWRF forecast operators, which predict lightning based on the HWRF forecast. In particular, a Deep Neural Network (DNN) model is developed to help with creating a link between GLM lightning features and modeled tropical cyclone properties. The main focus of the research during this period was on constructing a flexible DNN system. Developed are:

- Input pipeline (with flexibility to ingest any number of input features, each of multiple dimensions)
- Couple of DNN model architectures: (i) Fully Connected and (ii) CNN (both ready to be applied to broad variety of classification problems; with flexibility in adjusting the hipper-parameters)
- Inference models (for testing the results using independent datasets)

Using HWRF model dynamical and cloud variables as input, DNN models are trained with a goal to produce accurate representations of GLM lightning observations. The training data sets are generated using Hurricane Florence simulations. Twenty-eight instances of 267 x 537 scenes of HWRF output, centered on the hurricane eye, are collocated with GLM flash rate density observations. Figure 1 provides an example of the collocated normalized HWRF total-column ice and GLM flash rate density. One can notice a relatively good correlation between the HWRF total column ice and GLM observations.

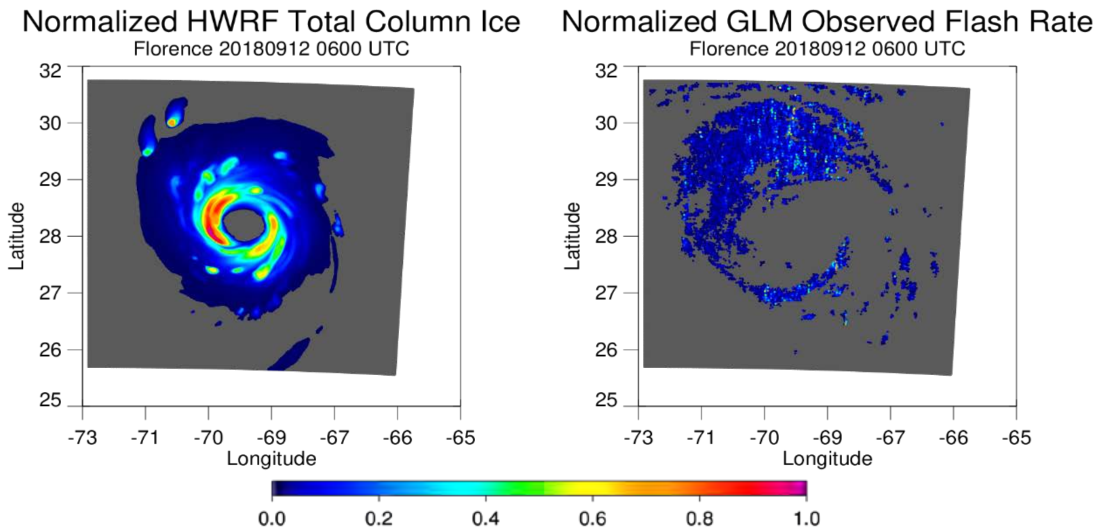


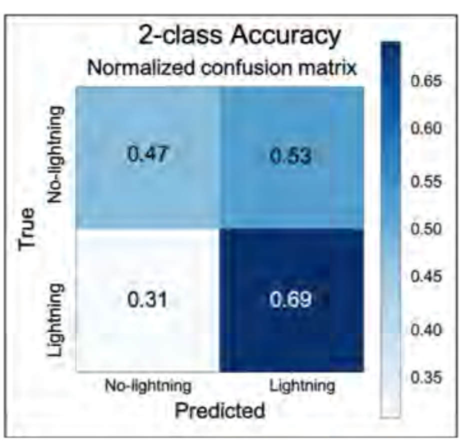
Figure 4 **Hurricane Florence on Sep 12 2018 at 0600: Normalized total column ice from HWRF simulation (left panel), and Normalized GLM lightning density (right panel). This is an example of relatively high spatial correlation.**

In future we plan to compare the prediction skill of the DNN model to that of the GSI lightning operator when each are exposed to the same information content.

2 - Verify HWRF lightning forecast against GLM observations

Verification of HWRF lightning forecast is being computed against GOES-16 GLM observations. In particular, we compare the forecast and observations in terms of lightning flash rate density. A set of lightning flash rate density observations for hurricane Florence has been prepared and used for testing. These verifying observations have been also an important component of the AI training data set.

The results in Fig.2 show the verification of 6-hour HWRF forecast against GLM observations, described in terms of AI parameters. Current results for the 2-class experiment (i.e., yes/no lightning) stand at the overall accuracy of 60% with probability of 70% to correctly predict occurrence of GLM positive lightning density (see Fig. 2 left panel). When multiple lightning density classes are used, results suggest that models are generally biased towards no-lightning or low-lightning class (see Fig. 2 right panel). In the regression runs,



3-class Accuracy [%]		Predicted		
		Low	Mod	High
Observed	Low	74	11	15
	Mod	64	15	21
	High	52	11	37

Figure 5 **Performance of a DNN classification model. Left: predicting no-lightning/lightning event. Right: predicting three equally-populated classes of lightning density as observed by the GLM sensor.**

when using only above-listed parameters, the best performing model reports similar skill to that of currently operational HWRF lightning observation operators.

PROJECT PUBLICATIONS:

Wu, T.-C., Petkovic, V., M. Zupanski, and K. Apodaca, 2020: Evaluation of GLM lightning observation operators in HWRF data assimilation system. To be submitted to *Mon. Wea. Rev.*

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: DayNightImager - CIRA Science Support to the Day-Night Imager Sensor

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Cindy Combs, Stan Kidder, Curtis Seaman, Galina Chirokova, Yoo-Jeong Noh, L. Grasso

NOAA TECHNICAL CONTACT: Sid Boukabara

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

The goal of this project is to conduct a low-light visible sensing feasibility study to address next-generation observing system architectures to enable low-light visible imaging, working alongside partners at *The Aerospace Corporation* to consider capabilities and associated cost for various options. The principal focus of this study in terms of geographic coverage was on the Alaska/Arctic region, as this region currently resides within the Key Performance Parameter (KPP) purview for Near-Constant Contrast (NCC) imagery from the DNB. Considerations was also given for extended utility and benefit of such an architecture to the mid- to low-latitudes. Complementing hardware specification and costing aspects of the study, led by collaborators at The Aerospace Corporation, the CIRA Team's focus was on the science and applications aspects of a CubeSat or small-satellite solutions proposed.

The objective was not to "sell" a specifc low-light nighttime visible option, but rather, to assess objectively the spectrum of options. Specifically, we considered the potential operational benefit of higher temporal refresh rates, compared to the current S-NPP/JPSS-1 tandem, addressed sensor and orbital requirements to achieving a specified temporal resolution, and considered advanced technology versions of low-light imaging (including multi-spectral) which may enable new science and applications.

Project Milestones:

1. Meetings and Other Interactions, Consultations with Aerospace
2. Inventory of Low-Light Visible Use in the Research and Operational Communities
3. Conduct Preliminary Comparisons of DNB vs. CUMULOS
    3.1. Conduct Preliminary Comparisons of DNB vs. CUMULOS
    3.2. Analysis and Prioritization of DNB/NIRAC Conjunctions
4. DNB CubeSat Orbital Analysis

PROJECT ACCOMPLISHMENTS SUMMARY:

1. Meetings and Other Interactions, Consultations with Aerospace

As part of this project, a large number of meetings and telecoms were held with the NESDIS TMP sponsor team as well as representatives from the Aerospace Company. Monthly reports were written and additional monthly "Tag-Up" telecoms were held with Katherine Lukens (NESDIS).

Aerospace's Dee Pack interacted closely with Curtis Seaman to exchange VIIRS and CUMULOS data for the available conjunctions that have been collected as part of this Year 1 work. Significant iterations took place as they iterated on data formats.

In January 2020, Dee Pack (Aerospace), gave a presentation at the Annual AMS Meeting (6-10 Jan 2020, Boston). Title: "*Comparing a CubeSat with VIIRS: What we learned from the CubeSat Multispectral Observing System – CUMULOS*".
His CIRA Co-Authors were: Steve Miller, Cindy Combs, Curtis Seaman, and Galina Chirokova

In October 2019, Steve Miller participated in the TMP Annual Review Meeting, NCWCP, College Park, MD. He presented research results of the TMP 18-08 Low-Light DNB project, titled: "TMP 18-08: Evaluation of Next-Generation Satellite Architecture Solutions to Nocturnal Low-Light Visible Observations in the Arctic and Beyond."

On 22 August 2019, Steve Miller presented the OPPA Monthly Brown Bag Seminar. Title of his talk was: "*TMP 18-08: Evaluation of Next-Generation Satellite Architecture Solutions to Nocturnal Low-Light Visible Observations in the Arctic and Beyond"*

2. Inventory of Low-Light Visible Use in the Research and Operational Communities

The goal of this milestone was to conduct a literature search for sources that discuss, describe or use directly the Day/Night Band (DNB) data. These references include presentations, posters, reports and peer-reviewed journal articles. At the start of this project, we did not fathom the full range and scope of references we would encounter, nor the variety of fields that use these data. Instrument and data performance references were expected, as was applications in weather, air pollution, fishing vessel detection and the effects of disasters. However, DNB also is being used in biology and health fields investigating Artificial Light At Night (ALAN) effects, urban studies, land use, rural development, populations, socioeconomics, and even the effects of military conflicts. What started as a simple Word document listing references ended up growing into a large Zotero database with over 1000 references.

The Zotero database was chosen because it offered many facilities meeting the needs of this inventory. It is open source, can be downloaded to Macs, Windows or Linux systems, and provides unlimited storage with a $120 per year subscription fee. PDFs and other files can be linked to each entry. In addition, each entry can be assigned multiple tags, allowing for flexible database searches. It can create a bibliography in many different formats, including the one used for American Meteorological Society (AMS) papers. Finally, there is an option to set up a private group, where the owner can invite others to access the database. This was chosen as an easy way to share the DNB literature search with Aerospace, NOAA, and other users in the community.
Through the process of tagging, a variety of statistics were compiled from the database to answer targeted use questions, such as "*How many applications involve artificial light (cities, fishing, gas flares, etc.) vs. natural light (airglow, wildfires, lightning, etc.*), *and how has this changed with the advent of*

VIIRS DNB compared to previously available DMSP/OLS?" Figure 1 below shows a time series of reference publish dates, divided between those using DMSP (legacy low-light sensing) only, VIIRS only, and combining the two. The number of references has climbed in 2019, and the database only goes through mid-August 2019. DMSP references remain fairly steady after 2014. Meanwhile, the overall volume of DNB references continues to grow rapidly.

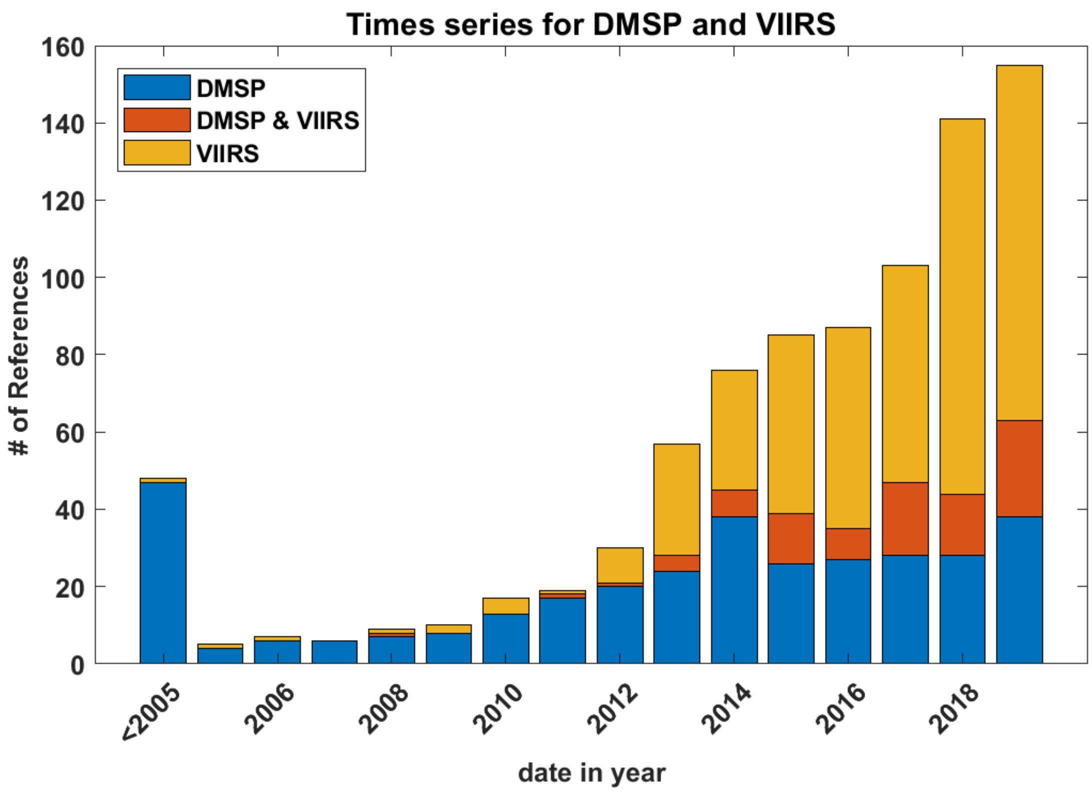


Figure 1: *Times series for DNB references by publishing date and sensor. Note that 2019 only goes through August 2019.*

3. <u>Conduct Preliminary Comparisons of DNB vs. CUMULOS</u>

3.1 <u>Conduct Preliminary Comparisons of DNB vs. CUMULOS</u>

A unique aspect of this project has been the opportunistic leveraging of CUMULOS, an Aerospace-operated instrument camera system payload onboard a CubeSat (ISARA) currently in-orbit which includes a low-light visible band. Work in the early part of this project has yielded a protocol for predicting and directing special data collections (tasking CUMULOS to point and collect imagery at specified locations and times) corresponding to occasional simultaneous nadir overpasses (SNO) with the Suomi-NPP and NOAA-20 satellites. The SNO enables head-to-head comparisons with the currently operational Day/Night Band, for the exact same cloud/surface conditions and the same viewing geometry.

<u>*Analysis and Prioritization of DNB/CUMULOS Conjunctions:*</u>

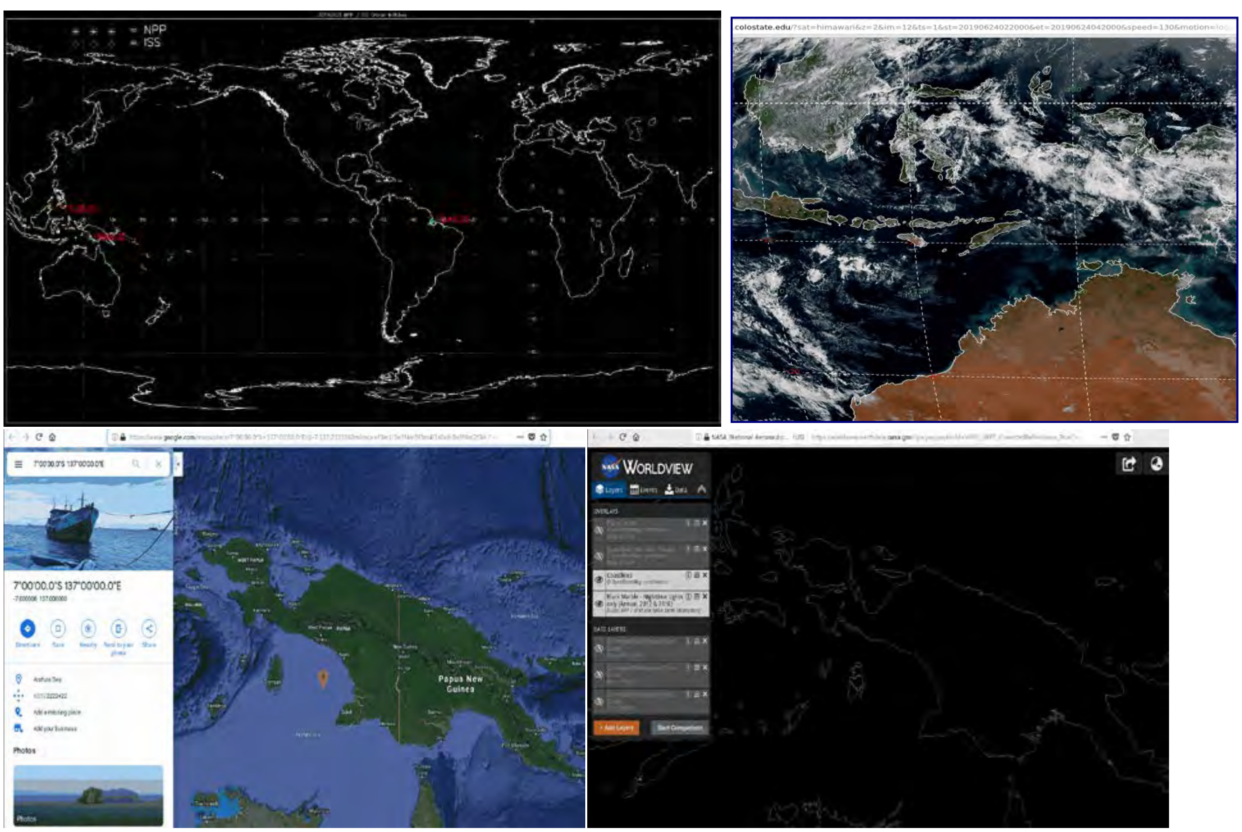
From the start of the project until 27 September 2019, the CIRA team generated predictions of the DNB/CUMULOS conjunctions (simultaneous nadir overpasses) between the NASA/ISARA satellite, which carries the CUMULOS instrument, and either Suomi-NPP (S-NPP) and NOAA-20. Both S-NPP and NOAA-20 carry the DNB as part of VIIRS.

As part of a bi-weekly procedure, a set of conjunctions for the ensuing 14 days was produced, based on updated orbital elements. A map, showing the conjunctions, along with an accompanying text file which provides the match-details (location and time) at 30 second temporal resolution, is provided for each day of the prediction series. As the programs and procedures were improved, the prediction period was increased to four weeks.

Each conjunction was analyzed for viability as a candidate for tasking CUMULOS. The criteria include location, day/night illumination, lunar phase and elevation (if night), and possible surface features of interest (e.g., anthropogenic lights). The regional weather forecast was also considered, to determine whether surface or meteorological targets should be the driving consideration for the potential collection. This information, along with a link to the Google maps location, was then compiled for the most promising candidates and sent to our collaborators at Aerospace.

By April 2019, much of this process had been automated over ocean areas and used going forward. The new automation code allows for filtering by any of the added flags or combination of flags. For example, the auto-created file can contain all cases, or only night-time cases, or only night-time overland cases with satellites within 100 km, etc. Such tools would potentially be useful for future conjunction prediction and selection protocols, either subjective (based on human assessment of interesting cases) or objective (based on the data and rules applied to them). (See Figure 2)

Date: 06/29/2019
Time: 15:58 UTC, local solar time 01:05:07, Night
Location: 6.62S 136.99E, over ocean



Link to google map , and World View , and Slider

Lunar Phase: Waning Crescent with moon 17.1% illuminated

Lunar Elevation: Moon above the horizon
Satellite: NPP, **min distance between satellites** : 439.37 km
Location Details: over Ocean, **distance to land**: 153.22 km
Description:
Forecast:

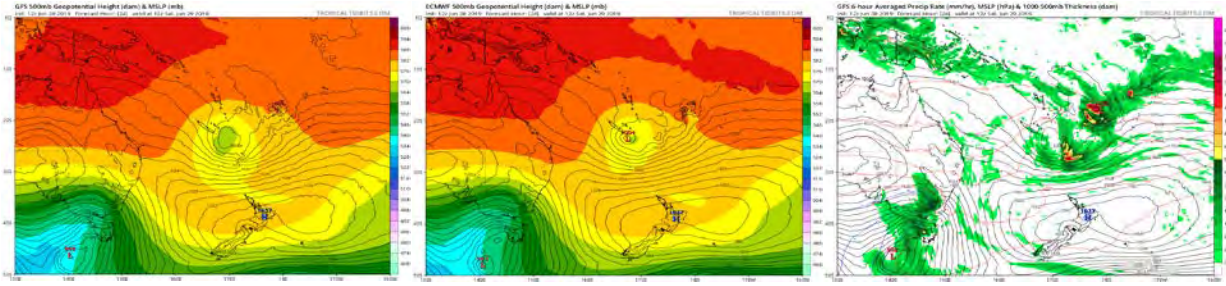


Figure 2 : *Example of a data compilation from the automated conjunction analysis system.*

Using this information, Aerospace decided which times/location the CUMULOS satellite should collect images. It then uplinked commands to ISARA and downlinks the collected data in non-real-time. Sometimes the downlinks fail—a challenge that is not unique to CUMULOS but to small satellites in general. This is an important factor (ensuring high-fidelity downlink from low-power systems) when NOAA considers possibly pathways toward SmallSat/CubeSat solutions to its next-generation satellite architecture. The CUMULOS results are shared with CIRA for match-up to VIIRS/DNB and subsequent analysis by both teams.

Analysis of Previous DNB/CUMULOS Conjunctions:

The above analysis produced several conjunctions between DNB and CUMULOS. This continued until October 2019. Per guidance from Dee Pack (Aerospace), the CUMULOS sensor is currently in a state where Aerospace will not be doing any more collections due to battery performance issues. While not the full range of moonlight conditions we had hoped for, there is a nice sampling. An initial analysis of the cloud cover for the VIIRS-CUMULOS conjunction case near Wakayama, Japan on November 30, 2018 shows the promise of this work. VIIRS cloud retrieval products were processed in the Clouds from AVHRR Extended (CLAVR-x) processing system, which is a development/transition tool for NOAA operational algorithms.

These preliminary results show that we are in good position to begin a detailed quantitative analysis of CUMULOS and DNB observations for various cloud products, as derived by the NOAA Enterprise cloud algorithms.

Aerospace has provided CIRA with calibrated and geo-referenced CUMOLOS digital data for various conjunctions with VIIRS. Dee Pack completed a set for several conjunction collects: 1) Witjira, Australia, 2) Wakayama, Japan, 3) Ocean Collect 5, New Zealand, and 4) Issyk Kul, Kyrgyzstan. He has also sent us an ftp site to get the data. Curtis Seaman has obtained the data and provided VIIRS data to Aerospace to match. So far, Dee and Curtis have concentrated on the Issyk Kul and Ocean 5 cases. This begins the head-to-head comparisons between the two data sets. It should enable pseudo calibration and to use CUMULOS for part of the DNB swath in NLCOMP (Nighttime Lunar Cloud Optical and Microphysical Properties), part of the NOAA Enterprise cloud product suite.

3.2 Analysis and Prioritization of DNB/NIRAC Conjunctions

In June 2019, a new opportunity to interact with Aerospace emerged, involving the new Near-InfraRed Airglow Camera (NIRAC) sensor on the International Space Station (ISS). The agility of the existing code reduced the task to simple modifications, acquisition of the new ISS Two Line Element (TLE), and construction of new output repositories.

The format and procedure followed for ISS/NIRAC were essentially the same as with ISARA/CUMULOS through September. Any daytime scenes for which successful conjunctions are captured will likely do comparisons against the VIIRS 1.6 micron (M10 and I3) bands, while nighttime comparisons will focus on the DNB unless the scene happens to capture a hot fire (e.g., natural gas flare). The VIIRS 1.6 micron bands do not hold low-light sensitivity, but the powerful gas flare emissions have been shown to be detectable at night.
A special reprocessing using updated two-line-elements was done for the period when Hurricane Dorian was making its way toward the Bahamas. We analyzed one conjunction near the path of Hurricane Dorian, for which information was forwarded immediately to the NIRAC Team with hopes that a collection could be made for this record-breaking storm. Given the power of the system, significant gravity wave activity was noted in the Day/Night Band overpasses across several nights. It is likely that NIRAC would have captured even more powerful nightglow wave signals, as its response is in a stronger part of the Meinel hydroxyl (OH*) airglow band.

From September thru December 2019, CIRA decided to try a different approach to the conjunctions predictions. Images showing the orbit conjunctions were provided for each day and each satellite set, along with the lunar phase for that day. A training slide (see Figure 3) was also included to facilitate interpretation of the graphics.

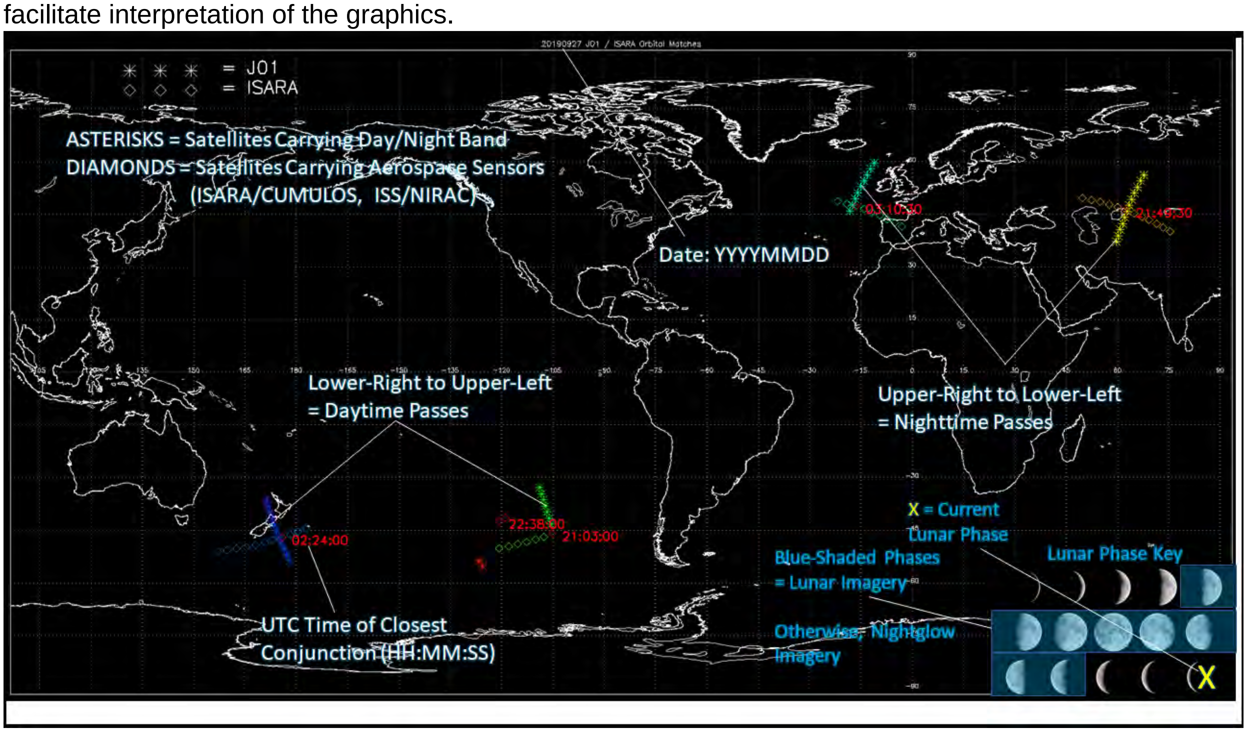


***Figure 3**: Training slide for orbit conjunctions.*

<u>Analysis of Previous DNB/NIRAC Conjunctions:</u>
The analysis of DNB and NIRAC is still in the initial stages. Figure 4 (provided by Aerospace) shows a comparison of NIRAC and VIIRS under mostly clear-sky, moonlit conditions. We are still looking forward to seeing the NIRAC data and making our own comparisons against the DNB, especially to see how surface light signals differ and how much stronger airglow signals (including gravity wave structures) appear at 1.6 μm on moonless nights. An outstanding question is to what extent the direct upwelling emissions from airglow produce contamination that can obscure the meteorological cloud features.

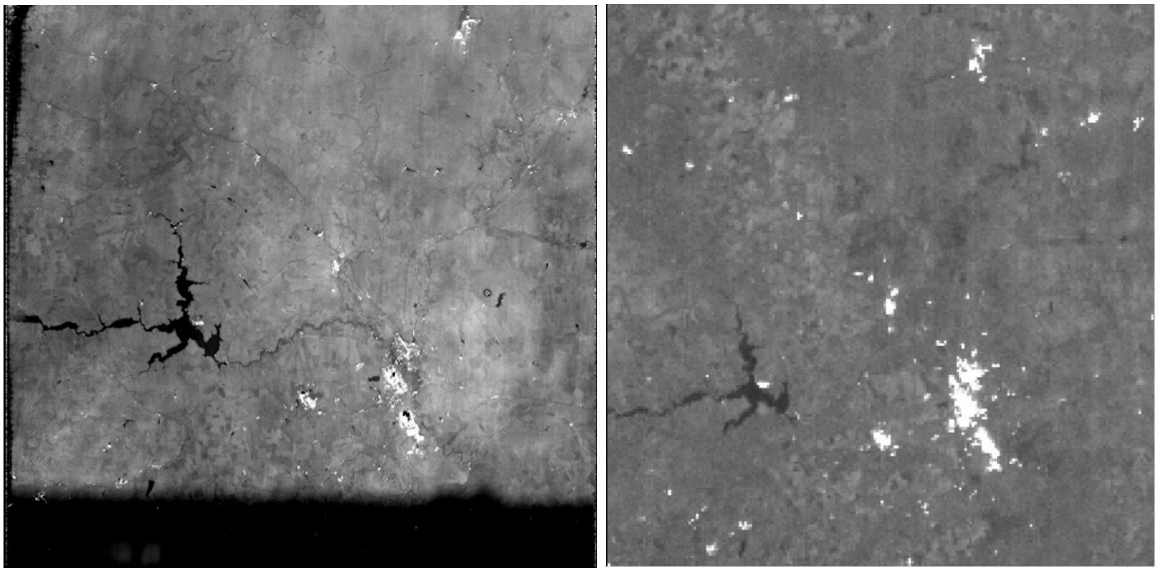


Figure 4*: Approximate matching scenes from 9/13/2019 at 22:02 UTC from NIRAC (on the left) and VIIRS DNB (on the right), courtesy L. Gelinas (Aerospace).*

4. DNB CubeSat Orbital Analysis

The VIIRS instrument, which includes the Day/Night Band, currently flies on the Suomi NPP and NOAA 20 satellites in sun-synchronous (98.7° inclination) orbits at an altitude (above the equator) of 824.0 km. The purpose of this portion of the project is to investigate what other orbits should be considered for use with CubeSats or small satellites carrying DNB instruments. During this phase of the research, we focused on sun-synchronous orbits.

Three questions were considered:

4.1 What swath width (or maximum instrument scan angle) is necessary to provide no-gap coverage at different latitudes for satellites flying at different altitudes?

4.2 How can the overlap of consecutive swaths be used to improve temporal coverage?

4.3 How can multiple satellites be utilized to improve coverage?

Short summaries of the detailed studies conducted to answer question A – C are given below:

4.1 The swath width and the maximum scan angle for contiguous (no gap, no over-lap) swaths of nadir-scanning instruments on sun-synchronous satellites at a range of orbital altitudes were calculated. Detailed tables of these calculations were provided. These calculations could be used as requirements for proposed instruments/satellites; although, adding a 10% margin was recommended. The tables were designed for interpolation for use in trade studies.

4.2 Swath overlap offers the opportunity to observe points more frequently than the standard twice-per-day observation of sun-synchronous satellites. At high latitudes, for instruments/satellites with a wide swath width, a small area around the poles can be observed every orbit. For areas south of about 70° N (or north of 70° S), depending on swath width, points can be observed for a maximum of 3 or 4 consecutive orbits, followed by a gap of 3 or 4 orbits, before the following ascending (or descending) orbit exhibits a similar pattern. At the equator, only the edges of each swath can be observed a second time. To further increase observation frequency from low Earth orbit requires multiple satellites.

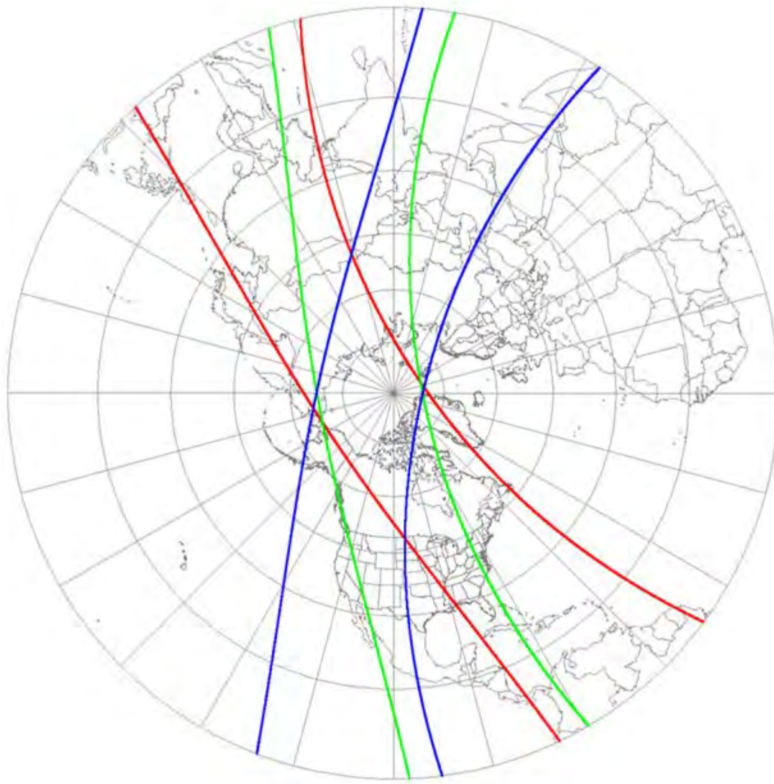


Figure 5: *Three swaths from a satellite flying at a 400 km altitude (similar to the International Space Station). See discussion below for details.*

4.3 To achieve better temporal resolution than swath overlap on a single satellite can provide, one needs to either use orbits different than sun-synchronous or employ multiple satellites. Four possibilities were explored:

1. A single satellite flying directly over the poles could provide observations every orbit for an area the width of the swath centered on the pole(s).
2. Two satellites in sun-synchronous orbits at the same altitude and flying in the same orbital plane, but on opposite sides of the Earth (like Suomi NPP and NOAA 20 do) provide a second observation of every point after a delay of 51 minutes (i.e., one half of the orbital period).
3. A suite of seven satellite pairs (like Suomi NPP and NOAA 20) could provide observations of every point on Earth each 51 minutes (see Fig. 8).
4. Formation flying, as in NASA's A-Train, could be used to have a suite of satellites fly the same ground track delayed by, say, 15 minutes to provide geostationary-like coverage for part of the day (see Figs. 10 & 11).

Many other orbital strategies could be employed to optimally utilize suites of CubeSats/SmallSats carrying Day/Night Band instruments.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Miller, S. D, 2019: TMP 18-08: Evaluation of Next-Generation Satellite Architecture Solutions to Nocturnal Low-Light Visible Observations in the Arctic and Beyond. *TMP Annual Review Meeting,* NCWCP, College Park, MD 21 October 2019.

Miller, S. D., W. C. Straka III, C. J. Seaman, Y.-J. Noh, and L. D. Grasso, 2019: The Power of the Dark Side: Visible Applications in Dark Environments, Revisited (VADER). *2019 American Meteorological Society Joint Satellite Conference with EUMETSAT*, Boston, MA, 29 September – 4 October 2019.

Seaman, C. J., K. Micke, Y.-J. Noh, J. F. Dostalek, S. Finley, S. D. Miller, D. W. Hillger, 2019: Polar Slider: A Website for the Display of Global Polar-Orbiting Satellite Data in Near Real-time. *2019 American Meteorological Society Joint Satellite Conference with EUMETSAT*, Boston, MA, 29 September – 4 October 2019.

Miller, S. D., W. C. Straka III, C. J. Seaman, Y.-J. Noh, and L. D. Grasso, 2019: The Power of the Dark Side: Visible Applications in Dark Environments, Revisited (VADER). *NESDIS JPSS-PGRR Seminar Series*, 18 September 2019, remote.

Miller, S. D., 2019: TMP 18-08: Evaluation of Next-Generation Satellite Architecture Solutions to Nocturnal Low-Light Visible Observations in the Arctic and Beyond. *OPPA Brown Bag TMP (NESDIS/STAR Technology Maturation Program) seminar*, 22 August 2019, remote.

Miller, S. D., 2019: Introduction to the JPSS VIIRS Day Night Band. NOAA/NASA Satellite Meteorology Summer Workshop. CIRA, Fort Collins, CO, 8-19 July 2019

PROJECT TITLE: Evaluation of Small-Satellite Architectures to Address the Future Needs of the NOAA Enterprise and its Stakeholders

PRINCIPAL INVESTIGATOR: Christian Kummerow

RESEARCH TEAM: Steven Miller, Milija Zupanski, Ting-Chi Wu, Anton Kliewer, Lewis Grasso, Haidao Lin, Wesley Berg, Richard Schulte, James Fluke, Philip Partain, Heather Cronk

NOAA TECHNICAL CONTACT: Harry Cikanek and Sid Boukabara, NOAA/NESDIS/STAR

NOAA RESEARCH TEAM: Changyong Cao, Kevin Garrett, Tony Reale, Flavio Iturbide-Sanchez

PROJECT OBJECTIVES:

- To explore quick and agile methodologies to entrain small-satellites that have limited lifetimes into the NOAA processing stream.
- To develop workflows that would allow NOAA, once it has identified an upcoming mission, to work with partners to ingest, calibrate, validate, and exploit these data in a minimum amount of time.
- To allow NOAA to better exploit upcoming constellations of very small satellites that have a very limited lifetime, as well as help NOAA assess the full utility of some small constellations of

satellites being considered by the NOAA Satellite Observing System Architecture (NSOSA) study team.

- To utilize current and potential future small satellites instruments such as:
    - Microwave humidity sounder from the TEMPEST-Demonstration radiometer sounder to be launched in June 2018
    - Wind profiles from the European Space Agency's ADM Aeolus sensor, to be launched in Fall 2018

PROJECT ACCOMPLISHMENTS SUMMARY:

Efforts at CIRA follow an end-to-end pathway that is based initially on existing concepts. The process begins with identification of candidate CubeSat and/or SmallSat sensors, coordinating with the Principal Investigators to share their data and any relevant processing algorithms. These data are then ingested by CIRA, as a trusted NOAA partner, where they are quality controlled and processed into environmental data records (geophysical parameters) where applicable. Calibration and validation follows, wherein the observations and/or retrievals are assigned uncertainties as required for their assimilation into numerical models. These uncertainty-assigned observations/products are then flowed through the NOAA-compliant data assimilation architecture to demonstrate their potential impact to forecasts. The target time frame for completing this cycle in an operational framework would be approximately 90 days from first light data. It naturally incorporates the development lifecycle of any sensor system and uses that time to develop forward models and assimilation systems that allow for the very rapid decisions required in this framework. This project begins to establish the framework for serving as NOAA's development hub for responding in a rapid and systematic way to nascent satellite technologies.

A number of lessons came out of the CIRA effort to do the necessary work to assimilate and assess the impact of the TEMPEST Microwave Humidity Sounder and the ADM-Aeolus Wind Lidar data into the FV3-GFS operational weather forecast system. Some are obvious, others are more subtle. Three overarching recommendations are:

1. **Appropriate timelines**: When new sensors of interest to NOAA become available, it is imperative to start with a schedule that results in a timely transition to operations if all the intermediate steps indicate a positive impact on forecasts. This will allow for the appropriate level of impact assessments that culminate in a better forecast. We found that even a rapid positive impact would not be useful if the operational upgrades are on a different schedule.

2. **The need for teams**: Rapid data assimilation requires expertise on the instrument side, on the format side (particularly the satellite data format and BUFR formats), Quality Control procedures for the satellite data, Data Assimilation, Verification, and project management to keep the process from freezing at the interface between team members. We found that our team, which had excellent knowledge of the sensor, quality control, data assimilation, and data management spent too much time on BUFR format issues and Verification protocols that could have been avoided had the team included such expertise from the beginning.

3. **Access to the operational forecast system**: This is perhaps obvious and both EPIC as well as improved supercomputer access will be required.

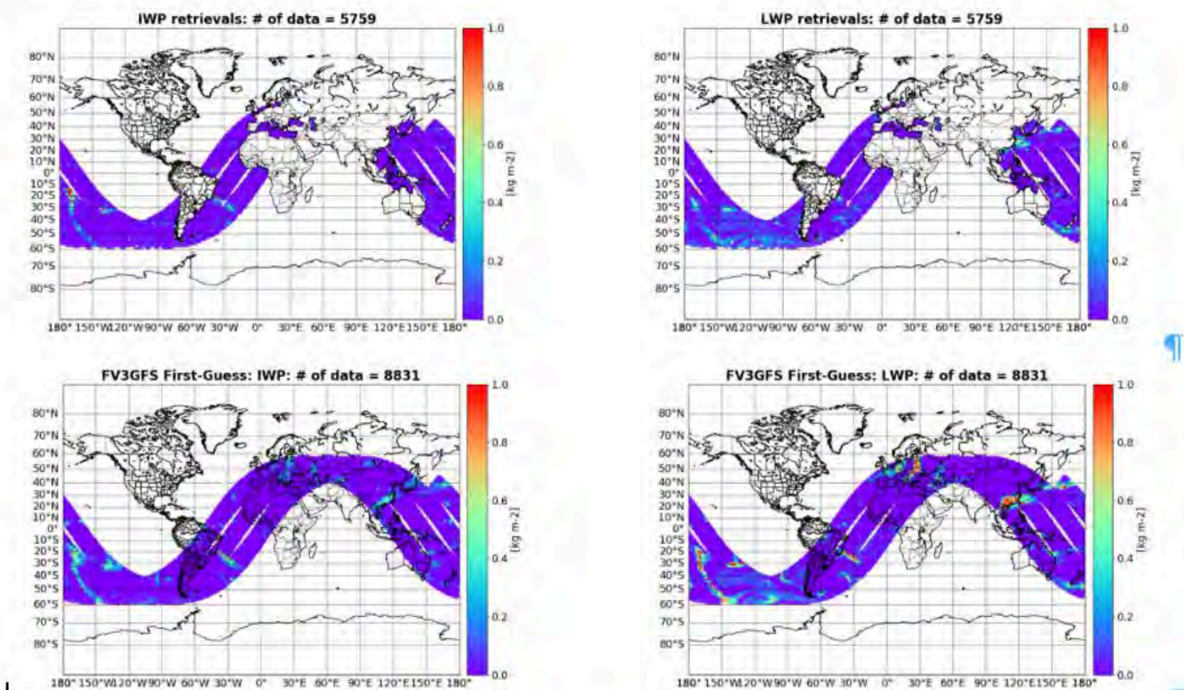


Figure 1: TEMPEST-D Ice Water Path (IWP; kg m-2, left) and Liquid Water Path (LWP; kg m-2, right) retrievals from CSU1DVAR (upper panel) and corresponding IWP and LWP calculated directly from FV3GFS valid at 0600 UTC 8 December, 2019 (lower panel).

PROJECT PUBLICATIONS:

Berg, Wesley et al., 2019: Demonstrating the Viability of the TEMPEST-D CubeSat Radiometer for Science Applications. Presentation at the International Geophysics and Remote Sensing Symposium (IGARSS), Yokohama, Japan, 29 July – 2 August.

Grasso, L. D., T.-C., Wu, H. Cronk, W. Berg, and R. Schulte, 2019: Quality Control of the Small Satellite TEMPEST-D. 2019 Joint Satellite Conference, 28 September to 04 October 2019, Boston, Mass. Poster #133.

Kliewer et al., 2019: Lessons Learned and Initial Assessment of Small Satellite for Data Assimilation: Part II - ADM–Aeolus. Poster presentation at the Joint Center for Satellite Data Assimilation Technical Review Meeting and Science Workshop, Washington, DC, 29-31 May.

Reising, Steven et al., 2019: Data Assimilation of TEMPEST Brightness Temperatures. Poster presentation at the NOAA Emerging Technologies Workshop, College Park, MD, 25-26 June.

Wu, Ting-Chi et al., 2019: Lessons Learned and Initial Assessment of Small Satellite for Data Assimilation: Part I - TEMPEST–D. Poster presentation at the Joint Center for Satellite Data Assimilation Technical Review Meeting and Science Workshop, Washington, DC, 29-31 May.

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: GOES History CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting

PRINCIPAL INVESTIGATORS: Thomas Vonder Haar, Gerald J. Dittberner

RESEARCH TEAM: John Forsythe

NOAA TECHNICAL CONTACT: Dan Lindsey

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

- Research history of geostationary orbiting operational weather satellites.
- Present results of this geostationary orbiting operational weather satellites study at AGU and AMS conferences.
- Generate appropriate publications, and provide periodic reports.

PROJECT ACCOMPLISHMENTS SUMMARY:

The first seven months of weather satellite history research have been productive and informative. Attached is a list of papers presented. They include selected US operational geostationary weather satellite accomplishments discussed at major science, forecasting and technical meetings. Thus far we highlighted major program technical advances, scientific discoveries, forecasting improvements and lessons learned from the first 3 decades (1960 – 1990). We have found a greater volume of important historical material than anticipated. Community interest and discussion of our early results has been high.

Four reader groups have been identified as foci for the continuing historical research and the NESDIS report / monograph we will prepare. They are a) NOAA NESDIS leaders, planners and advisors, b) weather forecasters and modelers, c) the scientific community and d) the next generations of operational satellite meteorologists to provide the heritage and lessons learned from 60 years of advances in this field.

Based upon the early results and an assessment of the research work and documentation to be done to cover the entire 60-year period we propose a one-year extension of the projects at the same level of effort.

PROJECT PUBLICATIONS:

Richard A. Anthes, Mark W. Maier, Steve Ackerman, Robert Atlas, Lisa W. Callahan, Gerald J. Dittberner, Richard Edwing, Pamela G. Emch, Michael Ford, William B. Gail, Mitch Goldberg, Steve Goodman, Christian Kummerow, Terrance Onsager, Kevin Schrab, Chris Velden, Thomas Vonderhaar, and James G. Yoe, 2019: Developing Priority Observational Requirements from Space using Multi-Attribute Theory. *Bull. Amer. Meteor. Soc.*, **100**, 1753-1773, https:/doi.org/10.1175/BAMS-D-18-0180.1.

PROJECT PRESENTATIONS/CONFERENCES:

Dittberner, G. J. and T. H. Vonder Haar, 2019: TIROS-1 and the History of the First Decade of Weather Satellites. Presentation 3.1, 17*th* *History Symposium*, Amer. Meteor. Soc., 99th Annual Meeting, January 7, 2019, Phoenix, AZ.

Dittberner, G. J. and T. H. Vonder Haar, 2019: TIROS-1 and the History of the First Decade of Weather Satellites. Presented in 15th Annual Symposium on New Generation Operational Environmental Satellite Systems, Amer. Meteor. Soc., 99th Annual Meeting, January 10, 2019, Phoenix, AZ.

Dittberner, G. J. and T. H. Vonder Haar, 2019: TIROS-1 and the History of the First Decade of Weather Satellites. Invited presentation at the Amer. Meteor. Soc. Washington Forum, Mar 29, 2019, Washington, D. C.

Dittberner, G. J. and T. H. Vonder Haar, 2019: From TIROS-1 to JPSS and GOES-R: An Historical Review of Early Operational Satellites and Instruments as a Basis for Shaping the Future Together. Presentation 10.2, Session Celebrating the 60th Anniversary of the First Weather Satellite, its Evolution, and International Partnership; 2019 Joint AMS-EUMETSAT-NOAA Satellite Conference. October 2, 2019, Boston, MA.

Vonder Haar, T. H. and G. J. Dittberner, 2019: History of Science Discoveries and Their Applications. Presentation 10.3, Session Celebrating the 60th Anniversary of the First Weather Satellite, its Evolution, and International Partnership; 2019 Joint AMS-EUMETSAT-NOAA Satellite Conference. October 2, 2019, Boston, MA.

Dittberner, G. J., 2019: DMSP Heritage Review – The History of Early Operational DMSP Satellites and Instruments. Presentation at USAF 557th Weather Functional Review. December 10, 2019, Washington, DC.

Vonder Haar, T. H., G. J. Dittberner, and J. Forsythe, 2019: Early Weather Satellites Detect and Help Warn of Natural Weather Disasters and Hazards (Invited). Poster presented as poster 0764 in Session IN53D of Satellites Providing Critical Support for Environmental Disaster Monitoring and Response: From TIROS-1, the United States First Weather Satellite, to the Current of Environmental Satellites – Posters, American Geophysical Union 2019 Fall Meeting. December 13, 2019, San Francisco, CA.

Callahan, A. J., G. J. Dittberner, and T. H. Vonder Haar, 2020: TIROS Origins: How Military and Civilian Organizations Contributed to the First Weather Satellite System. Presentation 3.1, at the 16th Annual Symposium on New Generation Operational Environmental Satellite System, 100th Amer. Meteor. Soc., January 13, 2020, Boston, MA.

Dittberner, G. J. and T. H. Vonder Haar, 2020: TIROS-1 Established the Foundation for Today's Remarkable Environmental Satellite Systems. Presentation 3.2 at the 16th Annual Symposium on New Generation Operational Environmental Satellite System, 100th Amer. Meteor. Soc., January 13, 2020, Boston, MA.

Vonder Haar, T. H., G. J. Dittberner, and J. Forsythe, 2020: Early Weather Satellite Observations Energized the History of Science Discoveries and Weather Forecasting. Presentation 3.3 at the 16th Annual Symposium on New Generation Operational Environmental Satellite System, 100th Amer. Meteor. Soc., January 13, 2020, Boston, MA.

PROJECT TITLE: GOES-R FDTE Sat Training Liaison - CIRA support to GOES-R Training: The Satellite Hydro-Meteorology (SHyMet) Education and Outreach Program & GOES-R commitment to the WMO CGMS Intl VLab & GOES-R FDTD

PRINCIPAL INVESTIGATOR: Bernadette Connell

RESEARCH TEAM: A. Schumacher

TECHNICAL CONTACT: Dan Lindsey NOAA/NESDIS/GOES-R

NOAA RESEARCH TEAM: Kevin Scharfenberg and Brian Motta, NOAA/NWS/OCLO/ Forecast Decision Training Division, Jim LaDue, NOAA/NWS/OCLO/Warning Decision Training Division

PROJECT OBJECTIVES:

This project supports a Satellite Training Liaison (Andrea Schumacher) at the Cooperative Institute for Research in the Atmosphere (CIRA) as a link between the Geostationary Operational Environmental Satellite R Series (GOES-R) program and National Oceanic Atmospheric Administration (NOAA) operational end users primarily at National Weather Service (NWS) Offices and National Centers. The Satellite Training Liaison is devoted to connecting and enhancing communication between satellite algorithm developers, trainers, and forecasters, to ensure that feedback and user needs are communicated back to the developers and trainers to best serve operational needs.

An overarching objective of the Liaison is to evaluate current training needs, develop a training plan, and then develop and deliver comprehensive distance-learning materials and courses on satellite hydrology and meteorology, in particular for the enhanced capabilities of the Geostationary Operational Environmental Satellites (GOES): GOES-R/16 and GOES-S/17. The development of training materials is an ongoing process that includes establishing foundational materials, providing applications training to ensure relevancy of products and usage in the forecast process, and encouraging continued use and deeper understanding of imagery and products over time. The project effort is coordinated with the NWS Office of the Chief Learning Officer (OCLO) in particular the Forecast Decision Training Division (FDTD) in Boulder, CO and the Warning Decision Training Division (WDTD) in Norman, OK.

Specific Objectives:
1-- Gain familiarity with the satellite training community and work with the operational community to better understand their satellite training usage and needs and identify training gaps.
2-- Help develop, improve, and share operations-focused satellite training.

PROJECT ACCOMPLISHMENTS SUMMARY:

1-- Gain familiarity with the satellite training community and work with the operational community to better understand their satellite training usage and needs and identify training gaps.

- Attended the Radar Applications Course at the National Weather Center in Norman OK to observe and interact with participants and meet with members of CIMMS and WDTD (4/14-17)
- WFO/National Center visits – documented the use of satellite data in operations (WFO Norman 4/16, Storm Prediction Center 4/17)
- Attended the Hazardous Weather Testbed (HWT) at the National Weather Center in Norman OK to observe and interact with participants during the Experimental Warning Project (5/12-17)
- Attended the Satellite Applications Workshop, Kansas City MO (7/30-8/1)
- Attended AMS Joint Satellite Conference, Boston MA (9/29-10/4) and presented on forecaster cognitive load.

- Feedback from interactions is being used to inform plans for HWT Spring 2020. Overall assessment will also inform future forecast visits and the development of a survey of forecaster product usage and training gaps.

2-- Help develop, improve, and share operations-focused satellite training.

- Took over management of VLAB Satellite Training and Operations Resources (STOR)
- Assisted in development of a new snow squall training exercise for Winter WOC (helped with analysis of satellite data)
- Helped Warning Decision Training Division (WDTD) staff update satellite-related content in Winter Warning Operations Course (WOC) modules
- Member of the NCEP Training Identification Effort (TIDE) representing Satellite Training. This group formed in summer 2019 and is working to develop National Center-specific AWIPS-II training.
- Worked with co-instructors K. Musgrave and C. Slocum to develop a 30-minute hands-on exercise for the AMS Annual Meeting satellite short course on the use of satellite data in forecasting tropical cyclones.

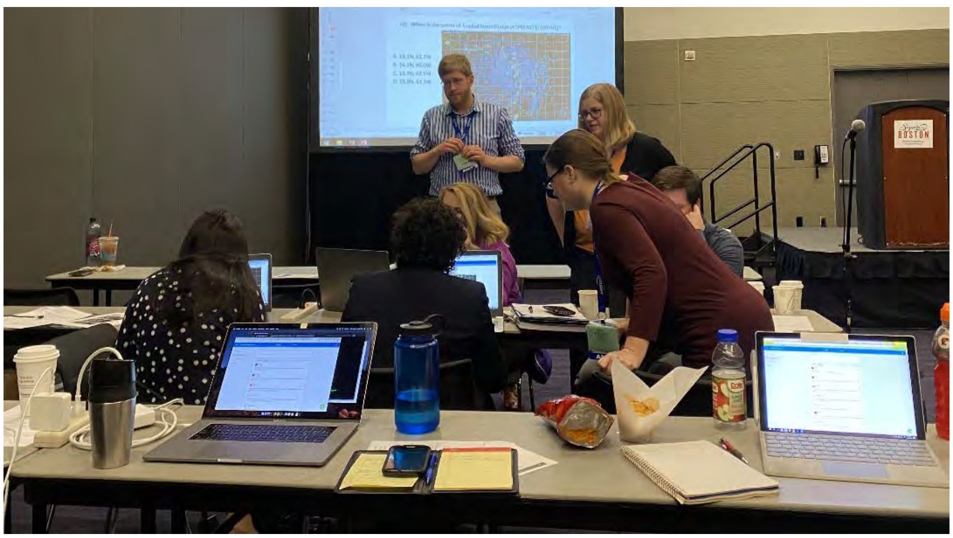


Figure 1. A. Schumacher (back row, right) and colleagues guiding a hands-on training exercise on using satellite data to forecast hurricanes at the AMS Annual Meeting on 12 January 2020.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Schumacher, A. B., J. LaDue, and K. Scharfenberg, 2019: Identifying Best Practices for Integrating GOES Imagery and Products into Short Term Forecasting and Warning Decision Making. AMS Joint Satellite Conference, 9/29-10/4 2019. Presentation.

PROJECT TITLE: GOES-R ML ABI Airmass - CIRA Support for GOES-R Risk Reduction projects using GOESR ABI Data combined with Machine Learning Techniques

PRINCIPAL INVESTIGATOR: Kyle Hilburn

RESEARCH TEAM: Steven D. Miller

NOAA TECHNICAL CONTACT: Dan Lindsey (NOAA/NESDIS/STAR/RAMMB)

NOAA RESEARCH TEAM: Chris Slocum (NOAA/NESDIS/STAR/RAMMB)

PROJECT OBJECTIVE:

The main **objective** of this project is to develop machine learning (ML) approaches for analyzing GOES imagery in the same way as human forecasters to derive information about airmasses. Individual pixel radiances do have some limited information for improving vertical profiles of temperature and moisture (*Li et al., 2020*), however this is not how human forecasters use the imagery. Our **hypothesis** is that the spatial and temporal patterns in the satellite imagery (and not the individual pixel radiances) are what carry the information content utilized by human forecasters.

PROJECT ACCOMPLISHMENTS SUMMARY:

One of the best explanations of how human forecasters (at the Storm Prediction Center) use satellite imagery from GOES was given by *Line et al. (2016)*, summarizing:

- Water vapor imagery is used for long- and short-wave troughs, moisture plumes and dry slots, jet streaks, regions of convergence and divergence
- Infrared and visible imagery is used for cloud-cover trends to assess impact on diurnal heating for potential destabilization and convective initiation
- Visible imagery, “the workhorse”, is used to identify wave and billow clouds indicating stable layers, cumulus development and convective initiation, orphan anvils indicating weakening of the capping inversion, surface boundaries

Note that forecasters are not using the satellite data in isolation, but in the context of NWP forecasts. Thus, the information forecasters get from satellite data are used to mentally increment NWP outputs (offsetting in space, time, and magnitude) to produce the most realistic forecast scenarios.

Starting with the large-scale, we evaluated the spatial information in three sets of water vapor channels: C09-alone (i.e., GOES heritage), all three GOES-R water vapor bands (C08, C09, C10), and the Airmass RGB product. The question of the best dataset to use for training to is nontrivial: HRRR provides the greatest number of observations but the vertical profiles are from a model, while RAOBs provide few observations but have the most detailed vertical structure (although representativeness may be an issue). Since our goal is to capture spatial patterns, we decided HRRR was the better choice. To start with, and to keep the datasets relatively small, we used the 0Z and 12Z times from HRRR for training over the two-year period 2018-2019 with an 80-20% chronological training-validation split, yielding 1120 training and 280 validation samples. The validation samples come from the period August-December 2019. This is done over a portion of the HRRR grid that is 1536 x 1024, chosen as powers of two to avoid padding in the pooling layers. We are using the 500 mb layer because of its meteorological significance and because it is near the peak of C09 (at 442 mb).

Table 1 provides the results for a Convolutional Neural Network (CNN) that is based on the U-Net architecture used in biomedical image segmentation (*Ronneberger et al., 2015*) with three encoding layers and three decoding layers. Regardless of input, the best correlation is with the relative humidity

(RH), which is physically expected based on radiative transfer theory (*Soden, 1998*). Use of C09-alone does surprisingly well, better in fact than the Airmass RGB. However, the Airmass RGB uses the ozone band to capture tropopause folds and jet streaks, which are not represented by these 500 mb variables. The best performance comes from use of the three water vapor bands on GOES-16, which provides a huge improvement in skill over C09-alone. It is interesting that the water vapor imagery also contains information about temperature (TMP) and geopotential height (HGT), which are correlated for a barotropic fluid. Note that the results in **Table 1** are for a network that has a total of 7 layers, but since we are interested in large-scale patterns, we would expect that a deeper network would provide meaningful improvements. Testing an 11-layer network (5 encoding/decoding layers) gives R^2 values of 0.75, 0.77, and 0.75 for HGT, TMP, and RH – confirming our expectations. **Figure 1** shows an example of the performance of the 11-layer network using as input the three water vapor bands from GOES.

Table 1. Coefficient of determination (R^2) for validation samples training GOES inputs (columns) to HRRR variables (rows) at 500 mb with a sequential 7-layer CNN trained over 50 epochs.

	C09	**C08, C09, C10**	**Airmass RGB**
HGT	0.3687	0.6390	0.3531
TMP	0.4035	0.6479	0.3965
RH	0.4829	0.6925	0.3902

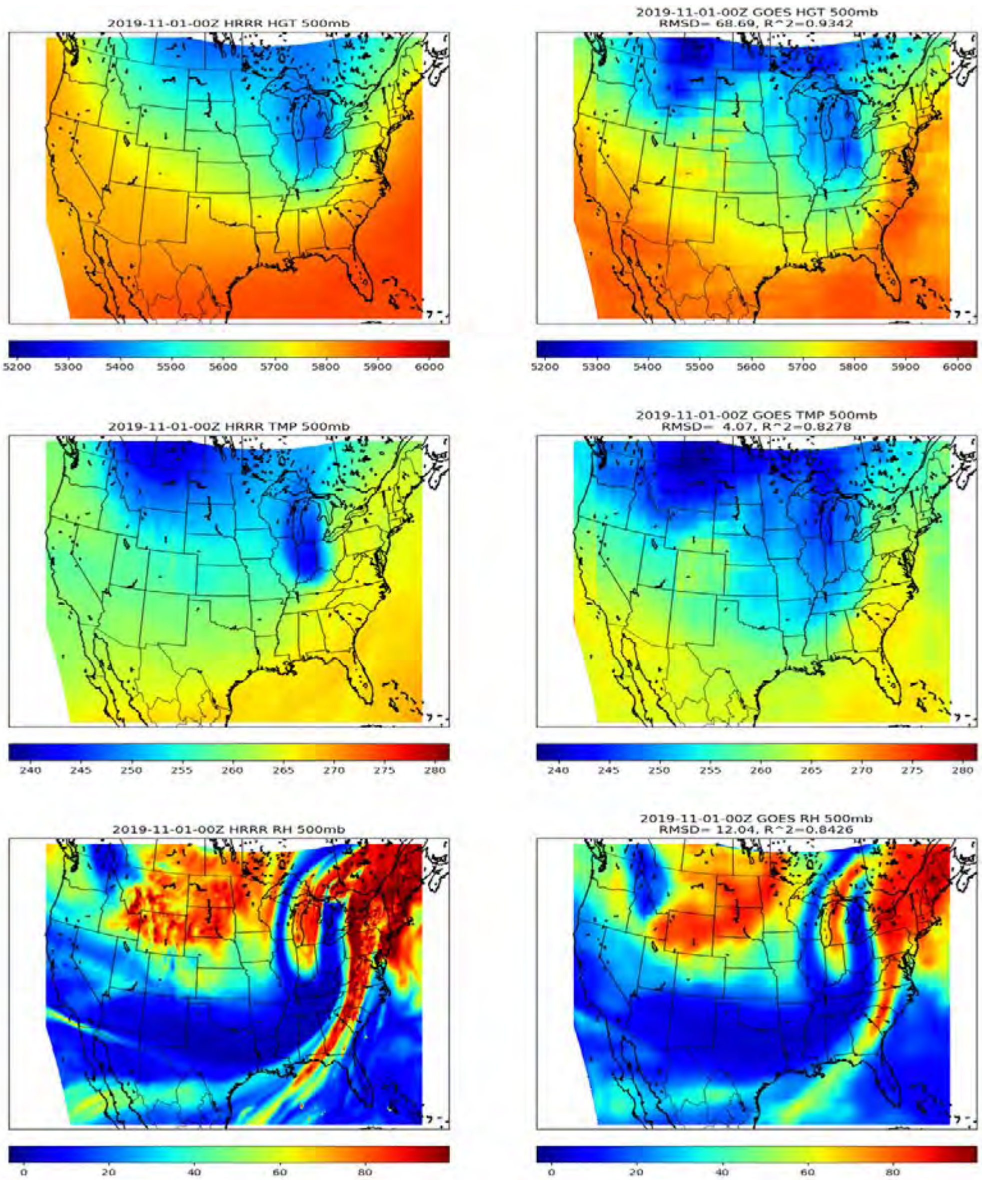


Figure 1. Results for validation sample 2019-11-01 00Z for HGT (top), TMP (middle), and RH (bottom) giving HRRR truth (left) and GOES prediction (right) using the 11-layer CNN with inputs: (C08, C09, C10). These results provide **strong evidence in support of our hypothesis**: individual GOES radiances obviously do not provide direct information about the 500 mb geopotential height, but it is the spatial patterns of water vapor that contain the information content. *Hilburn et al. (2020)* used experiments comparing 3x3 versus 1x1 convolutional filters to confirm that even when individual pixel radiance information saturates, as in heavy precipitation, radiance gradients carry a great deal of information content, and this is what provides the breakthrough skill for ML compared to traditional retrieval approaches.

Future Work: We plan to carry out experiments with deeper networks, up to a maximum of 21 layers (10 encoding / decoding layers) for the image size used here. While evaluation of training and validation convergence plots did not reveal overfitting for the 11-layer network, we expect to encounter this with deeper networks. The remedy will be to use observations at additional times-of-day (e.g., every 6, 3, or 1 hours). We have also noticed that the predictions are less skillful during the summer, and additional analysis and experiments are needed to assess the value of predictions at all times-of-year. Note that we have trained on individual variables in order to assess information content, but we expect that by training on all three variables together (HGT, TMP, RH) the network will learn the co-variance among them, leading to further improved predictions. We also plan to examine the use of split-window/tri-window radiances for estimation of low-level boundary layer water vapor.

We will extend our work using spatial convolutions (2D) to use spatio-temporal convolutions (3D) for visible and infrared imagery, and our early results suggest that the Day Cloud Phase product is the best one for characterizing the convective state. For training cloudy scenes, *Hilburn and Miller (2019)* showed that conditioning on HRRR samples that are in good agreement with GOES is a successful strategy. We seek to provide spatial maps of CAPE and CIN using the space-time information in cloud field evolution. This requires separating local changes from advective changes, and we have begun incorporating dense optical flow estimates from Jason Apke (CIRA) into our prediction model for that purpose.

Acknowledgements: Thank you to NOAA RDHPCS for access to the Fine Grain Architecture (i.e., GPU) System on Hera HPC, without which this research would not have been possible.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Hilburn, K. and S. D. Miller, 2019: Airmass Properties from GOES ABI Using Machine Learning. *1st Workshop on Leveraging AI in the Exploitation of Satellite Earth Observations and Numerical Weather Prediction*, College Park, MD, 23-Apr.

PROJECT TITLE: Creating Synthetic Microwave Imagery Using Goes-R L1b and L2+ Baseline Products for Improved Hurricane Monitoring and Rainfall Estimation Using Machine Learning

PRINCIPAL INVESTIGATORS: Chris Slocum and Kate Musgrave

RESEARCH TEAM: Chris Slocum, Kate Musgrave, Robert DeMaria

NOAA TECHNICAL CONTACT: Dan Lindsey NOAA/NESDIS/GOESR Program

NOAA RESEARCH TEAM: John Knaff

PROJECT OBJECTIVES:

- Create a database of L1b and L2+ products to test daytime features

- Derive a machine learning algorithm for daytime synthetic 89-GHz

- Extrapolate daytime model to nighttime 89-GHz

- Evaluate daytime and nighttime synthetic 89-GHz

PROJECT ACCOMPLISHMENTS SUMMARY:

GOES-R Product Database:

- Database put together of L1b and L2+ GOES-R products
- Products tested for selection to adjust initial machine learning algorithm (see Figure 1)
    - L1b:

        - Bands: 2, 4, 5, 7, 8, 10, 11, 12, 13, 15
        - Differences: 10-8, 7-13, 12-13, 7-15, 15-13, 13-11
        - Ratios: 4/2, 5/2
    - L2:
        - Geometric thickness, cloud top & base, cloud liquid water path
    - Issues with large correlations amongst IR channels
- Experiments conducted with GOES-R RGB products to reduce dimensionality

Daytime algorithm:

- Initial daytime-only machine learning algorithm has been developed
- Multiple tests underway to improve performance and reduce dimensionality
    - Laplacian filter
    - Principle component analysis
    - Additional L1b and L2+ product assessment for inclusion

Nighttime algorithm:

- Design of nighttime algorithm and identification of products to replace daytime-only components underway

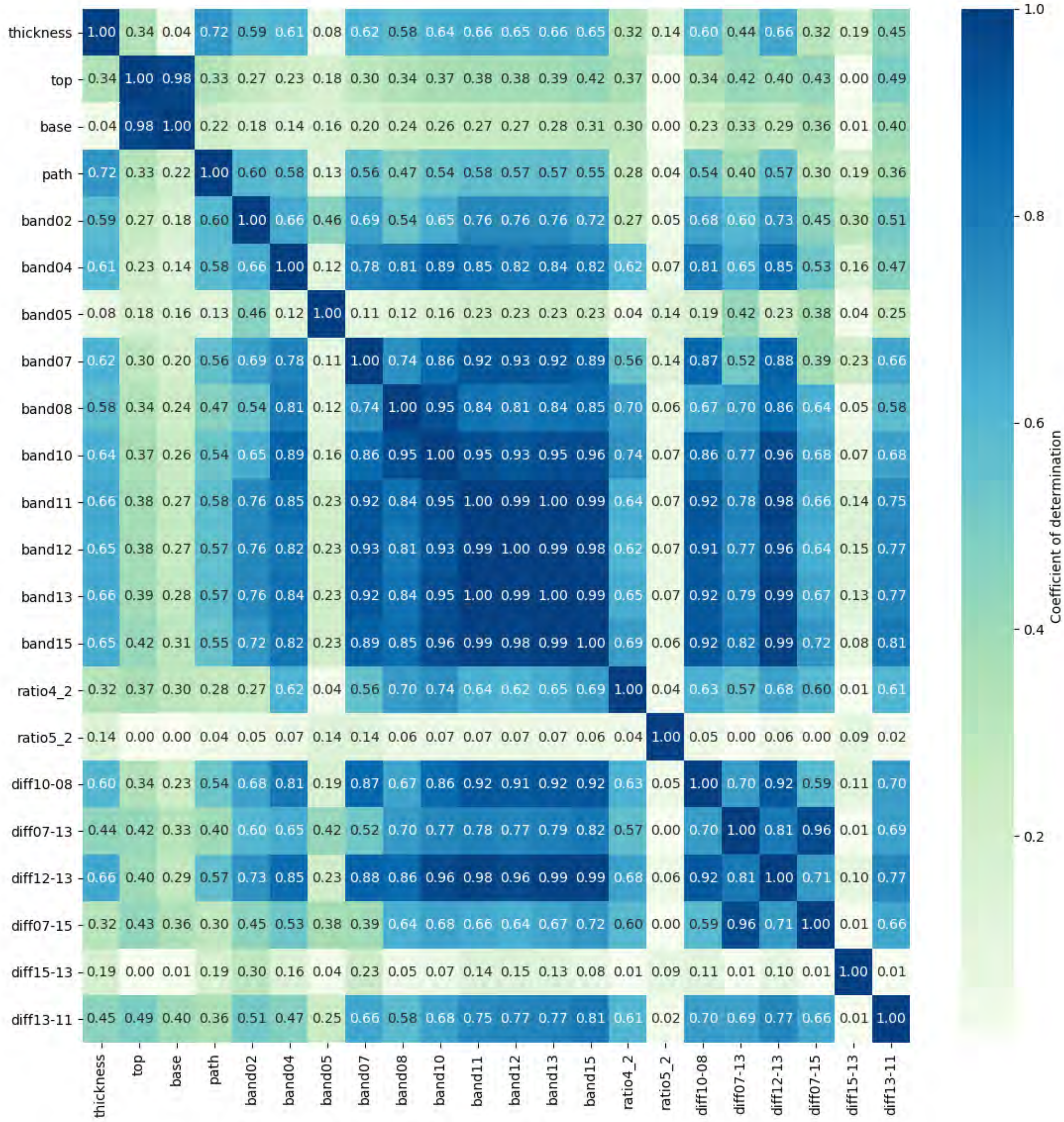


Figure 1. Correlation map of selected L1+ and L2 products for use in selecting products to test adjustments to initial machine learning algorithm.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Slocum, C. J. and J. A. Knaff, 2020: Using Geostationary Imagery to Peer through the Clouds Revealing Hurricane Structure. 100th AMS Annual: 19th Conference on Artificial Intelligence for Environmental Science. Boston, MA. J43.1.

PROJECT TITLE: GOES-R VLAB- CIRA support to GOES-R Training: The Satellite Hydro-Meteorology (SHyMet) Education and Outreach Program & GOES-R commitment to the WMO CGMS Int VLab & GOES-R FDTD Satellite Training Liaison

PRINCIPAL INVESTIGATOR: Bernadette Connell

RESEARCH TEAM: Erin Sanders, Luciane Veeck, Rosario Alfaro

NOAA TECHNICAL CONTACT: Dan Lindsey GOES-R Program Science Office

NOAA RESEARCH TEAM: Kevin Scharfenberg NWS/OCLO/FDTD, Natalia Donoho NESDIS/OSPO

PROJECT OBJECTIVES:

The World Meteorological Organization (WMO) Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) is a collaborative effort joining major operational satellite operators across the globe with WMO regional training centers of excellence in satellite meteorology. Those regional training centers serve as the satellite-focused training resource for WMO Members. Through its cooperative institute for Research in the Atmosphere (CIRA) at Colorado State University (CSU), NOAA/NESDIS sponsors Regional Training Centers of Excellence (CoE) in Argentina, Barbados, Brazil, and Costa Rica.

The top-level objectives of the VLab are:

1-- To provide high quality and up-to-date training and supporting resources on current and future meteorological and other environmental satellite systems, data, products and applications;
2-- To enable the regional training centers to facilitate and foster research and the development of socio-economic applications at the local level through the National Meteorological and Hydrological Services. Enhanced training and coordination of training that is specifically targeted for the JPSS series satellites and accomplished under this project will prepare forecasters, researchers, and managers on how to utilize imagery and products to provide services and training in these areas. Other CIRA RAMMB projects are leveraged to meet the VLab top level objectives.

Specific Objectives:

1. Represent CIRA and NOAA training interests in the WMO VLab and its management group (VLMG)
2. Provide training opportunities for the International Community: Provide virtual GOES imagery and product examples while also providing partial monthly support for international virtual Regional Focus Group sessions. Prepare GOES training materials for workshops using blended learning approaches.
3. In support of NOAA commitments to the WMO VLab, provide travel support for VLab trainers, and coordinate Spanish translation for GOES-related training materials.

PROJECT ACCOMPLISHMENTS SUMMARY:

1. Represent CIRA and NOAA training interest in National and International Training and Coordination Groups:
    - Participated in WMO virtual and in-person meetings associated with VLab, VLMG, and the WMO Coordination Group on Satellite Data Requirements (SDR).
    - Coordinated and collaborated with NOAA through participation in NOAA GEONETCast Americas (GNC-A) Coordination Group webinars, the JPSS Training Initiative, the Satellite International Training Working Group (SITWG) calls, and AmeriGEO calls.

2. Provide training opportunities for the International Community:

- During January through December 2019, CIRA/WMO VLab Regional Focus Group (RFG) conducted 12 monthly bilingual (English/Spanish) virtual sessions. A total of 31 different countries participated throughout the year. The RFG weather and climate briefings have connected instructors, researchers, forecasters, and weather enthusiasts and enabled them to view geostationary and low earth orbiting imagery and products, and to share information on weather patterns, hurricanes, severe weather, flooding, volcanic eruptions, and other significant events. http://rammb.cira.colostate.edu/training/rmtc/fg_recording.asp

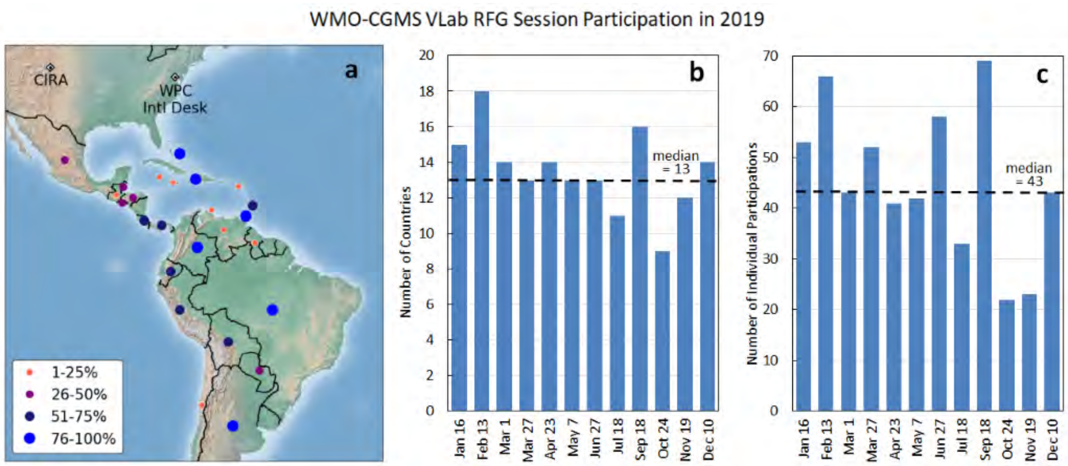


Figure 1. Participation in the 2019 Regional Focus Group sessions is summarized by (a) relative participation by country (% of total) for WMO Regional Associations (RA) III and IV, (b) number of countries participating by session (includes countries outside RA III and IV), and (c) the number of individual participations by session. (Note: 5 additional countries outside RA III and VI participated.)

- The 2019 WMO/Eumetcal Online Course for Trainers on Blended Learning took place 1 April – 2 June. B. Connell (CIRA) and L. Veeck (VLab TSO) were facilitators for the course and E. Sanders was a participant.

Figure 2. Participants, instructors, and organizers for the NOAA Satellite Workshop during AmeriGEO Week, 21-23 August 2019 in Lima, Peru.

- Coordinated with the GOES-R, JPSS, and GNC-A program offices, the NWS Office of International Affairs (IA), the NWS/WPC International Desk, the Meteorological and Hydrological Service (SENAMHI) of Peru and many others to develop and deliver a 2.5-day training on New Generation Geostationary and Polar Orbiting Satellite Imagery and Products to meet GEO priority areas. The workshop was held during AmeriGEO Week in Lima, Peru 19-23 August, 2019. Fifty-four people attended the live training (Peru, Bolivia, Costa Rica, and Paraguay) with additional remote participation from 38 people (Peru, Argentina, Brazil, Costa Rica, Ecuador, and Uruguay).

http://rammb.cira.colostate.edu/visitview/custom/AmeriGEOweek_Aug2019/AmeriGEOweek_Aug2019_Short.html

- B. Connell, L. Veeck, and E. Sanders developed and co-hosted the “WMO VLab Train the Trainers Workshop: How Can We Better Utilize Blended Learning in Continuing Professional Development?” held on 28-29 September 2019 prior to the Joint Satellite Conference in Boston, MAThe workshop focused on four topics: data access and display, blended training highlights, a blended learning design activity, and how we can promote continuing professional development. https://vlab.moodlecloud.com/course/view.php?id=3
- CIRA provided support to José Gálvez for workshops at the Paraguay (18-22 November) and Uruguay (25-29 November) Weather Services. José utilized and adapted materials that were prepared by CIRA for the Peru workshop and included content and lab exercises that focused on 1) understanding remote sensing spectra, 2) volcanic eruptions and 3) fires and hot spot identification.

3. Provide travel support for VLab trainers, and coordinate Spanish translation for JPSS-related training materials.
   - CIRA coordinated with NOAA/SIS/IIAD to support travel for three WMO VLab partners, one from the Barbados WMO VLab Center of Excellence (CoE), one from the Brazil WMO VLab CoE, and the WMO VLab Technical Support Officer (Luciane Veeck) to attend the Joint Satellite Conference and WMO VLab Trainer Workshop in Boston, MA, on September 28 – October 4, 2019.
   - Rosario Alfaro translated 4 RGB Quick Guides from English to Spanish. She is currently translating the Regional Focus Group paper that will appear in the WMO Global Campus Initiative publication in the second quarter of 2020.

PROJECT PUBLICATIONS:

Connell, B., M. Davison, J. Gálvez, K-A. Caesar, V. Castro, T. Mostek, E. Sanders, L. Veeck, M. Garbanzo, M. Campos, N. Rudorff, 2020: “Enhancing long-term impacts of training through international collaboration: the case of the VLab Regional Focus Group of the Americas and Caribbean.” WMO Global Campus Innovations Publication. (Accepted; expected to appear in 2nd quarter 2020)

PROJECT PRESENTATIONS/CONFERENCES:

B. Connell, L. Veeck, and E. Sanders developed and co-hosted the “WMO VLab Train the Trainers Workshop: How Can We Better Utilize Blended Learning in Continuing Professional Development?” prior to the Joint Satellite Conference, 28-29 September 2019, Boston, MA.

Connell, B., E. Sanders, and L. Veeck, 2019: “Building Short Examples to Highlight Successful Learning and Meet WMO Competency Guidelines for Satellite Skills for Operational Meteorologists.” Joint Satellite Conference, 30 September – 4 October 2019, Boston, MA.

Connell, B., E. Sanders, M. Davison, J. Gálvez, V. Castro, T. Mostek, K-A. Caesar, L. Veeck, M. Garbanzo, M. Campos, N. Rudorff, 2019: “Insights from 15 Years of Conducting the WMO VLab Regional Focus Group Monthly Sessions for the Americas and the Caribbean”, Joint Satellite Conference, 30 September – 4 October 2019, Boston, MA.

PROJECT TITLE: GOESR Water Vapor Products CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting

PRINCIPAL INVESTIGATOR: John Forsythe

RESEARCH TEAM: Andrew Jones, Stanley Kidder, Lewis Grasso, Natalie Tourville, Daniel Bikos

NOAA TECHNICAL CONTACT: Dan Lindsey, Andrew Heidinger

NOAA RESEARCH TEAM: Limin Zhao (NOAA/NESDIS/OSPO), Mark Klein (NOAA/NWS/WPC), Andrew Orrison (NOAA/NWS/WPC)

PROJECT OBJECTIVES:

This project seeks to answer science questions regarding the applicability of the new GOES-R Total Precipitable Water (TPW) data to improving multisensor TPW products. The GOES-R TPW is being evaluated both by comparison to validation sources and by forecaster comments and quantitative evaluation in testbeds. At project completion, a scientific and user-based foundation will be laid to promote GOES-R TPW products into operational NOAA blended TPW products which are routinely used by forecasters. A companion objection is to explore the utility of simulated cloud-free water vapor derived from passive microwave imagery via comparison to observed GOES-R data.

PROJECT ACCOMPLISHMENTS SUMMARY:

Routine production of GOES-R infused blended TPW products continues. The new TPW products were evaluated in the Hazardous Weather Testbed – Experimental Warning Program (6 weeks; April – June 2019) at the National Severe Storms Laboratory (NSSL) and the Flash Flood and Intense Rainfall (FFaIR) experiment (4 weeks – June-July 2019) at the NOAA Weather Prediction Center (WPC). At both of these experiments, near-realtime Merged Total Precipitable Water (TPW) data was provided in AWIPS-2 format, served via the CIRA LDM. Deb Molenar of the CIRA RAMMB is acknowledged for valuable technical assistance with this delivery.

A wide majority of forecasters (68 and 82 % in HWT and FFaIR,respectively) preferred the new TPW product using GOES-R in clear regions versus the current NOAA operational blended TPW, which does not use GOES-R. Work in the past year built upon forecaster recommendations from the testbeds, including the use of Global Positioning System (GPS)-derived TPW in widespread cloudy regions.

Evaluations of the cloud-free water vapor imagery during this time indicated that it has potential to reveal water vapor structure under clouds. An example of measured and observed 6.9 µm imagery for GOES-17 is shown in Figure 1.

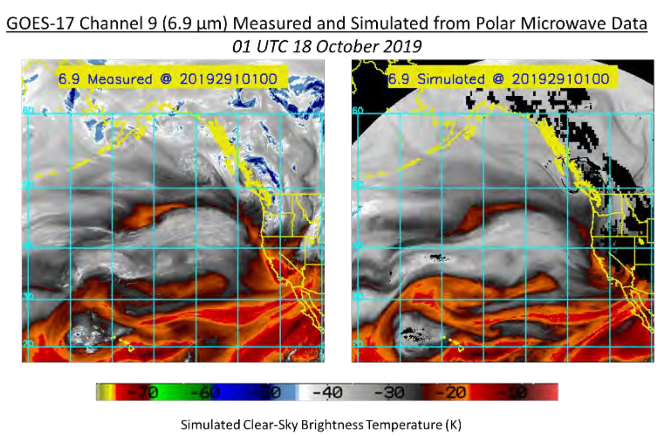


Figure 6: Measured (left) and cloud-free simulated (right) GOES-17 6.9 µm water vapor imagery from 01 UTC 18 October 2019. Black areas in the simulated imagery are missing doe to precipitation or high zenith angle.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Forsythe, J. M., S. Q. Kidder, S. Kusselson, A. Jones, D. Bikos, E. Szoke, 2019: Improving Blended Total Precipitable Water Products for Forecasters Via Advection and Inclusion of GOES-R. Oral presentation at AMS / EUMETSAT Joint Satellite Conference. Boston, MA, Oct. 2019.

PROJECT TITLE: Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Model Using Wind Structure and Eye Predictors

PRINCIPAL INVESTIGATOR: Galina Chirokova

RESEARCH TEAM: Stephanie Stevenson

NOAA TECHNICAL CONTACT: Brian Zachry

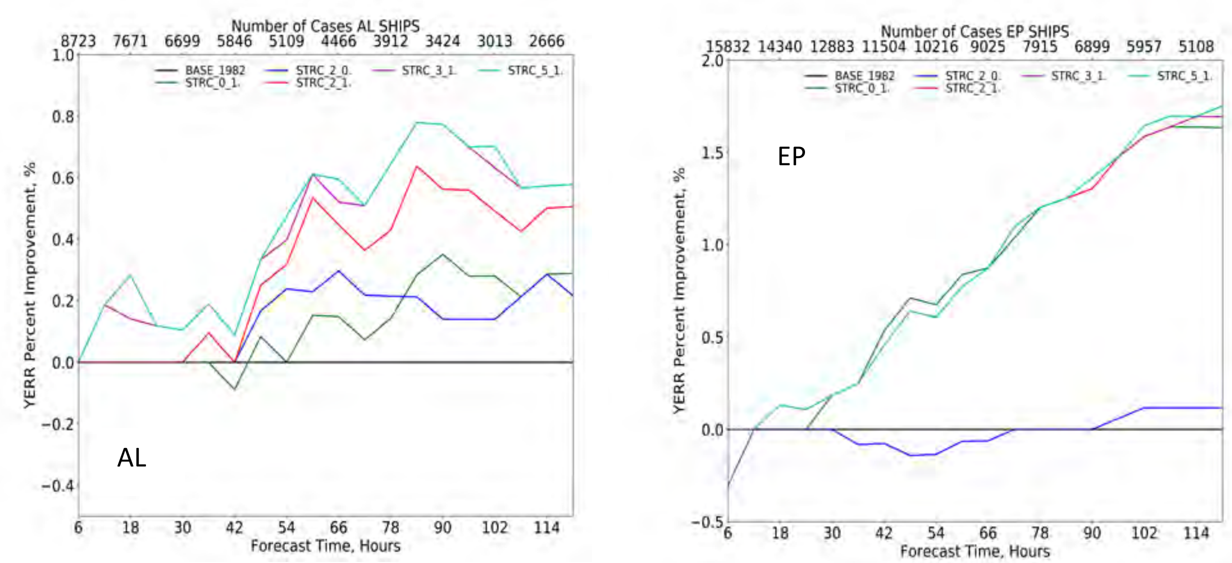
NOAA RESEARCH TEAM: John Kaplan, John Knaff

PROJECT OBJECTIVE:

1) Add a tropical cyclone (TC) wind structure-based predictor or combination of predictors to Statistical Hurricane Intensity Prediction Scheme (SHIPS), the Logistic Growth Equation Model (LGEM), the multi-lead time probabilistic SHIPS Rapid Intensification Index (SHIPS-RII). 2) Add a predictor or a group of predictors based on the probability of the TC eye existence to SHIPS/LGEM, and SHIPS-RII.

PROJECT ACCOMPLISHMENTS SUMMARY:

1. It was found that based on dependent sample testing the addition of six new predictors, including three TC-size parameters at t = 0h, R34 at -6h and -12h, and time-averaged latitude results in most forecast improvements for SHIPS for both Atlantic and east/central Pacific basins, and that the new structural predictors are comparable or greater in importance to many of the existing operational SHIPS-RII



predictors.

Figure 1: Percent improvement in forecast error (Yerr) for the Atlantic (right) and east Pacific (left) for dependent sample tests relative to the 2019 SHIPS. Shown test with added: (1) STRC-0-1 (green line) time-averaged latitude (TLAT); (2) STRC-2-0 (blue line) R5, R34A; (3) STRC-2-1 (red line) R5, R34A, TLAT; (4) STRC-3-1 (magenta line) R5, R34A, RMW, TLAT; and (5) STRC-5-1 (cyan line) R5, R34A, RMW, TLAT and R34 at t = -6 h and R34 at t = -12 h.

2. Dependent sample tests were completed for the 2019 version of SHIPS and RII with SEDR predictors. SEDR-based probability at t = 0 was found to be of greater importance to many of the existing operational SHIPS-RII predictors.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Kaplan J., G. Chirokova, J. Knaff, and M. DeMaria, 2020: An analysis of the effect of wind structure and eye predictors on operational statistical rapid intensity forecast models. HRD Science Meeting, 12 March 2020, Miami, FL.

Chirokova, G., J. Kaplan, and J. Knaff, 2020: Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors. *2020 TCORF, 26 February 2020, Lakeland, FL.*

Kaplan, J, 2019: A Meteorological Double Feature: Part 1: Statistical Rapid Intensity Prediction: A Review of Recent Model Results. Part 2: Preliminary Analysis of Wind Gusts in Recent Landfalling Hurricanes. *CIRA seminar, August 2019, Fort Collins, CO.*

PROJECT TITLE: JPSS-PGRR DNB VADER CIRA Support to JPSS Proving Ground Risk Reduction

PRINCIPAL INVESTIGATOR**:** Steve Miller

RESEARCH TEAM: Curtis Seaman, Yoo-Jeong Noh, Louie Grasso, Scott Longmore, Cindy Combs,

NOAA TECHNICAL CONTACT: Mitch Goldberg

NOAA RESEARCH TEAM: Don Hillger

PROJECT OBJECTIVES:

This project continues and expands upon the extremely productive and high-profile FY16-17 '*Pursuit of Shadows*' research program showcasing the VIIRS Day/Night Band (DNB). The research, led by CIRA in collaboration with CIMSS, is a core activity for DNB data exploitation, and supports myriad existing (and emerging) PG Initiatives through a multifaceted scope of nocturnal light applications and lunar modeling research. The project focusses on the fact that now dual DNB observations, displaced by 50 min, are available from the S-NPP/JPSS-1 tandem. The temporal information from this '*Revisit*' promises a new and exciting ability to characterize features through motion/change. These capabilities apply to artificial lights (ship motion, power outages, disasters) and natural-lights (e.g., fire lines, lightning activity, features seen in moon glint, and gravity waves in nightglow) alike. The revisit will also provide key information relevant to the ongoing search for bioluminescent ship wakes and milky seas. Continued development and validation of our lunar irradiance model, fundamental to quantitative DNB applications, will be extended to accommodate the DNB on JPSS-1. Compelling early findings related to DNB nocturnal cloud detection, and false cloud assignment by the VIIRS cloud mask in certain coastal zone environments, will be examined. Our cutting-edge DNB research tied to nocturnal nightglow, and specifically the information content residing within gravity wave observations as related to convective, tropical cyclone, frontal, terrain-induced, and potentially earthquake and tsunami-induced, will continue. This scope of research, enabled by the novel DNB observations and demonstrated by previous JPSS-PGRR support of our Team, is completely unique to the JPSS program and positions it on the true frontiers of science and discovery, and aligns with NOAA's Strategic Goal for a *Weather Ready Nation.*

This work is being conducted in collaboration with University of Wisconsin-Madison CIMSS. Our Teams interface closely with the JPSS Satellite Liaison to communicate DNB capabilities and interface with operational users and coordinate support of the relevant PGIs listed above.

PROJECT ACCOMPLISHMENTS SUMMARY:

Milestone 1: Continued S-NPP/NOAA-20 Monitoring for Use-Cases, Algorithms and Training

Polar-SLIDER: CIRA provides S-NPP and NOAA-20 VIIRS imagery on RAMSDIS Online and the SLIDER (includes Polar SLIDER) website. The URLs for these websites are provided below. The CIRA Team continues to monitor events worldwide. Polar SLIDER is becoming increasingly popular within the VIIRS user community. **Figure M1** shows an example of the Northern Hemisphere view on Polar SLIDER (from 20 November 2019) that blends NOAA-20 and S-NPP imagery.
http://rammb.cira.colostate.edu/ramsdis/online/npp_viirs_arctic.asp

http://rammb-slider.cira.colostate.edu/?sat=jpss

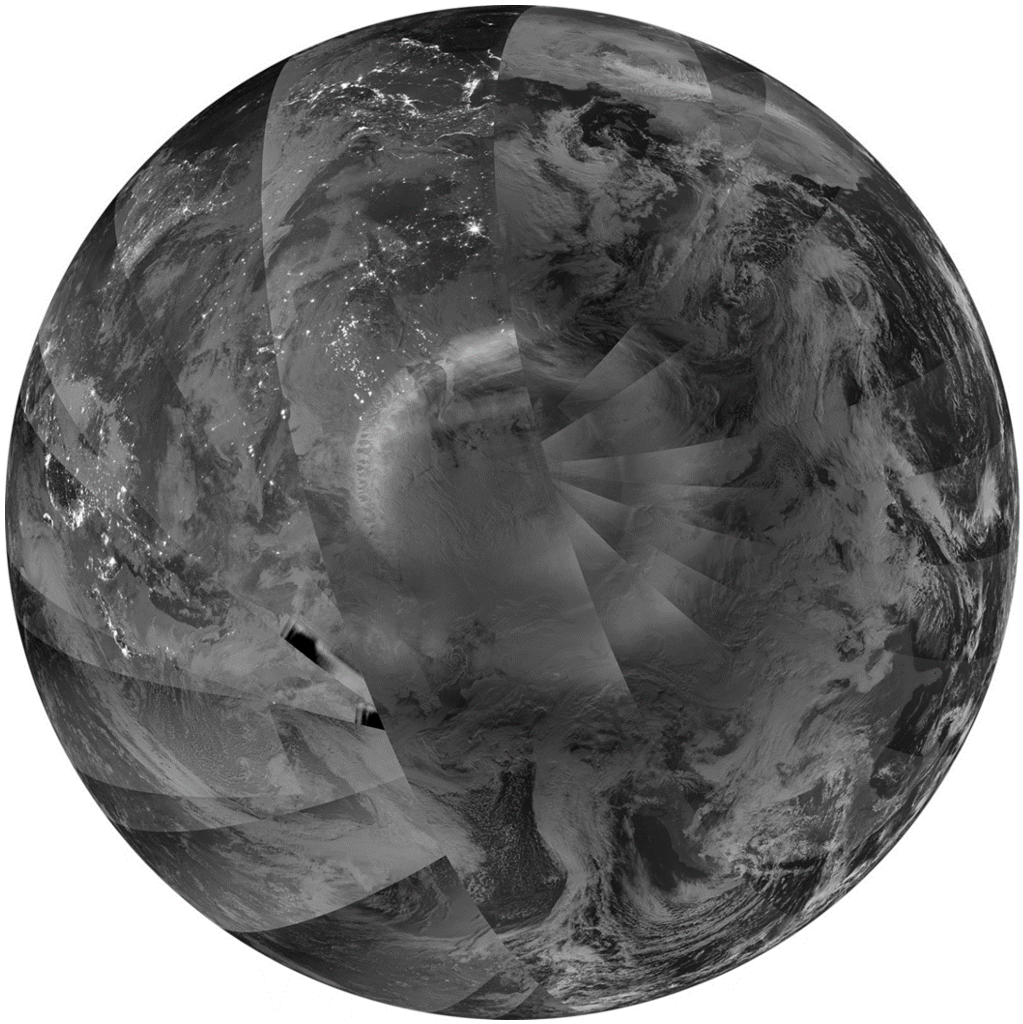


***Figure M1**: CIRA's Polar SLIDER, Day Night Band (combination of S-NPP and NOAA-20), Northern Hemisphere view from 20 November 2019, 22:43 UTC.*

C. Seaman attended the AOMSUC-10 in Melbourne, Australia (2-6 December 2019). He participated in the pre-conference training event led by Bodo Zeschke (Australia Bureau of Meteorology/BoM) that took place at the Royal Melbourne Institute of Technology (RMIT) on 2-3 December 2019. Of the ~45 attendees of this training event, approximately half were forecasters from Asia and the South Pacific island nations including (but not limited to): Australia, New Zealand, Fiji, Samoa, Solomon Islands, Indonesia, Laos, and the Maldives. **During the first day of the training event, C. Seaman provided a 45 min. hands-on training session on SLIDER that included a demonstration of Polar SLIDER**

Seven project-related oral presentations and one Short Course were held at the 2019 Joint AMS-EUMETSAT Satellite Conference in Boston, MA (30 September - 4 October 2019). For details see section:

DNB-VADER CIMSS Team S-NPP/NOAA-20 Monitoring
DNB Imagery and Applications for Various Events Occurring Worldwide were generated by William Straka (CIMSS), a member of the DNB-VADER research team and also the JPSS Disasters Outreach Coordinator. In this dual-hat capacity, Straka has been supporting VADER via a focus on S-NPP/NOAA-20 dual observations of significant weather events, providing a wealth of case studies from which to draw for detailed analysis of temporal information content and application development.

<u>Milestone 2</u>: Design algorithms and demonstrate visualization of ship light vectors, fire line motion, and tropical cyclone LLCC

Steve Miller met with Larry Connor and Sean Helfrich (NOAA/StAR) to discuss DNB capabilities in the Arctic, and how it might complement the NOAA CoastWatch and PolarWatch programs. Miller emphasized some of the unique capabilities of the DNB over conventional infrared observations in terms of seeing through thin cirrus clouds to reveal sea ice. The traditional observations used by the PolarWatch program are synthetic aperture radar (SAR), which also see through clouds, but are limited in their coverage. Here, the DNB may provide complementary information.

Another aspect discussed was the high temporal resolution afforded by the dual Suomi-NPP/NOAA-20 system. The optical flow (OF) technique was discussed as a possible tool for determining vector motion for sea ice. Helfrich agreed to provide a SAR imagery pair for the CIRA team to evaluate with OF.

Steve Miller and Yoo-Jeong Noh met with Prof. Sunghyun Nam in Seoul, South Korea, to discuss parts of this research. Prof. Nam is an expert in ocean dynamics, and we have enlisted his help in understanding some aspects of the false low-cloud at night problem. Specifically, we are considering the underlying mechanisms that could explain the timing and locations of certain false low cloud signatures, a subset of which appear to be related to tidal mixing. Through these discussions we developed a better understanding of when to expected surface conditions that are most conducive to mixing and cool water upwelling. These mixings are related to the tides.

<u>Milestone 3</u>: Evaluation of NOAA-20 Lunar Reflectance Calculations at Salar de Uyuni.

In support of our work on the Lunar Reflectance Model, EUMETSAT colleague Sebastian Wagner has provided us with an updated MSG lunar view database, which we will use to assess behavior near the full moon.

We gathered data for Salar de Uyuni evaluation of the JPSS-1 DNB, based on the updated lunar irradiance model described in last Quarter's report (adapted to the NOAA-20 DNB response function). This data is being used for checking for day/night consistency of the NOAA-20 reflectance, as well as for consistency between NOAA-20 and Suomi NPP.

We started gathering data for new moon periods over a multi-year dataset to search for any starlight signal in the DNB observations. The premise is that there is a seasonal variation of starlight (e.g., northern hemisphere summers have more starlight than winters, since the night-side of the earth is pointing toward the center of the Milky Way galaxy in the summer).

<u>Milestone 4</u>: Expand Analysis of False Clouds into a Predictive Tool

Specific case studies were saved that demonstrate a false low-level liquid cloud signature. One case in particular occurred in late July 2018; a GeoColor image from GOES-16 ABI at 0600 UTC 30 July 2018 is shown in **Figure M4**. A numerical simulation of this case was done in order to obtain atmospheric variables to be used in radiative transfer modeling. A direct comparison of sea surface temperatures (SST) in the simulation and buoy observations showed that values of simulated SSTs were too large by about 6 Kelvin. Radiative transfer was conducted with the NOAA operational Community Radiative Transfer Model (CRTM). Based on observed SSTs, simulated SSTs were reduced 6 K to be consistent with observations. It was able to capture a simulated false low-level liquid cloud signature in the waters southeast of Cape Cod, Massachusetts and over George's Bank. Values of the channel difference, Tb (10.35) – Tb (3.9) of +1.0 to +1.5 are consistent with observations from ABI. During a collaboration with Magdalena Andres, a scientist at the Woods Hole Oceanographic Institute, we learned about a physical mechanism which explains the “false cloud features”. Briefly, George’s Bank is an elevated plateau below the ocean surface. As a result, the shallow water above the Bank are susceptible to significant surface stresses resulting in vertical mixing. The vertical mixing brings cold water from surface of the Bank up to the ocean surface. Surface stresses are in response to the back and forth movement of the ocean over the elevated plateau from lunar tides.

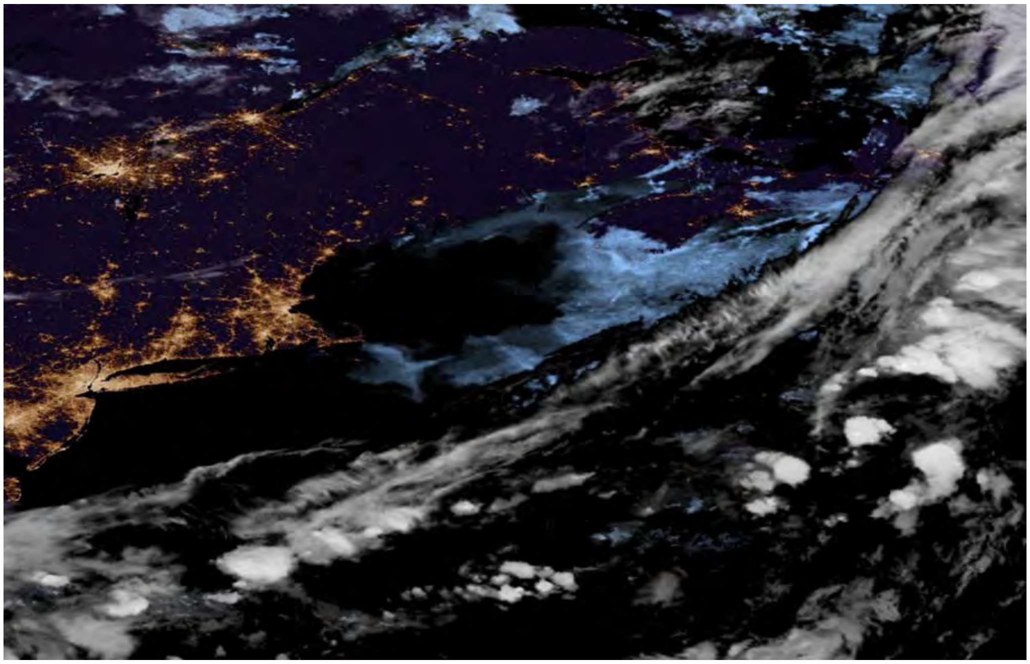


Figure M4: *GeoColor imagery from GOES-16 ABI at 0600 UTC 30 July 2018. City lights are evident for cities while the false-cloud signatures are highlighted in light blue just southeast of Cape Cod, Massachusetts and George’s Bank.*

<u>Milestone 5</u>: Continue Interaction with Partners / Liaisons / Collaborators / PGIs

Interactions with NWS/WFOs:

The DNB-VADER Team continuous to provide frequent examples of DNB imagery and demonstrations on the use of DNB to WFO forecast offices. William Straka (CIMSS) generates DNB (and other VIIRS) imagery for most tropical storms, power outages, wildfire and other natural hazard events which are widely distributed. (See Milestone 1).

JPSS Satellite Liaison J. Torres and CIRA’s WFO Liaison E. Szoke participate in WFO workshops and regularly demonstrate DNB imagery to operational forecasters.

NCC Teletraining for NWS Users was provided by J. Torres twice a month, where NWS offices ‘sign-up’ to take the teletraining.

Interaction with University of Alaska, Fairbanks, GINA:

One of the CIRA products in development is the <u>VIIRS Snow/Cloud Layers product,</u> which uses 11 different VIIRS bands – including the Day/Night Band – to discriminate clouds from snow and ice. GINA (U. Alaska-Fairbanks) is now providing CIRA-produced geoTIFF images to the Alaska Sea Ice Program (ASIP) in real-time. C. Dierking (GINA), J. Cable (GINA), C. Seaman and J. Torres have been coordinating with Mike Lawson (ASIP) on this activity.

Interaction with the National Hurricane Center (NHC):
The DNB-VADER Team continued to provide DNB imagery of tropical storms on the CIRA Tropical Cyclone (TC) Real-Time webpage (near real time and archive available) at:
http://rammb.cira.colostate.edu/products/tc_realtime/

Interactions with NOAA/AWC:
We continued our interaction with Amanda Terborg (CIRA employee, forward-deployed to the AWC). AWC uses the CIRA GeoColor product (including DNB city lights included as an information layer) and has expressed interest in using CIRA's nighttime Snow/Cloud Discrimination product.

Interaction with the JPSS-Satellite Training Advisory Team (JPSS-STAT):
J. Torres, E. Sanders, and B. Connell (all CIRA) are members of the JPSS-Satellite Training Advisory Team (JPSS-STAT) and interact closely with this Training Advisory Team. "Quick Guides" (1-2 page product reference documents) developed as part of this interaction can be accessed via two platforms: NOAA VLab for NWS forecasters, and the CIRA VISIT website for non-AWIPS users. Both web-links are provided below:

NOAA VLAB: https://vlab.ncep.noaa.gov/group/stor/polar2
CIRA VISIT: http://rammb.cira.colostate.edu/training/visit/quick_guides/

Interaction with COMET: J. Torres also provided examples of VIIRS NCC imagery, the VIIRS Active Fire product and NUCAPS retrievals to the COMET program for inclusion in a training module for forecasters on the use of GOES-R and JPSS products for wildfire detection and monitoring.

Attendance in various Proving Ground Initiative (PGI) teleconferences:
The DNB Team participated in the following Proving Ground Initiative (PGI) teleconferences:
Arctic, Aviation, Fire and Smoke, River Ice and Flooding

Milestone 6: Ongoing demonstrations, manuscript preparation, quarterly and other reports, presentations at JPSS-related meetings.

Blogs published:

Title: Polar Opposites (C. Seaman)
http://rammb.cira.colostate.edu/projects/npp/blog/index.php/uncategorized/polar-opposites/

Title: JPSS/GOES Fire Detection Capabilities - Swan Lake, AK (J. Torres)
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2019/09/23/jpssgoes-fire-detection-capabilities-swan-lake-fire-ak/

Title: Australian Wildfires (J. Torres)
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2019/11/18/australian-wildfires/

Training Material produced by J. Torres: **VIIRS NCC Quick Brief**
http://rammb.cira.colostate.edu/training/visit/quick_briefs/ncc/

PROJECT PUBLICATIONS:

Noh, Y.-J., L. D. Grasso, S. D. Miller, 2019: Toward Improvement of Nighttime Cloud Detection Over US Coastal Zones: Observations and Numerical Simulations". In preparation.

Yue, J., S. Perwitasari, S. Xu, Y. Hozumi, T. Nakamura, T. Sakanoi, A. Saito, S. D. Miller, W. C. Straka III, and P. Rong, 2020: Preliminary dual-satellite observations of atmospheric gravity waves in airglow. *Atmosphere*, in press, 2020.

Miller, S. D., D. T. Lindsey, C. J. Seaman, and J. E. Solbrig, 2020: GeoColor: A Blending Technique for Satellite Imagery. *J. Atmos. Ocean. Tech.*, 37(3), 429-448, https://doi.org/10.1175/JTECH-D-19-0134.1.

Solbrig, J. E., S. D. Miller, J. Zhang, L. D. Grasso, and A. Kliewer, 2019: Assessing the Stability of Surface Lights for use in Retrievals of Nocturnal Atmospheric Parameters. *Atmos. Meas. Tech.*, https://doi.org/10.5194/amt-2019-103, Accepted.

Levin, N., C. C. Kyba, Q. Zhang, A. Sánchez de Miguel, M. O. Román, X. Li, B. A. Portnov, A. L. Molthan, A. Jechow, S. D. Miller, Z. Wang, R. M. Shrestha, and C. D. Elvidge, 2019: Remote sensing of night lights: a review and an outlook for the future. *Remote Sensing of Environment*, 237, 111443. https://doi.org/10.1016/j.rse.2019.111443.

Zhang, J., S. L. Jaker, J. S. Reid, S. D. Miller, J. E. Solbrig, and T. D. Toth, 2018: Characterization and application of artificial light sources for nighttime aerosol optical depth retrievals using the Visible Infrared Imager Radiometer Suite (VIIRS) Day/Night Band. *Atmospheric Measurement Techniques*, 12(6), 3209-3222, https://doi.org/10.5194/amt-12-3209-2019.

Xu, S., J. Yue, X. Xue, S. L. Vadas, S. D. Miller, I. Azeem, W. C. Straka III, L. Hoffman, and S. Zhang, 2019: Dynamical Coupling Between Hurricane Matthew and the Middle to Upper Atmosphere via Gravity Waves. *J. Geophys.Res.: Space Physics,* 124(5), 3589-3608, https://doi.org/10.1029/2018JA026453.

PROJECT PRESENTATIONS/CONFERENCES:

Seaman, C. J., K. Micke, D. T. Lindsey, S. D. Miller, Y.-J. Noh, N. Tourville, J. Dostalek, D. Hillger, G. Chirokova and S. Finley, 2019: SLIDER: A website for displaying geostationary and polar-orbiting satellite data in realtime. *10th Asia-Oceania Meteorological Satellite Users' Conference, Melbourne, Victoria, Australia (2 - 6 December 2019)*

Miller, S. D., C. J. Seaman, Y.-J. Noh, L. Grasso, and W. Straka, III, 2019: Unlocking the Potential of the Day/Night Band for Nocturnal Environmental Characterization. *Invited seminar at Seoul National University*, Seoul, S. Korea, 15 November 2019.

Miller, S. D, C. Combs, C. Seaman, S. Kidder, G. Chirokova, and Y. -J. Noh, 2019: TMP 18-08: Evaluation of Next-Generation Satellite Architecture Solutions to Nocturnal Low-Light Visible Observations in the Arctic and Beyond. *TMP Annual Review Meeting,* NCWCP, College Park, MD 21 October 2019.

Miller, S. D., W. C. Straka III, C. J. Seaman, Y.-J. Noh, and L. D. Grasso, 2019: *The Power of the Dark Side:* Visible Applications in Dark Environments, Revisited (VADER). *2019 Joint AMS EUMETSAT Satellite Conference*, 28 September - 04 October, Boston, MA.

Seaman, C. J., K. Micke, Y.-J. Noh, J. Dostalek, S. Finley, S. D. Miller, D. T. Lindsey, N. Tourville and D. Hillger, 2019: Polar SLIDER: A website for the display of global polar-orbiting satellite data in near-realtime. *2019 Joint AMS EUMETSAT Satellite Conference*, 28 September - 04 October, Boston, MA.

J. Solbrig, S. D. Miller, J. Zhang, L. Grasso, A. Kliewer, 2019: Assessing the Variability of VIIRS Day/Night Band Observed Nocturnal Light Sources for Use in Atmospheric Retrievals Via K-Means Clustering. *2019 Joint AMS EUMETSAT Satellite Conference*, 28 September - 04 October, Boston, MA.

Straka III, W.C., B. Sjoberg, S. Li, S. D. Miller, M. Goldberg, 2019: Use of the VIIRS and Other Instruments Other Channels in Disaster Response and Monitoring. *2019 Joint AMS EUMETSAT Satellite Conference*, 28 September - 04 October, Boston, MA

Miller, S. D., W. C. Straka III, C. J. Seaman, Y.-J. Noh,, and L. D. Grasso, 2019: *The Power of the Dark Side*: Visible Applications in Dark Environments, Revisited (VADER). *JPSS-PGRR Seminar Series*, 18 September 2019, remote.

Miller, S. D., .C. Combs, C. Seaman, S. Kidder, G. Chirokova, and Y. -J. Noh, 2019: TMP 18-08: Evaluation of Next-Generation Satellite Architecture Solutions to Nocturnal Low-Light Visible Observations in the Arctic and Beyond. *OPPA Brown Bag TMP (NESDIS/STAR Technology Maturation Program) seminar*, 22 August 2019, remote.

Miller, S. D., 2019: Observing the Night with the VIIRS Day/Night Band. Invited Presentation: NOAA/NASA Satellite Summer Workshop, Ft. Collins, CO, 11 June 2019.

PROJECT TITLE: JPSS-PGRR Gridded NUCAPS in AWIPS CIRA Support to Proving Ground Risk Reduction

PRINCIPAL INVESTIGATOR: Jack Dostalek

RESEARCH TEAM: N/A

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: Kris White, Gail Weaver, Carrie Haisley

PROJECT OBJECTIVE:

This is a collaborative effort by several agencies—CIRA, SPoRT, GINA, NWS. CIRA's objective is to maintain the cold air aloft web page (http://rammb.cira.colostate.edu/ramsdis/online/cold_air_aloft.asp). Although the primary tool of the NWS is AWIPS, the web page is an additional resource, or backup should problems with the AWIPS feed arise.

PROJECT ACCOMPLISHMENTS SUMMARY:

The web page has been, and continues to run for the 2019-2020 cold air aloft season. Below is an image from the web page showing cold air aloft over western Alaska on 28 February 2020.

PROJECT PUBLICATIONS:

Weaver, G.M., N. Smith, E.B. Berndt, K.D. White, J.F. Dostalek, and B.T. Zavodsky, 2019: Addressing the Cold Air Aloft Aviation Challenge with Satellite Sounding Observations. *J. Operational Meteor.,* 3, 1-7.

PROJECT PRESENTATIONS/CONFERENCES:

CIRA participates in the monthly JPSS PGRR NUCAPS Initiative Teleconferences. The participants of those teleconferences are primarily product developers. An additional teleconference consisting of a greater number of user participants, the NUCAPS Users' Group Teleconference, had its first meeting in February 2020.

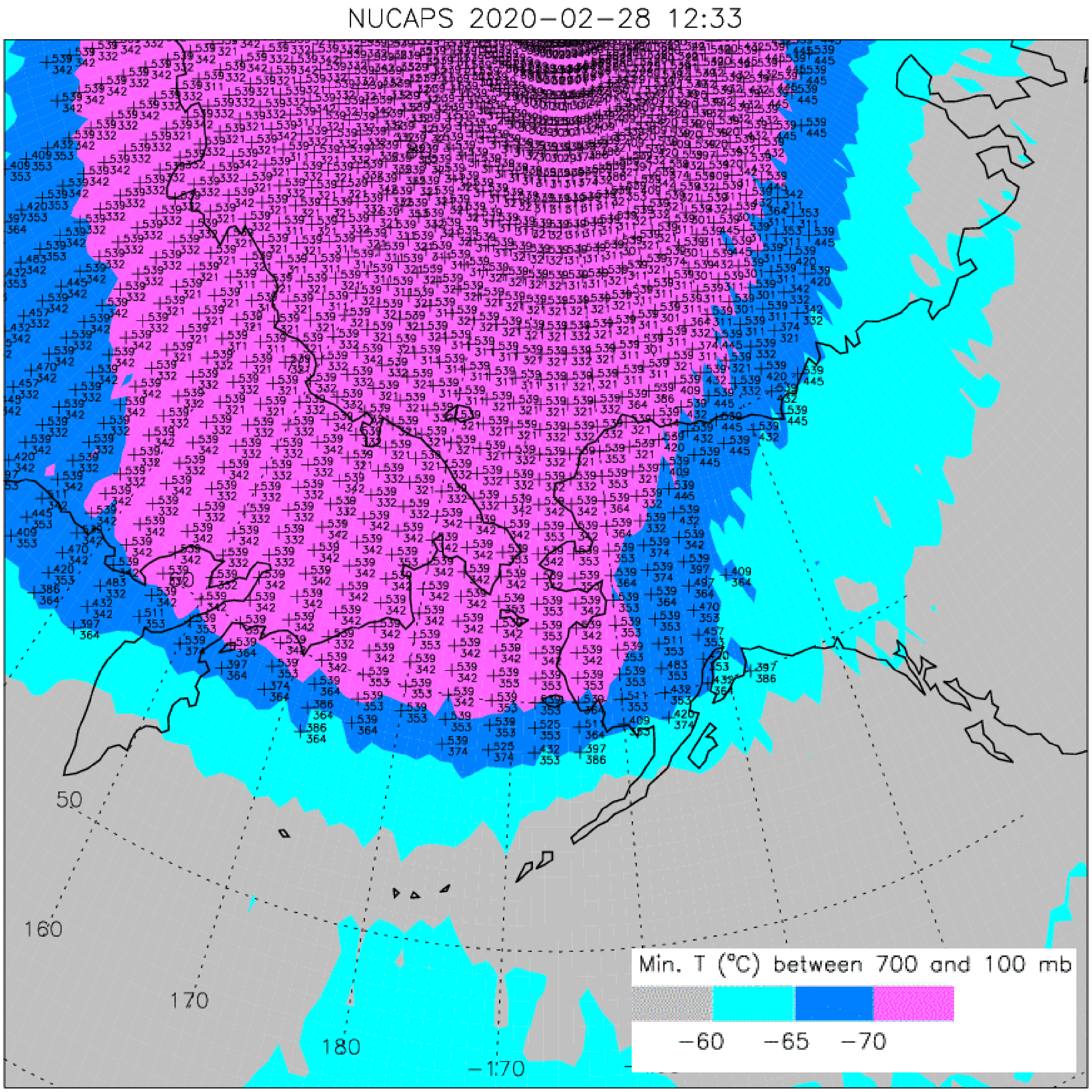


Figure: 1233 UTC 28 February 2020 Alaska regional plot from CIRA's cold air aloft web page. Colors indicate the minimum temperature between 700 mb and 100 mb, and the numbers to the right of the '+' indicate the vertical bounds of the -65ºC air at that point, given in units of flight level (hundreds of feet). Temperatures at or below -65ºC are the threshold for the issuance of a Meteorological Impact Statement from the Anchorage CWSU.

PROJECT TITLE: JPSS-PGRR History CIRA Support to Proving Ground Risk Reduction

PRINCIPAL INVESTIGATOR: Thomas Vonder Haar, Gerald J. Dittberner

RESEARCH TEAM: John Forsythe

NOAA TECHNICAL CONTACT: Mitch Goldberg

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

- Research history of polar orbiting operational weather satellites.
- Present results of this polar orbiting operational weather satellites study at AGU and AMS conferences.
- Generate appropriate publications, and provide periodic reports.

PROJECT ACCOMPLISHMENTS SUMMARY:

The first seven months of weather satellite history research have been productive and informative. Attached is a list of papers presented. They include selected US polar orbiting operational weather satellite accomplishments discussed at major science, forecasting and technical meetings. Thus far we highlighted major program technical advances, scientific discoveries, forecasting improvements and lessons learned from the first 3 decades (1960 – 1990). We have found a greater volume of important historical material than anticipated. Community interest and discussion of our early results has been high.

Four reader groups have been identified as foci for the continuing historical research and the NESDIS report / monograph we will prepare. They are a) NOAA NESDIS leaders, planners and advisors, b) weather forecasters and modelers, c) the scientific community and d) the next generations of operational satellite meteorologists to provide the heritage and lessons learned from 60 years of advances in this field.

Based upon the early results and an assessment of the research work and documentation to be done to cover the entire 60-year period we propose a one-year extension of the projects at the same level of effort.

PROJECT PUBLICATIONS:

Richard A. Anthes, Mark W. Maier, Steve Ackerman, Robert Atlas, Lisa W. Callahan, Gerald J. Dittberner, Richard Edwing, Pamela G. Emch, Michael Ford, William B. Gail, Mitch Goldberg, Steve Goodman, Christian Kummerow, Terrance Onsager, Kevin Schrab, Chris Velden, Thomas Vonderhaar, and James G. Yoe, 2019: Developing Priority Observational Requirements from Space using Multi-Attribute Theory. *Bull. Amer. Meteor. Soc.*, **100**, 1753-1773, https:/doi.org/10.1175/BAMS-D-18-0180.1.

PROJECT PRESENTATIONS/CONFERENCES:

Dittberner, G. J. and T. H. Vonder Haar, 2019: TIROS-1 and the History of the First Decade of Weather Satellites. Presentation 3.1, 17th *History Symposium*, Amer. Meteor. Soc., 99th Annual Meeting, January 7, 2019, Phoenix, AZ.

Dittberner, G. J. and T. H. Vonder Haar, 2019: TIROS-1 and the History of the First Decade of Weather Satellites. Presented in *15th Annual Symposium on New Generation Operational Environmental Satellite Systems*, Amer. Meteor. Soc., 99th Annual Meeting, January 10, 2019, Phoenix, AZ.

Dittberner, G. J. and T. H. Vonder Haar, 2019: TIROS-1 and the History of the First Decade of Weather Satellites. Invited presentation at the Amer. Meteor. Soc. *Washington Forum*, Mar 29, 2019, Washington, D. C.

Dittberner, G. J. and T. H. Vonder Haar, 2019: From TIROS-1 to JPSS and GOES-R: An Historical Review of Early Operational Satellites and Instruments as a Basis for Shaping the Future Together. Presentation 10.2, Session *Celebrating the 60th Anniversary of the First Weather Satellite, its Evolution, and International Partnership;* 2019 Joint AMS-EUMETSAT-NOAA Satellite Conference. October 2, 2019, Boston, MA.

Vonder Haar, T. H. and G. J. Dittberner, 2019: History of Science Discoveries and Their Applications. Presentation 10.3, Session *Celebrating the 60th Anniversary of the First Weather Satellite, its Evolution, and International Partnership;* 2019 Joint AMS-EUMETSAT-NOAA Satellite Conference. October 2, 2019, Boston, MA.

Dittberner, G. J., 2019: DMSP Heritage Review – The History of Early Operational DMSP Satellites and Instruments. Presentation at USAF 557th Weather Functional Review. December 10, 2019, Washington, DC.

Vonder Haar, T. H., G. J. Dittberner, and J. Forsythe, 2019: Early Weather Satellites Detect and Help Warn of Natural Weather Disasters and Hazards (Invited). Poster presented as poster 0764 in Session IN53D of *Satellites Providing Critical Support for Environmental Disaster Monitoring and Response: From TIROS-1, the United States First Weather Satellite, to the Current of Environmental Satellites – Posters,* American Geophysical Union 2019 Fall Meeting. December 13, 2019, San Francisco, CA.

Callahan, A. J., G. J. Dittberner, and T. H. Vonder Haar, 2020: TIROS Origins: How Military and Civilian Organizations Contributed to the First Weather Satellite System. Presentation 3.1, at the *16th Annual Symposium on New Generation Operational Environmental Satellite System,* 100th Amer. Meteor. Soc., January 13, 2020, Boston, MA.

Dittberner, G. J. and T. H. Vonder Haar, 2020: TIROS-1 Established the Foundation for Today's Remarkable Environmental Satellite Systems. Presentation 3.2 at the *16th Annual Symposium on New Generation Operational Environmental Satellite System,* 100th Amer. Meteor. Soc., January 13, 2020, Boston, MA.

Vonder Haar, T. H., G. J. Dittberner, and J. Forsythe, 2020: Early Weather Satellite Observations Energized the History of Science Discoveries and Weather Forecasting. Presentation 3.3 at the *16th Annual Symposium on New Generation Operational Environmental Satellite System,* 100th Amer. Meteor. Soc., January 13, 2020, Boston, MA.

PROJECT TITLE: JPSS-PGRR Nighttime CCL CIRA Support to Proving Ground Risk Reduction

PRINCIPAL INVESTIGATOR**:** Yoo-Jeong Noh, Steve Miller

RESEARCH TEAM: John Haynes, John Forsythe, Curtis Seaman, Steve Finley, Renate Brummer

NOAA TECHNICAL CONTACT: Mitch Goldberg (NOAA/NESDIS)

NOAA RESEARCH TEAM: Andy Heidinger (NOAA/NESDIS)

PROJECT OBJECTIVES:

This project is collaboration with Andrew Heidinger of NOAA/NESDIS/STAR/ASPB and his colleagues at the Cooperative Institute for Meteorological Satellite Studies (CIMSS). The ultimate goal is to improve nighttime Cloud Base Height (CBH) and Cloud Cover/Layers (CCL) products. CBH is a key parameter in constructing a 3-D cloud field which bears high relevance to the aviation community. As part of the JPSS Cloud Cal/Val efforts, we developed a statistical CBH algorithm constrained by Cloud Top Height (CTH) and Cloud Water Path (CWP) using A-Train satellite data, which is also used for improved CCL products as part of the operational NOAA Enterprise Cloud Algorithms. However, nighttime performance has not been fully explored due to a lack of reliable VIIRS CWP data. Our continuing efforts are directed to optimized retrievals at night, particularly during the winter months at high latitudes where VIIRS plays an important role in gap-filling due to the lack of high-resolution geostationary coverage.

Research Objectives:

1-- Continue improvement of the CBH/CCL algorithms and visualization based on user feedback.

2-- Obtain adjusting statistical regressions using a data fusion of VIIRS, MiRS-ATMS, and NWP-based water path information, and implement algorithm updates accommodating the blended cloud water information into the CLAVR-x processing system.

3-- Continue evaluation of CBH/CCL retrievals against ARM site measurements, utilizing simultaneous satellite active sensor observations upon data availability.

4-- Visit the Aviation Weather Center in Kansas City to meet with potential users of the product and demonstrate early results.

5-- Quarterly reporting, participation at an annual PGRR program review, and JPSS related meetings.

PROJECT ACCOMPLISHMENTS SUMMARY:

1-- Supporting the JPSS Aviation Initiative effort, we newly developed a website for the VIIRS Cloud Vertical Cross-sections for flight routes over Alaska (Figure 1) to demonstrate VIIRS cloud products and accommodate user feedback. The 3-D cloud information from S-NPP and NOAA-20 VIIRS over Alaska are available in near real time at http://rammb.cira.colostate.edu/ramsdis/online/npp_viirs_arctic_aviation.asp, which is now popular among Alaska users (Figure 2). Selected flight routes are between major airports in Alaska, and have been extended to additional airports per user requests. We have been updating the product demonstration and user guide documents based on user feedback from AAWU forecasters and local pilots through Aviation Initiative telecons. We continued to support JPSS cloud product Alaska Demonstrations for summer and fall in 2019 by providing product display and training tools including CIRA's main SLIDER (http://rammb-slider.cira.colostate.edu).

2-- We continued to utilize the Nighttime Lunar Cloud Optical and Microphysical Properties (NLCOMP) algorithm with VIIRS DNB lunar reflectance (which lunar model was developed by Steve Miller at CIRA) for nighttime CWP which is input for nighttime CBH/CCL retrievals. The current operational algorithm implemented in the NOAA operational system (v2r1) still adopts NWP-based CWP. The VIIRS CBH data is now publically available at NOAA CLASS (since March 2019). We continue to use machine learning model ("Random Forest") through training data for full-moon cases to effectively leverage these multiple datasets from VIIRS, MiRS-ATMS, NWP, and IR. Errors in MiRS-ATMS data over ice and snow surfaces were identified, and we will continue to improve data training. A modification to use the extinction method for frequent missing CBHs due to invalid NWP CWP at night was implemented in the CLAVR-x CBH code to improve nighttime retrievals in collaboration with CIMSS team.

3-- We continued to work on collect validation data for long-term validation and monitoring of the algorithm performance. Ground-based measurements from ceilometer, lidar, and surface meteorological observations) in the ARM sites (NSA, Alaska and SGP, Oklahoma) were collected and compared with CBH products. The validation results were presented in the NOAA-20 VIIRS product validated maturity review.

4-- John Haynes (CIRA) visited the Aviation Weather Center in August 1-2, 2019 and gave a talk on the CBH/CCL products and the work we have been doing to improve them. The purpose of this trip was to share research performed under the JPSS and GOES-R projects involving CBH/CCL product we are developing at CIRA and obtain feedback from AWC researchers and forecasters on the operational utility of the products and ways we can improve it. There was definite interest in evaluating the further improved CCL and the Alaska cross sections. The machine learning based low cloud detection work leveraging CIRA's GOES-R research for multi-layer clouds (to be adopted for JPSS VIIRS as well) was also received well. Pathways to get these products working there were also discussed.

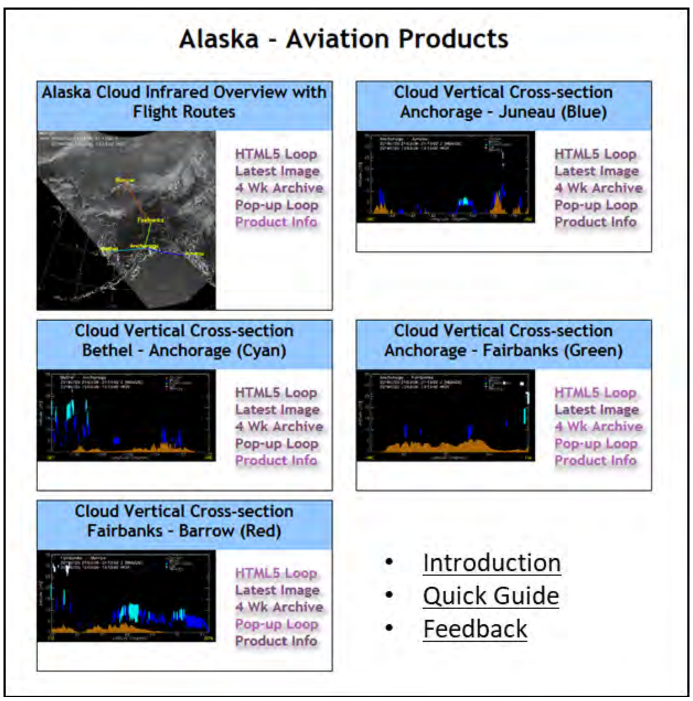


Figure 1. VIIRS Cloud Vertical Cross-section products newly developed for aviation users over Alaska. Cloud Vertical Cross-sections (CVC) along flight routes from S-NPP and NOAA-20 VIIRS are available in near real time at http://rammb.cira.colostate.edu/ramsdis/online/npp_viirs_arctic_aviation.asp. Users can obtain brief descriptions on the products with a quick guide and provide their direct feedback.

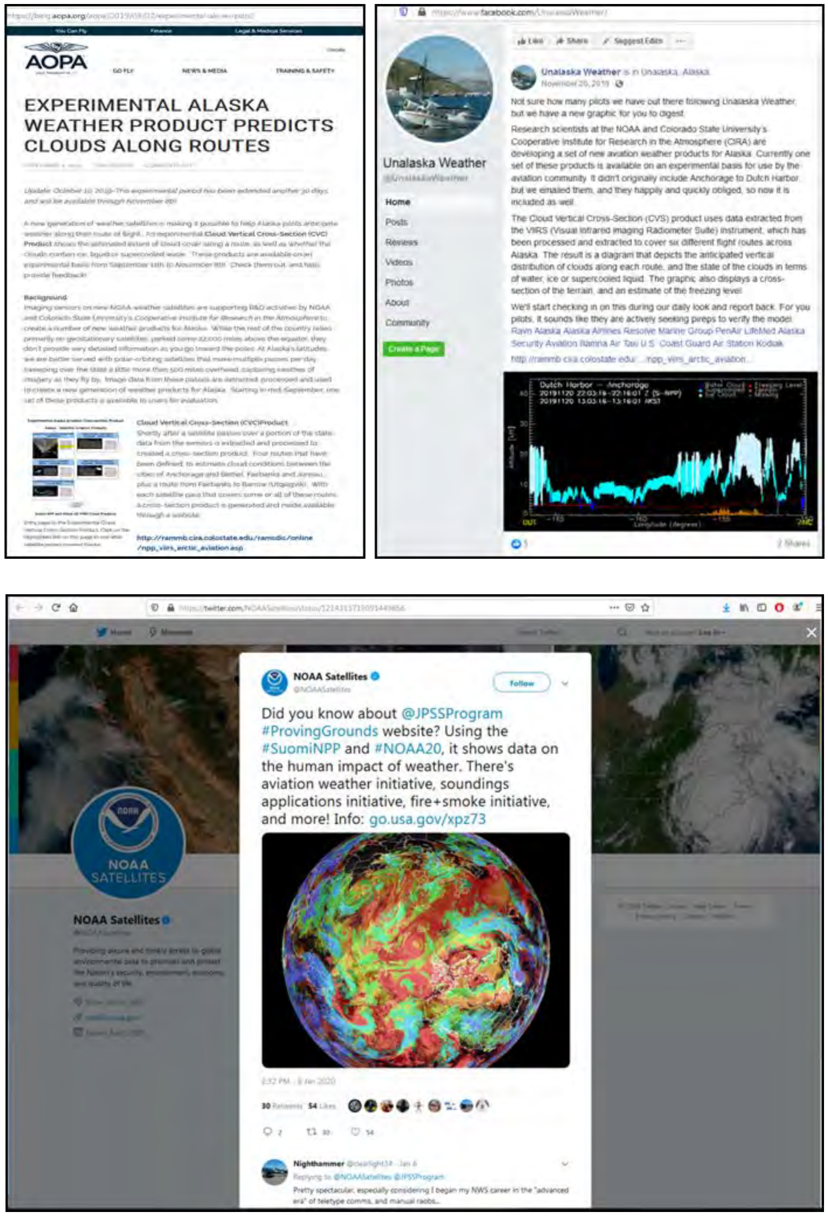


Figure 2. User feedback and interaction on CIRA's VIIRS Cloud Vertical Cross-section website over AK and Polar Slider. Upper left: a blog by Tom George (Aircraft Owners & Pilots Association) which advertise the VIIRS Cloud cross-section webpage at https://blog.aopa.org, Upper right: Facebook page managed by Andy Dietrick (Unalaska Weather) to introduce an addition of the new flight route between Dutch Harbor (DUT) to Anchorage (ANC), and Bottom: @NOAASatellites twitter account used a cloud product image from Polar SLIDER to promote NOAA's new "Proving Ground Website".

5-- The CIRA team regularly participated in JPSS Aviation and Arctic Initiative teleconferences, and completed NOAA-20 VIIRS product validated maturity review (16 May 2019). Input materials were provided to Andrew Heidinger (Cloud Team Lead) and Jeff Weinrich (JPSS Aviation Initiative). Results and ongoing research efforts were presented at the AMS-EUMETSAT Joint Satellite Conference and multiple abstracts were accepted for oral presentations for the 100th AMS Annual Meeting (12-14 January 2020, Boston, MD). The presentation information is listed in the presentation section.

PROJECT PUBLICATIONS:

Noh, Y. J., S. D. Miller, A. Heidinger, G. Mace, A. Protat, and S. Alexander, 2019: Satellite-based detection of daytime supercooled liquid-topped mixed-phase clouds over the Southern Ocean using the Advanced Himawari Imager. J. Geophys. Res., 124(5), 2677-2701, doi:10.1029/2018JD029524.

PROJECT PRESENTATIONS/CONFERENCES:

Noh, Y. J., S. D. Miller, J. M. Haynes, J. M. Forsythe, C. J. Seaman, A. Heidinger, A. Walther, and Y. Li, 2019: Improvement of Nighttime Cloud Geometric Thickness Retrieval Integrating Multi-Sensor Observations and Numerical Model Simulations. 2019 AMS-EUMETSAT Joint Satellite Conference. 28 September - 4 October 2019, Boston, MD.

Seaman, C. J. K. Micke, Y. J. Noh, J. F. Dostalek, S. Finley, S. D. Miller, and D. W. Hillge, 2019: Polar SLIDER: A Website for the Display of Global Polar-orbiting Satellite Data in Near Realtime. 2019 AMS-EUMETSAT Joint Satellite Conference. 28 September - 4 October 2019, Boston, MD.

Miller, S., W. C. Straka III, C. J. Seaman, Y. J. Noh, and L. Grasso, 2019: The Power of the Dark Side: Visible Applications in Dark Environments, Revisited (VADER). 2019 AMS-EUMETSAT Joint Satellite Conference. 28 September - 4 October 2019, Boston, MD.

Haynes, J. M., Y. J. Noh, S. D. Miller, A. Heidinger, and J. M. Forsythe, 2019: Cloud Boundary Detection in Multilayer Scenes with the GOES ABI. 2019 AMS-EUMETSAT Joint Satellite Conference. 28 September - 4 October 2019, Boston, MD.

Noh, Y. J., 2019: CIRA’s satellite products, COMET Weather Analysis and Forecasting course for Korea Meteorological Administration forecasters. 14 May 2019, Boulder, CO.

Noh, Y. J., 2019: Improvement of Satellite Cloud Cover/Layer Products and Aviation Weather Applications. Colloquium, School of Earth & Environ. Sci./Seoul Nat’l University, Oct. 15, 2019. South Korea.

Noh, Y. J., J.-H. Kim, S. D. Miller, 2019: Satellite Cloud Vertical Layers for Aviation Weather Applications. 2019 Korean Meteorological Soc. Annual Fall Meeting, Oct. 30 – Nov. 1, 2019, Gyeongju, South Korea.

Noh, Y. J, S. Miller, J. Haynes, J. Forsythe, C. Seaman, A. Heidinger, A. Walther, Y. Li, S. Wanzong, and W. Straka, 2019: Satellite Cloud Base/Layer Product and Aviation Weather Applications. 4th KNU CARE Int. Conference, Sept. 23-24, 2019, Gyeongju, Korea. (Invited talk).

PROJECT TITLE: JPSS-PGRR NUCAPS Data Fusion CIRA Support to Proving Ground Risk Reduction

PRINCIPAL INVESTIGATOR: Jack Dostalek

RESEARCH TEAM: John Haynes

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: Kris White

PROJECT OBJECTIVES:

1) Continue efforts to improve the Experimental NUCAPS retrievals.

2) Validation of the quality of the Experimental NUCAPS retrievals with respect to the Operational NUCAPS retrievals

PROJECT ACCOMPLISHMENTS SUMMARY:

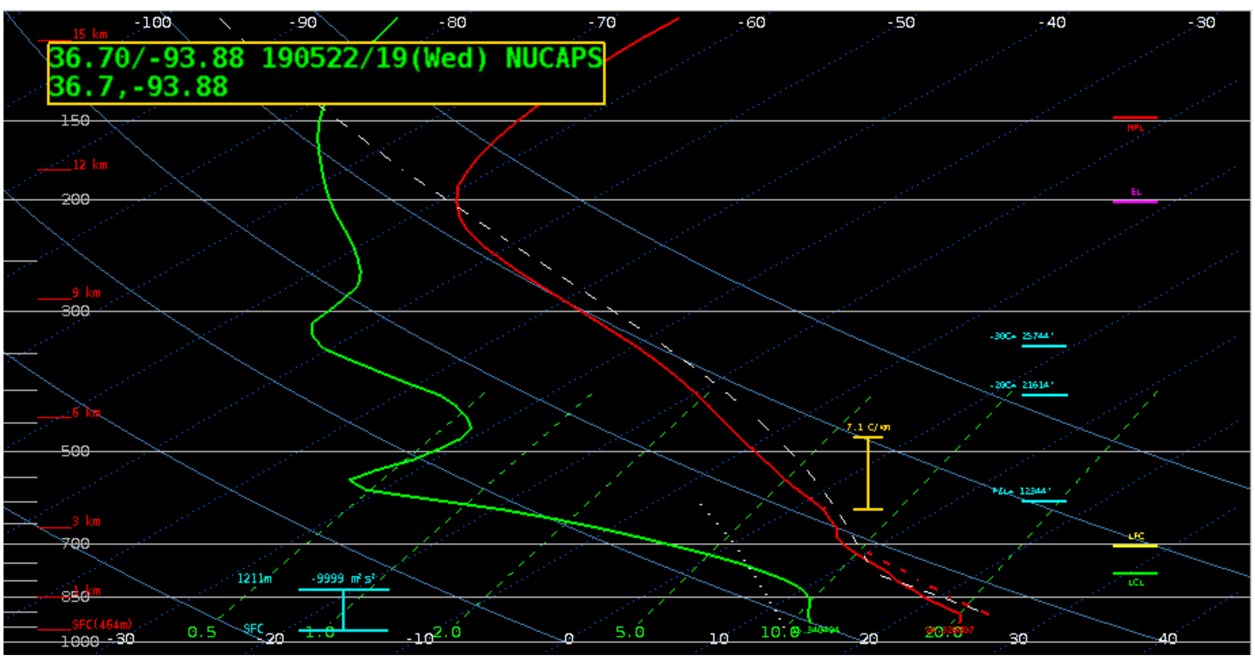
Accomplishments regarding Objective 1 include updating the NUCAPS modification program (example given below) to accept input from the legacy GOES Land Surface Temperature product instead of the simple 11/12 µm formulation currently used. Also, the modification program is now being produced for both S-NPP and NOAA-20. The half-orbit separation between the two eliminates gaps in coverage of the NUCAPS retrievals. Validation activities (Objective 2) continue. CIRA shared modified NUCAPS retrieval files with NESDIS to run on the NOAA Products Validation System, software which performs colocations and matchup statistics among various profile datasets (satellite retrievals, model profiles, rasdiosondes).

PROJECT PUBLICATIONS:

An article entitled “NUCAPS Boundary Layer Modification in Pre-Convective Environments: Development of a timely and more accurate product to assist forecasters in making severe weather forecasts” by Jack Dostalek was published in the 2019 JPSS Science Seminar Annual Digest. The article gives an overview of the technique used to modify the operational NUCAPS retrieval to better reflect conditions at and near the surface. It was a follow on to a JPSS science seminar given in June.

PROJECT PRESENTATIONS/CONFERENCES:

CIRA participates in the monthly JPSS PGRR NUCAPS Initiative Teleconferences. The participants of those teleconferences are primarily product developers. An additional teleconference consisting of a greater number of user participants, the NUCAPS Users’ Group Teleconference, had its first meeting in February 2020.



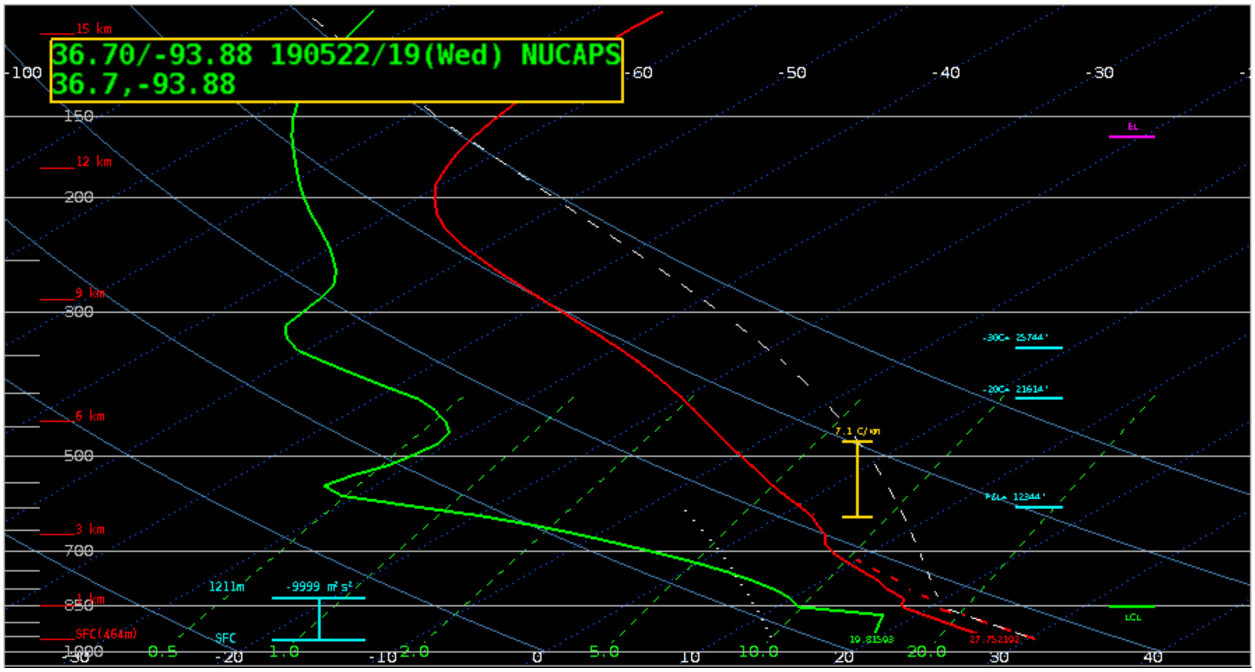


Figure: Operational (upper) and modified (lower) NUCAPS retrieval over southwest Missouri from 22 May 2019. The modification algorithm changed the operational retrieval to have a warmer and more moist boundary layer.

PROJECT TITLE: JPSS-PGRR TC ATMS CIRA Support to Proving Ground Risk Reduction

PRINCIPAL INVESTIGATOR: Galina Chirokova

RESEARCH TEAM: Alex Libardoni, Robert DeMaria, Stephanie Stevenson

NOAA TECHNICAL CONTACT: Mitch Goldberg NOAA/NESDIS/STAR

NOAA RESEARCH TEAM: John Knaff NESDIS/STAR

PROJECT OBJECTIVES:

This project's goal is to improve operational Tropical Cyclones (TC) position, intensity, and wind structure estimates, as well as intensity forecasts, using JPSS data. This effort supports the JPSS PGRR initiative (H) Hurricanes and TCs. Improving TC forecasts is an important task that will lead to improved warnings and longer lead times for mitigation activities from TCs and contribute directly to the NOAA and OAR strategic plan objectives. Intensity forecasts have improved slowly compared to track forecasts in the last couple of decades (DeMaria et al. 2014), and forecasting TC Rapid Intensification (RI), very rapid changes in TC intensity, remains an especially challenging and important problem - one of the highest priorities within NOAA. The goal of improving TC forecasts will be accomplished by improving existing and developing new JPSS applications using JPSS SNPP and NOAA-20 ATMS and VIIRS data, including high-quality MiRS temperature and moisture profiles and VIIRS DNB imagery that allows for producing visible-like imagery at night. Both SNPP and NOAA-20 carry the same instrument suite, thus all existing SNPP TC applications can be extended to NOAA-20 which will more than double the amount of JPSS data available for each TC and make JPSS data more useful for statistical TC intensity forecast (STCIF) models. The enhanced and newly developed applications will improve position (combined proxy-visible nighttime imagery and TC-DNB) and intensity and structure (Hurricane Intensity and Structure Algorithm (HISA) and Objective Radius of Maximum Winds (ORMW) estimates, and will also likely lead to improved intensity forecasts (Moisture In-Flux Storm Tool (MIST) and use of JPSS-based predictors in STCIF models), including improved RI forecasts. The new and improved applications will be made available online, provided in near-real time to NHC via LDM, and/or ready to be transitioned to operations at NHC, CPHC, and JTWC by the end of the project.

Specific goals this year include:

1) Continue development of the database of VIIRS, ATMS-MIRS, AMSU-MiRS, MW imagery, and ancillary data;
2*)* Develop preliminary version of ORMW algorithm;
3) Incorporate TC size predictors to HISA;
4) Develop algorithm for combining proxy-visible and VIIRS DNB imagery.

PROJECT ACCOMPLISHMENTS SUMMARY:

1) The development of JPSS TC applications requires the use of multi-year historical databases, including ATMS-MiRS data from SNPP and NOAA-20, AMSU-MiRS data from NOAA-18, -19, MetOp-A,-B, VIIRS data for multiple bands, and MW imagery from SNPP and NOAA20 ATMS, NOAA-18,-19, MetOp-A,-B AMSU, GCOM-W1 AMSR2, TRMM TMI, and GPM GMI. VIIRS, ATMS-MiRS, AMSU-MiRS, and MW imagery data have been collected in real-time, and gaps in TC data have been filled in historical databases, when possible. Work is in progress on incorporating the new pass prediction code to MIST processing to ensure more efficient way of selecting ATMS- and AMSU-MiRS data corresponding to satellite-TC overpasses, which will be then used as input for MIST for each case. In addition, verification of the input MW imagery data set for ORMW application has been completed. The ORMW application will be developed using NASA XCAL intercalibrated MW data (Berg at al. 2015). Figure 2 shows the comparison of AMSU plots between the raw AMSU data and the XCAL dataset, demonstrating that limb correction has been applied to both datasets.

2) Two RMW databases were assembled. The first database uses NHC's RMW data from ATCF best track for the cases when there is RMW estimate from aircraft reconnaissance within two hours. The second database uses RMW data estimated from aircraft reconnaissance by J. Knaff using objective analysis. It was found that there is a significant difference between the two estimates, with common differences up to 90 n mi. Figure 2 shows the scatter plot of RMW estimates from these two databases. The initial development is being conducted using NHC data, and J Knaff dataset will be used later for verification and testing. The baseline version of the ORMW algorithm was developed, and work is in progress on updating the combined database of RMW estimates and MW imagery data from multiple satellites and instruments, corresponding to the closest satellite-TC overpass within three hours of RMW estimate.

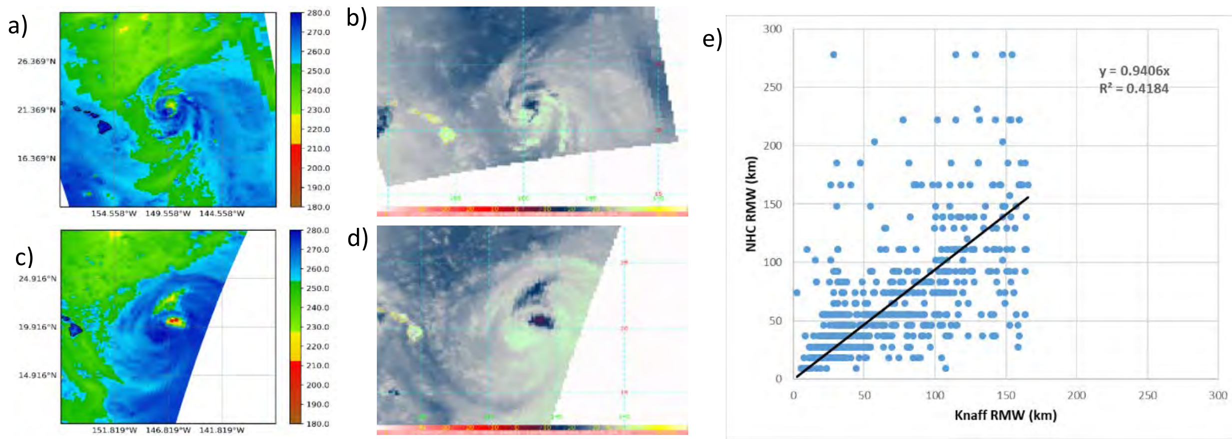


Figure 2. AMSU 89 GHz plots of Major Hurricane Julio (ep102014) on August 9. a) and b) at 23:40 UTC and c) and d) at 11:59 UTC. a) and c) XCAL data and b) and d) raw uncalibrated MW data. Julio looks similar in both datasets, which indicates that limb correction was applied to XCAL data. Near the swath edge [c) and d)] the storm looks larger than near the swath center [a) and b)] due to a different instrument scan angle. e) *RMW estimates provided by John Knaff compared to estimates provided by the NHC.*

3) The HISA and MIST processing is being updated and converted to Python3. In addition, work is in progress on rewriting parts of MIST code that were originally developed using Python 2.6, and cannot be directly converted to Python 3. That includes rewiring fortran modules that were originally included in MIST processing using f2py. The database of RMW and R34 data has been updated and will be used to incorporate size predictors to HISA statistical code used to estimate storm intensity. The code updates will result in a more stable and portable processing system with improved performance.

4) A preliminary version of the combined VIIRS-DNB-ProxyVisible algorithm has been developed. Specifically, a software was developed for re-gridding VIIRS data to GOES-16/17 grid and for displaying two datasets as a single combined image. Figure 4 shows an example of the combined ProxyVisible – VIIRS DNB image on September 13, 2019 at 06:50 UTC. The time of the image is near the full moon that was on 14 September 14, and shows the best VIIRS DNB performance. The darker insert at the center of the image is composed of VIIRS SNPP data near the time of GOES-R full disk ProxyVisible image. The combined ProxyVisible-VIIRS DNB imagery will allow for evaluation of the usefulness of DNB and ProxyVisible in different situations and will provide ongoing verification of ProxyVisible imagery.

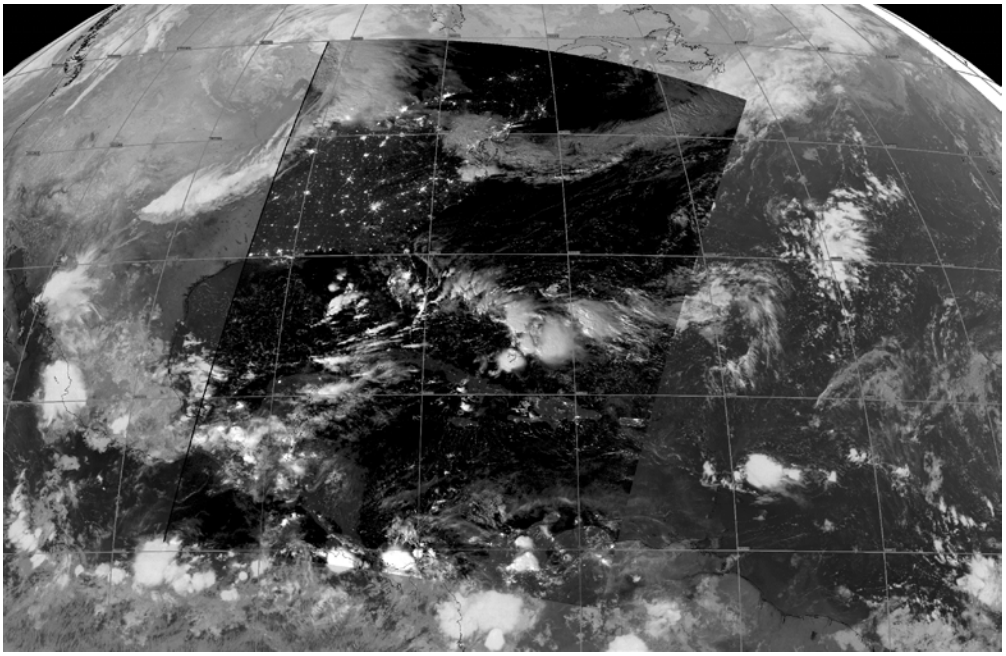


Figure 4. Combined GOES-16 ProxyVisible – VIIRS DNB image on September 13, 109 at 06:50 UTC. The darker insert at the center of the image is composed of VIIRS SNPP data near the time of GOES-R full disk ProxyVisible image.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Chirokova G., J. Knaff, A. Libardoni, L. Rivoire, and C. Grassotti, 2020: How JPSS data can improve operational TC analysis and forecasting. JPSS/GOES-R Proving Ground / Risk Reduction Summit. 24 – 28 February 2020, College Park, MD.

Chirokova G., 2020: Improving tropical cyclone forecast capabilities using the JPSS data suite. JPSS Stakeholders Meeting, 28 January 2020, online

Chirokova G., 2020: How JPSS Data can improve operational tropical cyclones analysis and intensity forecasting? Invited presentation at the JPSS Science Seminar, 27 January 2020, online.

Grassotti C., S. Liu, R. Honeyager, Y. Lee, Q. Liu, J. M. Forsythe, and G. Chirokova, 2019: Noaa's Microwave Integrated Retrieval System (MiRS): Operational Update, Applications, and Recent Scientific Progress. *2019 AMS Joint EUMETSAT/AMS Satellite Conference, Boston, MA, 28-September – 04 October 2019.*

Knaff, J, C. Sampson, G. Chirokova, K. Musgrave and C. Slocum, 2019: CIRA/RAMMB Satellite and Forecast Tools, Products and Updates. *2019 Joint INDOPACOM Theater METOC Summit and Tropical Cyclone Conference, Honolulu, HI, 9-12 April 2019.*

PROJECT TITLE: JPSS-PGRR VIIRS Multispec CIRA Support to JPSS Proving Ground Risk Reduction

PRINCIPAL INVESTIGATORS: Curtis J. Seaman, Steven D. Miller

RESEARCH TEAM: Louie Grasso

NOAA TECHNICAL CONTACT: Satya Kalluri

NOAA RESEARCH TEAM: Donald Hillger

PROJECT OBJECTIVES:

1--Acquire simulated (pre-launch) METImage data and develop software package for reading data and displaying imagery.

2--Transition existing VIIRS multispectral imagery algorithms for use with METImage data.

3--Investigate applications of METImage channels not present on VIIRS through examination of imagery provided by other existing imagers and through radiative transfer modeling as necessary.

PROJECT ACCOMPLISHMENTS SUMMARY:

1-- METImage will be the primary imager on the upcoming European Polar Satellites-Second Generation (EPS-SG) satellite constellation, planned for launch in 2022. In August 2019, CIRA was provided with a sample dataset containing simulated METImage data. This data was interrogated and imagery was displayed and shared at an early planning meeting in September 2019. The goal of this meeting was to inform NOAA/NESDIS/STAR on the properties and characteristics of the METImage instrument and determine if the current requirements for imagery set by the JPSS program will be met by the requirements set by EUMETSAT for EPS-SG. It has been determined that METImage will meet most of the requirements set for VIIRS except in terms of pixel growth near the edge of the swath. We have also responded to every NOAA/NESDIS/STAR request for planning documents (e.g. flowcharts) for the eventual operational production of METImage imagery products at NESDIS.

2-- Examples of the first-release sample data are shown in Figs. 1 and 2. In early February 2020, CIRA was provided with an updated sample of simulated METImage data that more closely approximates the operational dataset (in terms of file formats and metadata content) that EUMETSAT will provide to NOAA/NESDIS post-launch and post-checkout. The development of software for the mapping and display of imagery from the new simulated L1b data files is ongoing.

3-- The majority of bands on METImage are similar to bands that are available on VIIRS and MODIS. Using the MODIS spectral response functions as a proxy, L. Grasso has been creating synthetic satellite imagery using the Community Radiative Transfer Model (CRTM) applied to FV3 model output to simulate METImage data locally (Fig. 3). As the new set of sample data provided by EUMETSAT includes the pre-launch spectral response functions for METImage, this work will soon be adapting these for simulating METImage bands in a “more controlled” environment to evaluate the imagery in a variety of atmospheric conditions. This work is ongoing.

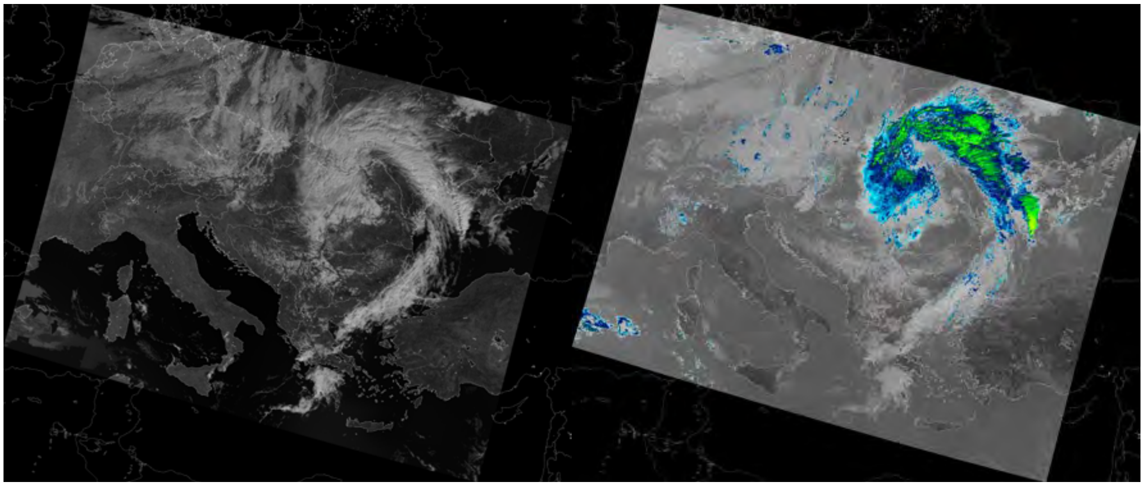


Figure 1. Simulated imagery from METImage data provided by EUMETSAT. Left: the 0.86 um "vegetation" band. Right: the 12.0 um "dirty window" band.

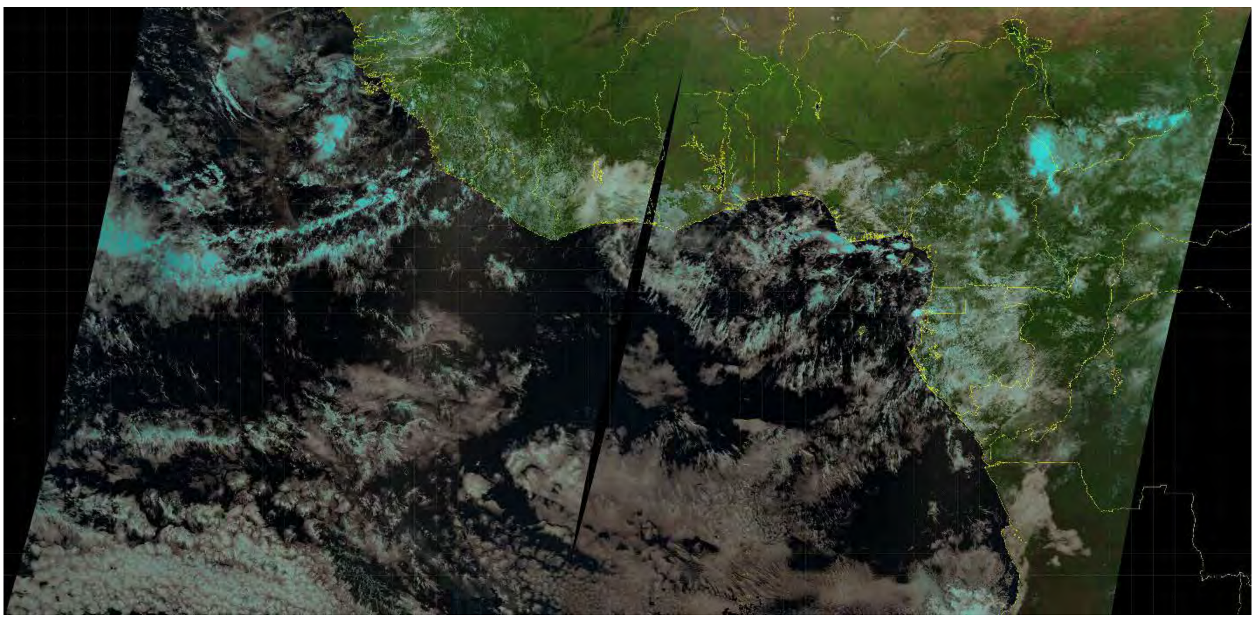


Figure 2. Simulated METImage Natural Color RGB images from consecutive orbits showing the lack of complete global coverage along the Equator.

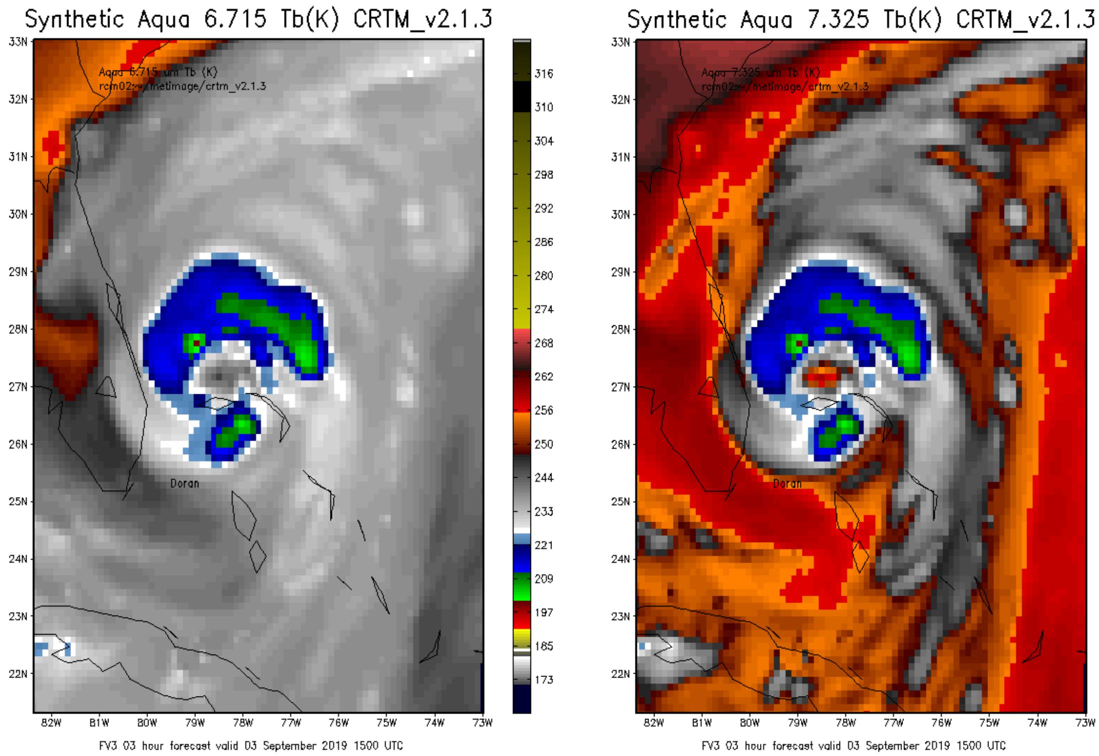


Figure 3: Proxy METImage water vapor, 6.715 µm and 7.325 µm, imagery of hurricane Dorian from FV3 output based on Aqua MODIS spectral response functions.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Merged Water Vapor CIRA Support to Proving Ground Risk Reduction

PRINCIPAL INVESTIGATOR: John Forsythe

RESEARCH TEAM: Stan Kidder, Dan Bikos, Andy Jones, Sheldon Kusselson, Anthony Wimmers

NOAA TECHNICAL CONTACT: Ralph Ferraro NOAA/NESDIS/STAR

NOAA RESEARCH TEAM: Limin Zhao (NOAA/NESDIS/OSPO), Chris Velden (CIMSS), Limin Zhao (NESDIS), Eric Holloway (NWS), Kennard Kasper (NWS), Aaron Jacobs (NWS), Andrew Orrison (WPC), Ralph Ferraro (NESDIS)

PROJECT OBJECTIVES:

Forecasters have used the multisensor blended total precipitable water (TPW) product operationally since 2009. CIRA initially developed this product and supports them in operations. By blending many separate spacecraft scans into one product, forecasters can track the water vapor plumes that fuel heavy precipitation events. These products are observationally driven with minimal model dependence and thus provide forecasters with situational awareness independent of forecast models.

Current operational products do not avail themselves of “advective blending.” CIMSS pioneered this technique, where model winds move satellite water vapor fields to yield a physically realistic animation of the flow of water vapor in the atmosphere. This project combines CIRA and CIMSS capabilities to develop a new advected TPW product that is ready for a straightforward transition to NOAA operations.

At project completion, well-documented, error-characterized blended water vapor products will be ready for transition to NOAA operations. Since the science development will occur in the same CIRA system which is currently operational at NESDIS, the effort required to transition the results of this research will be low. Suomi-NPP and NOAA-20 passive microwave retrievals are foundational inputs for this work. Training modules will be created in this product to prepare users for the improved hydrometeorological products generated by this effort.

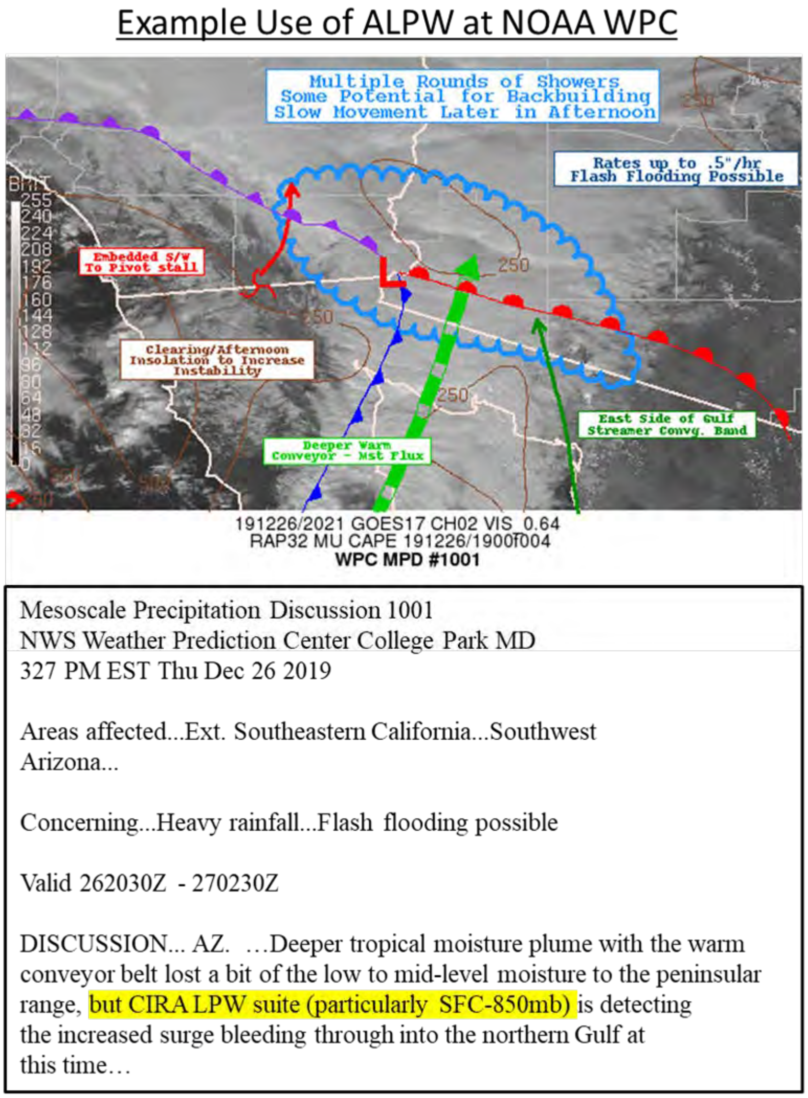
John Forsythe of CIRA and Tony Wimmers of CIMSS are PIs of this coupled but separate project. Each CI has its own project though the quarterly reporting is done jointly.

PROJECT ACCOMPLISHMENTS SUMMARY:

NOAA users have been engaged to develop requirements for the advected TPW product. CIRA operational data processing infrastructure will host the CIMSS advection engine (MIMIC) to create a new hourly advected product. Initial runs of the MIMIC back-trajectory model on CIRA systems, which mimic the NOAA operational production system, have occurred. Advectively Blended TPW products are being distributed to NWS collaborators for evaluation and improvement. The project participated in the NOAA Hazardous Weather Testbed (HWT) and Flash Flood and Intense Rainfall (FFaIR) experiments in spring and summer 2019. We will participate in these experiments again in 2020.

Advected Layer Precipitable Water (ALPW) continues to be produced under this project at CIRA with momentum towards implementation in NOAA operations. CIRA serves ALPW to 23 WFO’s and the NOAA WPC and NHC. NASA SPoRT is acknowledged for continuing to support distribution of the ALPW product. A typical forecast use in a WPC Mesoscale Precipitation Discussion (MPD) advising of flash flooding in Southern California and Arizona is shown in Figure 1.

The advectively blended TPW product continues to be validated against independent high-accuracy surface (GPS) and satellite measurements (NASA Orbiting Carbon Observatory – 2) to inform users of product uncertainty and guide blended product development.



Mesoscale Precipitation Discussion 1001
NWS Weather Prediction Center College Park MD
327 PM EST Thu Dec 26 2019

Areas affected...Ext. Southeastern California...Southwest Arizona...

Concerning...Heavy rainfall...Flash flooding possible

Valid 262030Z - 270230Z

DISCUSSION... AZ. …Deeper tropical moisture plume with the warm conveyor belt lost a bit of the low to mid-level moisture to the peninsular range, but CIRA LPW suite (particularly SFC-850mb) is detecting the increased surge bleeding through into the northern Gulf at this time…

Figure 7: Example usage of the hourly ALPW product in a Mesoscale Precipitation Discussion (MPD) from the NOAA Weather Prediction Center (WPC). The ALPW product was used by forecasters to detect Pacific moisture crossing Baja and moving across the Gulf of California.

PROJECT PUBLICATIONS

Gitro, C. M., D. Bikos, E. J. Szoke, M. L. Jurewicz Sr., A. E. Cohen, and M. W. Foster, 2019: New satellite technology and products to help in the identification and tracking of the elevated mixed layer. *J. Operational Meteor.*, **7** (13), 180-192.

PROJECT PRESENTATIONS/CONFERENCES:

Forsythe, J. M., S. Q. Kidder, S. Kusselson, A. Jones, D. Bikos, E. Szoke, 2019: Improving Blended Total Precipitable Water Products for Forecasters Via Advection and Inclusion of GOES-R. Oral presentation at AMS / EUMETSAT Joint Satellite Conference. Boston, MA, Oct. 2019.

Kusselson, S., J. M. Forsythe, S. Kidder, A. Jones, D. Bikos, 2019: The CIRA Advected Layer Precipitable Water Product and Applications to Help Forecast Hazardous Precipitation. National Weather Association Annual Meeting, Huntsville, AL, Sept. 2019.

PROJECT TITLE: NDE Transition for Blended Hydrometeorological Products

PRINCIPAL INVESTIGATORS: Andrew Jones

RESEARCH TEAM: Stan Kidder and John Forsythe

NOAA TECHNICAL CONTACT: Limin Zhao

NOAA RESEARCH TEAM: Limin Zhao, Walter Wolf, Ralph Ferraro, and others

PROJECT OBJECTIVE:

Move and assist with the quality tests for the operational Blended Total Precipitable Water (BTPW) and Rain Rate (RR) products at ESPC. The BTPW and RR products are now running on the IBM AIX polarprod system in near real-time, and are being transitioned to the new Linux-based ESPC NPP Data Exploitation (NDE) framework (Layns et al., 2017). Blended TPW and RR products will be operationally generated at ESPC via the CSU BTPW and BRR "Blended-Hydro" system. This work will create a Linux test system at CIRA to mirror the ESPC NDE Linux configuration for generating and conducting a 1 month science data test to ensure that the NDE transition is performed correctly. The BTPW and BRR will use the current operational satellite data ingest configuration, and no new input Microwave Integrated Retrieval System (MiRS) data products will be added. The MiRS system ingests passive microwave radiances from a variety of sensors and retrieves atmospheric moisture, temperature and hydrometeor profiles. Among many retrieved atmospheric variables, MiRS-derived total precipitable water (TPW) and rain rate (RR) are used in multisatellite blended products to create analysis fields for National Weather Service (NWS) forecasters.

PROJECT ACCOMPLISHMENTS SUMMARY:

Completed CIRA general tasks and milestones by objective for this performance period (1-Jan-2019 – 31-Dec-2019):

- ✓ Jul 19: Provided general consultant assistance during the code migration
- ✓ Dec 19: Provided assistance for configuration of PCF and production rules

Future project objectives and milestones for the next annual reporting period:

- ✓ Feb 20: Updated software from software review (review was scheduled for Feb 2020)
- ✓ Feb 20: CIRA Linux machine built and configured (machine was purchased in Feb 2020)
- – Mar 20: Assist in evaluation of products generation from the ASSISTT and NDE (prepare for 1 month data case study of implementation "check" analysis using CIRA systems).
- – Jun 20: Evaluate sensor data gaps and timing issues, latency interactions
- – Jun 20: Create before/after data visualization tests, include quantitative summary of results in evaluation report

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Support to NESDIS Environmental Applications Team (NEAT)

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Prasanjit Dash

NOAA TECHNICAL CONTACT: Paul DiGiacomo, STAR/SOCD

NOAA RESEARCH TEAM: Paul DiGiacomo, STAR/SOCD

PROJECT OBJECTIVES:

Role 1:
1. Monitoring of SOCD ocean products
2. Ocean event tracker
3. In-situ match-up framework

Role 2:
4. CIRA-CP point-of-contact

Role 3:
5. Contribute to STAR leadership support team

PROJECT ACCOMPLISHMENTS SUMMARY:

3 Roles	**Task**	**Status/Mode**	**Objective**
Satellite Ocean Data Visualization/Quality Monitoring and Program Innovation Scientist	*OceanWatch Monitor* (https://www.star.nesdis.noaa.gov/socd/om/)	Maintenance (developed 2018-19) Expansion envisioned in the near-future (in situ val)	Support CoastWatch
	Match-Up Creation (MUC) A framework to create in-situ match-up for multiple parameters (SST, SSS, OC, SSW, SSH)	Under Development First full implementation: end 2021	Feed match-up data to: - CoastWatch Data Portal - OceanWatch Monitor for val - OceanView (see next)
	OceanView A modern mapper, event-tracker, interactive online web-application A visualization support tool to: assist in assessing the state of the ocean; track oceanic events; track moving objects; integrate Obs-Model-In situ Viz; offer interaction with map controls; handle raster, vectors and special vector (velocity); easy and instant social media sharing; easy image extraction for presentations.	Conceptualization Envisioned first release: early 2021 Cross-team spin-off potential for the Polar Altimeter Team (being conceptualized)	- Help in easy visualization in the overwhelmingly data-rich environment - SOCD boiler-plate with multiple spin-off potentials; Technology maybe shared across division teams/programs for strengthening overall SOCD effectiveness - Approach industry standard & embed a predictive model

			(Statistical → ML → AI) in the future
College Park CIRA Point-of-Contact	i9 employment verification	Routine; 4 new employees	CSU CIRA remote trusted agent (TA)
	CIRA Search committee	Routine: Resume (6), Interview (3)	Interview committee member for new hire in CP; support NEAT
	Organize employee appreciation	2019	Keep NEAT employees happy!
	Other tasks (minor)	Routine	Ensure CIRA-CP ops
STAR Leadership and Support Team LST) member	Assist STAR's senior leadership in running some of the in-house operations; improve external public facing; increase internal effectiveness	Routine	Improve STAR's overall functionality and visibility in terms of: policy, procedure, technology, web presence *etc.* (scope not restricted)

Collaborations:

Participate in SOCD collaborative efforts as desired: EUM. *Status: ongoing*

Scholarly Primary Guest Editor:

Guest edit a special issue in MDPI; *Status: active*
(https://www.mdpi.com/journal/remotesensing/special_issues/sea_surface_temperature)

PROJECT PUBLICATIONS:

Jing, F.; Chauhan, A.; P Singh, R.; Dash, P. Changes in Atmospheric, Meteorological, and Ocean Parameters Associated with the 12 January 2020 Taal Volcanic Eruption. *Remote Sens.* 2020, *12*, 1026. https://www.mdpi.com/2072-4292/12/6/1026

Saha, K.; Dash, P.; Zhao, X.; Zhang, H.-M. Error Estimation of Pathfinder Version 5.3 Level-3C SST Using Extended Triple Collocation Analysis. *Remote Sens.* 2020, *12*, 590. https://www.mdpi.com/2072-4292/12/4/590

O'Carroll, A.G., Armstrong, E.M., Beggs, H., Bouali, M., Casey, K.S., Corlett, G.K., Dash, P., Donlon, C., Gentemann, C.L., Høyer, J.L. and Ignatov, A., 2019. Observational needs of sea surface temperature. *Frontiers in Marine Science*, *6*, p.420. https://doi.org/10.3389/fmars.2019.00420

PROJECT PRESENTATIONS/CONFERENCES:

E. A. Obligis, I.Tomazic, A.O'Carroll, G.Corlett, J.Piolle, P.Dash, T.Hewison, *et al*. Sentinel-3 Slstr Ongoing Cal/Val Activities for Sea Surface Temperature Measurements. 2019 Joint Satellite Conference, 28 September – 4 October 2019, Boston, MA, USA

K. Saha, P.Dash, X.Zhao, H.Zhang, Error Estimation of Pathfinder Version 5.3 SST Level 3C Using Extended Triple Collocation Approach. 2019 Joint Satellite Conference, 28 September – 4 October 2019, Boston, MA, USA

P. Dash et al., *Monitoring of multi-sensor and multiple ocean parameters: SST, Salinity, Height, Wind, and Color, First International* Operational *Satellite Oceanography* Symposium, 18 to 20 June, 2019. Park, MD, USA

PROJECT TITLE: CIRA Support to NESDIS Environmental Applications Team (NEAT)

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Xiaoming Liu

NOAA TECHNICAL CONTACT: Menghua Wang, NESDIS/STAR/SOCD/MECB

NOAA RESEARCH TEAM: Menghua Wang, NESDIS/STAR/SOCD/MECB

PROJECT OBJECTIVES:

1. Calibration/Validation and monitoring of VIIRS ocean color products

2. Conduct ocean color related applications and research

PROJECT ACCOMPLISHMENTS SUMMARY :

1. Calibration/Validation and monitoring of VIIRS ocean color products

- Added the routine cal/val and monitoring of NOAA-MSL12 generated SENTINEL-3B OLCI ocean color data products in regions of interests, and comparison with in situ data from MOBY and AERONET-OC stations.

- Added the routine cal/val and monitoring of NOAA-MSL12 generated SGLI/GCOM-C ocean color data products in regions of interests, and comparison with in situ data from MOBY and AERONET-OC stations.

- Continue the routine cal/val and monitoring for SNPP and NOAA-20 VIIRS ocean color data products in regions of interests, including Hawaii, South Pacific Gyre, Chesapeake Bay and U.S. east coast regions. The in situ data at four NOAA-funded stations including MOBY, AERONET-CSI, AERONET-LISCO and AERONET-USC, are routinely compared with VIIRS/NOAA-20 ocean color products.

- Continue the routine monitoring of SNPP and NOAA-20 VIIRS ocean color data products in global deep waters, oligotrophic waters, and coastal/shallow waters. The NOAA-20 VIIRS ocean color data are also routinely compared with SNPP VIIRS data.

2. Conduct ocean color related applications and research
   Refer to list of publications and presentations below.

PROJECT PUBLICATIONS:

Liu, X., and M. Wang (2019), Filling the gaps in ocean maps, Eos, 100, https://doi.org/10.1029/2019EO136548.

Liu, X., and M. Wang (2020), Super-resolution of VIIRS-measured ocean color products using deep convolutional neural network, submitted to IEEE Trans. Geosci. Remote Sensing, in review.

M. Wang, L. Jiang, S. Son, X. Liu, and K. J. Voss, Deriving consistent ocean biological and biogeochemical products from multiple satellite ocean color sensors, Optics Express, Vol. 28, No. 3 / 3 February 2020

Wang, M., L. Jiang, X. Liu, S. Son, K. Mikelsons, J. Sun, W. Shi, L. Tan, X. Wang, M. Chu, and V. Lance, "Multi-sensor ocean color data fusion and applications" Proc. IGARSS '19, pp.5090-5093 (2019). doi:10.1109/IGARSS.2019.8900282

PROJECT PRESENTATIONS/CONFERENCES:

X. Liu and M. Wang, “VIIRS High Spatial Resolution Ocean Color Data Derived Using the Deep Convolutional Networks”, Ocean Science Meeting, February 2020, San Diego, CA

PROJECT TITLE: CIRA Support to NESDIS Environmental Applications Team (NEAT)

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Xiao-Long Wang, Lide Jiang, Xiaoming Liu, Wei Shi, Liqin Tan, SeungHyun Son, and Mike Chu

NOAA TECHNICAL CONTACT: Menghua Wang, NESDIS/STAR/SOCD/MECB

NOAA RESEARCH TEAM: NOAA SOCD

PROJECT OBJECTIVE:

Develop Ocean Color Data Application & Processing System (OCDAPS) to support VIIRS, NOAA-20, GOCI, OLCI, and LANDSAT Ocean color products image visualization, data manipulation and processing.

PROJECT ACCOMPLISHMENTS SUMMARY:

1. Improved various satellite image data visualization, analysis and processing. Supported VIIRS, NOAA-20, GOCI, OLCI, MODIS and LANDSAT Ocean Color products in image display, image data manipulation, multiple band image difference computation, data quality flags view, band data density plotting, image mapping and re-projection, graphic IO utility, true-color image generation and netCDF input/output etc.

2. Worked on various new LANDSAT high-resolution imageries and various data source (bathymetry and MODIS land etc.) to construct new landmask files. Conducted regional analysis for pixel based water/land classifications.

3. Improved OCDAPS graphic functions to help team users in image analysis and multiple band data density plotting with contour capability.

4. Enhanced and converted new color tables into OCDAPS color system for convenient visualization.

5. Updated and improved OCDAPS system documentation and user guide in HTML files for user references.

6. Provided sample command scripts to support team member’s routine analysis in global or regional ocean color monitoring with batch automatically generated multiple Ocean Color satellite imagery.

7. Coordinated with colleagues to perform daily system monitoring for web based satellite image quality. Reported system problems to team for image recovery and image improvement.

8. Continuously building comprehensive system GUI mode / command mode support to perform current and future new satellite data computations and image data analysis and processing for group user's routine batch jobs and command scripts.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Support to NESDIS Environmental Applications Team (NEAT)

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Wei Shi

NOAA TECHNICAL CONTACT: Menghua Wang, NESDIS/STAR/SOCD/MECB

NOAA RESEARCH TEAM: Menghua Wang, NESDIS/STAR/SOCD/MECB

PROJECT OBJECTIVE:

NPP VIIRS calibration and validation, ocean color algorithm development and ocean process study with satellite ocean color remote sensing

- Development of new satellite ocean color algorithm
- NPP VIIRS calibration and validation
- Application of satellite ocean color data for coastal and in-land water ecosystem monitoring

PROJECT ACCOMPLISHMENTS SUMMARY:

During this period, I conducted research to study the NIR-based IOP retrievals from VIIRS satellite observations. This includes algorithm development, hydrolight model validation and its application in the coastal and inland waters. In addition, we also reach on the application of VIIRS to evaluate the processes in the La Plala River Estuary. Three papers were published in this period

Inherent optical properties in Lake Taihu derived from VIIRS satellite observations.

A Blended IOP Algorithm for Global Satellite Ocean Color Observations.

Characterization of particle size distribution of global highly turbid waters from VIIRS ocean color observations.

PROJECT PUBLICATIONS:

Shi, Wei; Wang, Menghua. *Limnology and Oceanography, Methods*, **17**, 377-394, 2019, doi:10.1002/lom3.10320.

W. Shi and M. Wang. Title: Inherent optical properties in Lake Taihu derived from VIIRS satellite observations. *Remote Sens.,* 11, 1426, 2019, doi:10.3390/rs11121426

W. Shi and M. Wang. Characterization of particle size distribution of global highly turbid waters from VIIRS ocean color observations. *J. Geophys. Res. Oceans,* 124, 3796-3817, 2019, doi:10.1029/20018C014793

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Support to NESDIS Environmental Applications Team (NEAT)

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Shuyan Liu

NOAA TECHNICAL CONTACT: Quanhua Liu, NOAA/NESDIS/STAR

NOAA RESEARCH TEAM: Christopher Grassotti, Cooperative Institute for Satellite and Earth System Studies, Earth System Science Interdisciplinary Center, University of Maryland; Yong-Keun Lee, Cooperative Institute for Satellite and Earth System Studies, Earth System Science Interdisciplinary Center, University of Maryland; Ming Fang, I.M. Systems Group, Rockville, MD; Yan Zhou, Cooperative Institute for Satellite and Earth System Studies, Earth System Science Interdisciplinary Center, University of Maryland; Xingming Liang, Cooperative Institute for Satellite and Earth System Studies, Earth System Science Interdisciplinary Center, University of Maryland

PROJECT OBJECTIVES:

1) Extend, develop, and improve NOAA Microwave Integrated Retrieval System (MiRS)

2) Validate products from MiRS

3) Maintain MiRS software, data, and website

PROJECT ACCOMPLISHMENTS SUMMARY:

1) Updated and delivered MiRS V11.4 to NDE, OSPO, and CIMSS at the end of March 2019. The main improvements in V11.4 include: updated NOAA-20 bias correction data, integrated a new version of snowfall rate algorithm, extended to MetopC, improved sea ice climatology.

2) Validated NOAA-20 and SNPP products against new reference datasets includes MRMS for rainfall; JAXA AMSR2 for cloud liquid water, sea ice, and snow water equivalent.

3) NOAA-20 products were officially announced as Validated Maturity after validate maturity review.

4) Accomplished Cloud Pilot project by set up and tested MiRS on Amazon Cloud.

PROJECT PUBLICATIONS:

Grassotti, C., S. Liu, Q. Liu, S. Boukabara, K. Garrett, F. Iturbide, and R. Honeyager, “Precipitation Estimation from the Microwave Integrated Retrieval System (MiRS)”, Chapter in book “Satellite Precipitation Measurement”, Editor in Chief Vincenzo Levizzani, Springer Publishing, submitted, Expected publication in March 2020.

Liu, S., C. Grassotti, Q. Liu, Y.-K. Lee, R. Honeyager, Y. Zhou, and M. Fang, 2020: The NOAA Microwave Integrated Retrieval System (MiRS): Validation Intercomparison of Rainfall from Multiple Polar Orbiting Satellites, Submitted to Journal of Selected Topics in Applied Earth Observations and Remote Sensing (JSTARS).

PROJECT PRESENTATIONS/CONFERENCES:

Grassotti, C., S. Liu, Y.-K. Lee, and Q. Liu, Preliminary Development and Assessment of the NOAA Microwave Integrated Retrieval System for Tropical Cyclones (MiRS-TC): A Passive Satellite Microwave Retrieval Algorithm Optimized for Tropical Cyclones, AGU Fall Meeting, 9-13 December, 2019, San Francisco, CA.

Grassotti, C., S. Liu, Y.-K. Lee, and Q. Liu, Preliminary Development and Assessment of the NOAA Microwave Integrated Retrieval System for Tropical Cyclones (MiRS-TC), GOES-R/JPSS Proving Ground Risk Reduction Summit, 24-28 February, 2020, College Park, MD.

Lee, Y.-K., C. Grassotti, S. Liu, Y. Zhou and Q. Liu, 2020: “The Microwave Integrated Retrieval System (MiRS): Validation Activities for NOAA-20/ATMS Products and New Science Developments”, 16th Annual Symposium on New Generation Operational Environmental Satellite Systems, AMS 100th annual meeting, 12-16, January 2020, Boston, MA.

Lee, Y.-K., C. Grassotti, S. Liu, Y. Zhou, Q. Liu, M. Fang and et al., 2019: “Retrieval from Satellite measurements and their application: MiRS and GOES-R ABI LAP”, 2nd S2S Workshop, 19-20, November 2019, Jeju, South Korea.

Lee, Y.-K., C. Grassotti, S. Liu, Y. Zhou, Q. Liu, and M. Fang, 2019: “The Microwave Integrated Retrieval System (MiRS): Validiation Activities for NOAA-20/ATMS Products and New Science Developments”, CISESS Science Meeting, 12-14, November 2019, College Park, MD.

Lee, Y.-K., C. Grassotti, S. Liu, Y. Zhou, Q. Liu, and M. Fang 2019: “The Microwave Integrated Retrieval System (MiRS): Valdiation Update and Applications”, NASA Sounder Science Team Meeting, 25-27, September 2019, College Park, MD

Honeyager, R., Y. Zhou, C. Grassotti, Y.-K. Lee, S. Liu, Q. Liu: Machine Learning within NOAA’s Microwave Integrated Retrieval System, 1st Workshop on Leveraging AI in the Exploitation of the Satellite Earth Observations & Numerical Weather Prediction, 23-25 April 2019, College Park, MD.

Zhou, Y., C. Grassotti, R. Honeyager, Y.-K. Lee, S. Liu, Xingming Liang, M. Fang, Development of a Machine Learning-Based Radiometric Bias Correction for NOAA's Microwave Integrated Retrieval System (MiRS), CISESS Science Meeting, 12-14, November 2019, College Park, MD.

Zhou, Y., C. Grassotti, R. Honeyager, Y.-K. Lee, S. Liu, Xingming Liang, M. Fang, Development of a Machine Learning-Based Radiometric Bias Correction for NOAA's Microwave Integrated Retrieval System (MiRS), 16th Annual Symposium on New Generation Operational Environmental Satellite Systems, American Meteorological Society the 100th Annual Meeting”, 16th Annual Symposium on New Generation Operational Environmental Satellite Systems, AMS 100th annual meeting, 12-16, January 2020, Boston, MA.

Zhou, Y., C. Grassotti, R. Honeyager, Y.-K. Lee, S. Liu, Xingming Liang, Development of a Machine Learning-Based Radiometric Bias Correction for NOAA's Microwave Integrated Retrieval System (MiRS), GOES-R/JPSS Proving Ground Risk Reduction Summit, 24-28 February, 2020, College Park, MD.

Liu, S., C. Grassotti, Q. Liu, Y.-K. Lee, R. Honeyager, The NOAA Microwave Integrated Retrieval System Multiple Satellite Rainfall Retrieval and Monitoring, IEEE Geoscience and Remote Sensing Society Symposium, 28 July – 2 August 2019, Yokohama, Japan.

Liu, S., C. Grassotti, Q. Liu, Y.-K. Lee, R. Honeyager, Multiple Satellite Microwave Retrieval of Tropical Cyclone Rain Rate and Warm Core Structure, IEEE Geoscience and Remote Sensing Society Symposium, 28 July – 2 August 2019, Yokohama, Japan.

PROJECT TITLE: CIRA Support to NESDIS Environmental Applications Team (NEAT)

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Seunghyun Son

NOAA TECHNICAL CONTACT: Dr. Menghua Wang, STAR/SOCD/MECB

NOAA RESEARCH TEAM: Dr. Menghua Wang, STAR/SOCD/MECB

PROJECT OBJECTIVES:

1. Processing and validation/evaluation of VIIRS-SNPP and VIIRS-NOAA20 data
2. Development of bio-optical and biogeochemical algorithms for the satellite ocean color data use in the various ocean waters (clear open ocean, coastal and inland waters).
3. Processing and validation/evaluation of OLCI, OLCI-B, and SGLI data.

PROJECT ACCOMPLISHMENTS SUMMARY:

1. The VIIRS-SNPP and VIIRS-NOAA20 data from various processing methods (e.g., IDPS-EDR, OC-SDR-EDR, NOAA-MSL12) have been processed over the various clear ocean and coastal/inland waters (Hawaii region, South Pacific Gyre, US east coast, Yellow & East China seas, Mediterranean Sea, etc.). In situ bio-optical data were compared for validation of the VIIRS data in various regions.
2. Regional turbidity algorithm for use of satellite ocean color data in the Great Lakes is developed, and the optical properties in the Great Lakes are characterized. The results have been published in an international scientific journal. Other regional water quality and biogeochemical algorithms for use of satellite ocean color data in the Great Lakes are developed and the results are being prepared for a manuscript.
3. The Korean GOCI data sets have been reprocessed over the Northwestern Pacific area, and evaluated and compared with VIIRS data. The results were presented in an international workshop.
4. The OLCI and OLCI-B data sets from the European ocean color sensor, Sentinel and SGLI data sets from Japanese ocean color sensor have been processed and routinely validated in the Hawaii MOBY site and various AERONET-OC sites. In addition, the OLCI ocean color products are compared with the VIIRS ocean color data.
5. Routine codes were updated for validation of the ocean color products from the VIIRS-SNPP, VIIRS-NOAA20, OLCI, OLCI-B, and SGLI for the Hawaii MOBY site and various AERONET-OC sites.

PROJECT PUBLICATIONS:

S. Son & M. Wang (2019), VIIRS-derived water turbidity in the Great Lakes, *Remote Sensing* 11, 1448, doi:10.3390/rs1121448.

M. Wang, L. Jiang, S. Son, X. Liu, & K. Voss (*in press*), Deriving consistent ocean biological and biogeochemical products from multiple satellite ocean color sensors, *Optics Express*.

PROJECT PRESENTATIONS/CONFERENCES:

M. Wang, J. Lide, X. Liu, S. Son, J. Sun, K. Mikelsons, W. Shi, L. Tan, X. Wang, M. Chu & V. Lance, VIIRS ocean color products from SNPP and NOAA-20 (at the International Ocean Colour Symposium, Busan, Republic of KOREA). (2019) Apr 9–12,

S. Son, M. Wang & L. Jiang, Comparison of GOCI and VIIRS ocean color products in the western Pacific region (at the International Ocean Colour Symposium, Busan, Republic of KOREA). (2019) Apr 9–12,

PROJECT TITLE: CIRA Support to NESDIS Environmental Applications Team (NEAT)

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Liqin Tan (CIRA/CSU)

NOAA TECHNICAL CONTACT: Menghua Wang, NESDIS/STAR/SOCD/MECB

NOAA RESEARCH TEAM: Menghua Wang, NESDIS/STAR/SOCD/MECB

PROJECT OBJECTIVES:

- Performing VIIRS instrument characterization and calibration for ocean color (OC) data processing and applications. Evaluating the effect of VIIRS instrument performance on the science data quality and quantify the impact

- Understanding, evaluation, and refining VIIRS ocean color (OC) data processing system

PROJECT ACCOMPLISHMENTS SUMMARY:

- Performed the status tracking and monitoring to the JPSS SNPP and NOAA-20 VIIRS instrument calibration activities, the operational VIIRS SDR algorithm code development and update, AUX/ANC/Look-up-tables (LUTs) update, and IDP VIIRS SDR operational data production for both SNPP and NOAA-20. Continued generating IDPS SNPP and NOAA-20 VIIRS SDR data operation code and F-LUT update time-line information. Communicated with STAR VIIRS SDR team, STAR ASSISTT, JPSS GRAVIE and U. of Wisconsin SSEC. Attended STAR VIIRS SDR team weekly meeting.

- Performed routine data collecting and archiving of operational IDPS SNPP/NOAA-20 VIIRS missing RDR ANC/AUX, calibration Look-Up tables (LUT), and Ephemeris data from STAR SCDR or GRAVITE for VIIRS instrument calibration analysis and SDR/EDR data reprocessing.

- Finished the installation of new ADL code (ADL5.3.25_I2.1_Mx07) on our Linux system. Updated my ADL-based VIIRS RDR to SDR data reprocessing tool to be able to run with the new ADL code version. Finished test runs.

• Reprocessed the IDPS NOAA-20 VIIRS SDR early mission data (12/14/2017-4/27/2018) from the RDR using ADL5.3.16_Mx03 with the entire original set of IDPS operational SDR LUTs of 04/27/2018 (including the 4/27/2018 updated F-LUT), which are used as base-line SDR in the same period for our science quality EDR production, to replace the original lower quality IDPS operational SDR.

• Generated daily IDPS NOAA-20 VIIRS F-factor files from IDPS NOAA-20 VIIRS-SDR-PREDICTED-LUT files to support the routine ratio approach of calibration correction to the IDPS operational NOAA-20 VIIRS SDR.

• Performed daily data operation monitoring, troubleshooting, missing input data collection, and data gap/data failure make-up reprocessing for the Ocean Color Science Team S-NPP and NOAA-20 VIIRS OC EDR global Level 1 to Level 3 data processing to ensure the best Near Real-Time stream and Science-Quality stream data quality data operation.

PROJECT PUBLICATIONS:

Wang, M., L. Jiang, X. Liu, S. Son, K. Mikelsons, J. Sun, W. Shi, L. Tan, X. Wang, M. Chu, and V. Lance, "Multi-sensor ocean color data fusion and applications" *Proc. IGARSS '19*, pp.5090-5093 (2019). doi:10.1109/IGARSS.2019.8900282

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Support to NESDIS Environmental Applications Team (NEAT)

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Lide Jiang

NOAA TECHNICAL CONTACT: Menghua Wang, STAR/SOCD/MECB

NOAA RESEARCH TEAM: Menghua Wang, STAR/SOCD/MECB

PROJECT OBJECTIVES:

1. VIIRS/SNPP project support, including VIIRS ocean color Level-1 -> Level-2 -> Level-3 data processing, reprocessing and distribution
2. NOAA-20 VIIRS project support, including VIIRS ocean color Level-1 -> Level-2 -> Level-3 data processing
3. Implement new sensor processing capability in MSL12 and produce ocean color products
4. Implement new and improved ocean color algorithms in MSL12 and apply them to ocean color related studies
5. Near-real-time and science quality ocean color data support

PROJECT ACCOMPLISHMENTS SUMMARY:

1. VIIRS/SNPP project support, including VIIRS ocean color Level-1 -> Level-2 -> Level-3 data processing, reprocessing and distribution:
    a. Implemented a new suspended particulate matter into L3 evaluation product, evaluated the global results, and identified some problem with the original algorithm;
    b. Routinely monitoring and generating F-factors for science quality data processing;

2. VIIRS/NOAA20 project support, including VIIRS ocean color Level-1 -> Level-2 -> Level-3 data processing, reprocessing and distribution:
    a. Developed an automatic system for vicarious calibration for MSL12 compatible sensors using either in-situ data or satellite data, e.g., using SNPP data to perform vicarious calibration for NOAA20. The code package also produces a variety of evaluation statistics for the L2 outcome using the derived gain set;
    b. Updated gain state generation scheme using new version of ADL because the old version did not work for the VIIRS sensor onboard NOAA20 satellite;
    c. Improved the efficiency of running new ADL version by investigating and simplifying the processing flow;

3. Maintain and improve MSL12 code
    a. Delivered MSL12 v1.30 code package to CoastWatch
    b. Implemented the new QAA algorithm (NIR blended) into MSL12 and verified the results
    c. Added straylight flag for OLCI and fix a cloud-mask-related straylight bug
    d. Fixed multiple bugs related to band-adjustment-based chlorphyll-a and kd algorithm and update metadata to remove long dashes
    e. Added L2 flag bits: negative Raleigh-corrected reflectance (NEGLRC), short blue band correction (LOWLWCORR)

4. Near-real-time and science quality ocean color data support
    a. Process/provide satellite data in support of the ocean color Cal/Val Team members and other users including Chuanmin Hu from University of South Florida, Zhongping Lee and Xiao-Long Yu from University of Massachusetts and Joaquim from Columbia University

PROJECT PUBLICATIONS:

Yu, X., Z. Lee, F. Shen, M. Wang, J. Wei, L. Jiang, and Z. Shang, "An empirical algorithm to seamlessly retrieve the concentration of suspended particulate matter from water color across ocean to turbid river mouths", Remote Sens. Environ., 235, 111491 (2019). doi:10.1016/j.rse.2019.111491this link opens in a new window

Sun, J., M. Wang, L. Jiang and X. Xiong, "NOAA-20 VIIRS polarization effect and its correction", Appl. Opt., 58, 6655–6665 (2019). doi:10.1364/AO.58.006655

Wang, M., L. Jiang, X. Liu, S. Son, K. Mikelsons, J. Sun, W. Shi, L. Tan, X. Wang, M. Chu, and V. Lance, "Multi-sensor ocean color data fusion and applications" Proc. IGARSS '19, pp.5090-5093 (2019).

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: NHC Satellite Application Developer - CIRA Support to a GOES-R Proving Ground for National Weather Service Forecaster Readiness and Training

PRINCIPAL INVESTIGATOR: Kate Musgrave

RESEARCH TEAM: S. Stevenson

NOAA TECHNICAL CONTACT: Mark DeMaria NOAA/NWS/National Hurricane Center

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

1 – Coordinate with NHC users, program managers, and product developers at NESDIS, CIRA, CIMSS, and NASA/SPoRT to identify and test products with the potential to improve NHC operations

2 -- Work with NHC's TSB and researchers in the JHT and HFIP to improve existing multiplatform products through the incorporation of GOES-R data.

3 -- Work closely with HRD to develop and display tropical cyclone products that combine aircraft and satellite data.

4 -- Approximately 20% of researcher's time may be spent on GOES-16/17 and/or JPSS-related research activities. This research time includes analyses, presenting results at scientific conferences, and preparing manuscripts for publication.

PROJECT ACCOMPLISHMENTS SUMMARY:

1 -- Worked with developers to generate full-disk GOES-16 GLM grids for AWIPS-II in coordination with the GLM Science Team. Coordinated with developers at NASA/SPoRT on GOES-related tropical cyclone product development. Worked with NESDIS and CIRA to address user requests for GOES data at NHC.

2 – Worked with NHC's TSB to implement CIRA-developed JHT projects on the WCOSS supercomputer, including the Tropical Cyclone Genesis Index (TCGI) and SHIPS-based wind radii. TCGI was updated to include a GOES-R water vapor predictor.

3 – Trained NHC forecasters on the use of NOAA WP-3D tail-Doppler radar (TDR) analyses in AWIPS-II. Reconfigured data ingest software of TDR at NHC. Coordinated with HRD on additional datasets to get into AWIPS-II, with the new multi-mode radar (MMR) established as the next target dataset.

4 – Participated in GOES-R training efforts for RA-IV GOES-R/JPSS/GNC-A The Americas Satellite Workshop in Barbados. Collaborated with CIRA research scientists on GOES GLM tropical cyclone research, including development of a lightning-based rapid intensification index. Presented at the GLM Science Meeting, Joint Satellite Conference, and JPSS/GOES-R Proving Ground/Risk Reduction Summit (listed below) on GLM and GOES-related activities at NHC.

PROJECT PUBLICATIONS:

Stevenson, S. N., 2019: GLM at the National Hurricane Center: Operational and research developments. *GLM Science Meeting*, Huntsville, AL.

Stevenson, S. N., C. Slocum and J. Zajic, 2019: Tropical cyclone lightning observed from the GOES-16/17 GLM. *2019 Joint Satellite Conference*, Boston, MA.

Stevenson, S. N., 2020: National Hurricane Center: GOES-R perspective, *JPSS/GOES-R Proving Ground/Risk Reduction Summit*, College Park, MD.

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: NWS OPG - CIRA Support to the NOAA NWS Operations Proving Ground

PRINCIPAL INVESTIGATOR**:** Steve Miller

RESEARCH TEAM: New Hire at NWS OPG

NOAA TECHNICAL CONTACT: Dan Lindsey

NOAA RESEARCH TEAM: Kim Runk

PROJECT OBJECTIVES:

This project is entailing activities focused at maximizing the forecast value of satellite data and products, particularly activities centered on NWS Weather Forecast Office (WFO) operations to improve forecast and warning services to the nation. The to-be-hired CIRA employee will interact with NWS operational forecasters and NESDIS satellite analysts to prepare them for both operational and experimental products that are currently and will become available from NESDIS satellites.

The CIRA employee will actively pursue the testing of new satellite products and decision aids. He/She will decide on a concept of exploring these satellite products in the light of public weather hazards and associated threats to public safety, and will determine whether the products can contribute to improving hazard forecasts, warning accuracies, and impact-based decision support services. He/She will select which satellite products/decision aids will be the focus of new training units and lead the necessary training of WFO forecasters. Science coordination at field experiments, proving grounds, or other type of operational forecaster training will be spearheaded by this employee.

PROJECT ACCOMPLISHMENTS SUMMARY:

There has been a delay with hiring a new CIRA employee who will conduct the work on this project at the NWS-OPG in Kansas City. Plans are for the project to start in July 2020.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Research Collaboration at the NWS Aviation Weather Center (AWC) in Support of the Aviation Weather Testbed (AWT), Aviation Weather Research Program (AWRP), NextGen Weather Program.

PRINCIPAL INVESTIGATOR: James Henderson

RESEARCH TEAM: Lee Powell, Amanda Terborg, Mick Ohrberg and Bret Sorensen

NOAA TECHNICAL CONTACT: Joshua Scheck

NOAA RESEARCH TEAM: Austin Cross (NOAA/NWS/AWC)

PROJECT OBJECTIVES:

This research team is responsible for AWC's ground based satellite field and datacenter infrastructure with a primary mission of providing hardware platforms, virtual resources, technical expertise, and growth opportunities for research being done by fellow CIRA representatives in close collaboration with Federal liaisons. This three-person team is known as AWC's Datacenter Team. Geographically, responsibilities include the primary datacenter at the AWC in Kansas City, MO and a growing footprint to include the FAA's Air Traffic Control System Command Center (ATCSCC) in Warrenton, VA. This team supports disaster recovery exercises and facilities at Scott and Offutt Air Force Bases. Their ultimate impact is realized when scientific improvements and breakthroughs are implemented in aviation weather prediction models. The Datacenter Team is instrumental in a product's research to operations (R2O) journey which is an intense procedure leveraging features and capabilities found in AWC's Aviation Weather Research Program (AWRP) and includes the Aviation Weather Testbed (AWT) and the center's web services platform.

The AWT at the AWC provides the infrastructure and facilities to develop, test, and evaluate new and emerging scientific techniques, products and services. The Datacenter Team falls into AWC's Aviation Support Branch (ASB) which collaborates with the other National Center for Environmental Prediction (NCEP) centers and the National Weather Service (NWS) to provide data and research for operational support. The (AWRP) products include Current and Forecasted Icing Products (CIP, FIP) and Graphical Turbulence Guidance (GTG). The ASB also supports AWC's web services which include the Aviation Digital Data Service (ADDS), the World Area Forecast System (WAFS) Internet File service (WIFS) and the International Flight Folder Document Program (IFFDP). The Datacenter Team supports all these programs in addition to everyday and emergency operations at the AWC, ATCSCC and other partner facilities.

Milestones and projects shift yearly allowing the Datacenter Team to focus on specific areas of the IT infrastructure. This delivers modern IT management capabilities and standards-based infrastructure to reduce cost and increase efficiency. These projects along with milestones are set and monitored by CIRA personnel and AWC Management to ensure objectives are achieved in a timely fashion each year. The center utilizes weekly quad charts enabling visualization of progress and highlighting areas needing attention in order to achieve set goals. Yearly objectives do not always account for side projects or smaller research endeavors that may arise during the year. For the timeframe of April 1, 2019 – December, 2019 the team set the following goals:

Task	Delivery Quarter
DMZ Refactor to Support MPLS	Q1
Backup Infrastructure Reconstruction	Q1
vSphere Upgrades at AWC and ATCSCC	Q2
Data center Rack Reorganization: AWIPS Racks	Q2
AWC FY 20 Accreditation and Assessment	Q3
Data center Storage Upgrade	Q3
Summer Experiment Support	Q3
Deploy NOAA Enterprise Management Solutions	Q4

PROJECT ACCOMPLISHMENTS SUMMARY:

In response to security concerns about a non-Trusted Internet Connection Access Provider (non-TICAP) circuit that AWC and the larger National Center of Environmental Prediction (NCEP) Central Operations (NCO) was using for weather.gov and aviationweather.gov, the Datacenter Team developed a three step process designed to be executed over the next 18 months from inception that reduced impact to AWC significantly. Two of the steps have been executed; results are a reflection of the time and attention paid to the task. AWC and weather.gov have experienced almost zero downtime during the migration.

The backup reconstruction project was designed to enhance restoration times in the event of a disaster. New hardware was utilized and new processes developed and tested to reflect a 20% improvement over old techniques.

The datacenter team accomplished several datacenter upgrades in all locations, traveling across the nation twice as much as initially expected due to a high level of security vulnerabilities this Fiscal Year (FY). This ensured a concrete foundation for higher level processes.

The datacenter at AWC is a result of dynamic requirements and pressure to achieve technological goals driven by mission requirements. Twenty years of decisions needed consolidation according to new rack technologies, cooling systems and environmental support systems. The goal was to reduce the footprint and enhance flexibility. This year the datacenter team leveraged all the above to physically reorganize the *Advanced Weather Interactive Processing System (AWIPS)* II racks to support the future. This included a complete network re-cabling of each component.

AWC continued to shine through the annual accreditation and assessment of AWC's IT infrastructure and supporting environment. This audit follows NIST 800-53 guidelines for medium systems. Findings were mitigated a quarter of FY19 before the prescribed deadline. This structured approach to managing an IT infrastructure has shown to be a strong reason the Datacenter Team finds success working with peers, deploying new technologies, and supporting AWC's mission.

In addition to the highlights above the team worked to support AWC in any and all research – to - operations requirements (R2O).

Satellite...

- Operationalized Geostationary Operational Environmental Satellite (GOES)-17 at AWC in January of 2019
- Retired the old GOES-15 equipment, allowing AWC to be released from the need for certain software support and saving around $5K for other CP needs
- Working towards a complete transition away from old software, to relieve AWC of the reminder of satellite software support costs
- Built new satellite processing such that AWC, the Command Center, and AWC's two back up sites can run independently, thus greatly improving the robustness of AWC's satellite operations.

AWIPS-2...

- Began working with AWC management, labor reps, and science staff to transition AWC from National Centers for Environmental Prediction (N)-AWIPS to AWIPS-2. When complete, AWC will be on consistent operating platforms with Weather Forecast Offices (WFOs) and Center Weather Service Units (CWSUs), and will be relieved from support of old software and hardware.

PROJECT TITLE: Research Collaboration at the NOAA/NWS Aviation Weather Center (AWC) in Support of the Aviation Weather Testbed (AWT)

PRINCIPAL INVESTIGATOR: James Henderson

RESEARCH TEAM: Daniel Vietor, Bret Lucas

NOAA TECHNICAL CONTACT: Joshua Scheck (NOAA/NWS/AWC)

NOAA RESEARCH TEAM: Austin Cross (NOAA/NWS/AWC), Stephanie Avey (NOAA/NWS/AWC)

PROJECT OBJECTIVES:

The Aviation Weather Center (AWC) Aviation Support Branch (ASB) is responsible for providing support to the research and operations processes, maintaining server and networking infrastructure, and supporting the www.aviationweather.gov website.

The primary goal of the ASB is to maintain the internal network, servers and workstations at the AWC to ensure continuity of operations. The 24x7 support is critical to AWC forecast and web operations. The ASB collaborates with the other National Center for Environmental Prediction (NCEP) centers and the National Weather Service (NWS) to provide data and research to operations support. The branch supports the research operations at the AWC, headed by a team of Technique Development Meteorologists (TDMs). This includes support for the Aviation Weather Testbed (AWT). The ASB also supports the AWC website which includes Aviation Digital Display Service (ADDS), World Area Forecast System (WAFS) Internet File service (WIFS) and the International Flight Folder Program (IFFDP).

As part of the CIRA effort, the ASB has close links to the research and development projects going on at the AWC. This includes:

- providing better tools to decrease weather impacts to the National Airspace System (NAS) including efforts at the Federal Aviation Administration (FAA) Command Center and with the Traffic Flow Management (TFM) project,
- providing direct support to the TDMs at the AWC for ongoing research projects including Geostationary Operational Environmental Satellite (GOES)-R, ensemble model diagnostics and product verification,
- expanding its collaboration efforts with the other testbeds within National Oceanic and Atmospheric Administration (NOAA) and the NWS focusing on R2O projects.

PROJECT ACCOMPLISHMENTS SUMMARY:

In the past year, efforts have been centered on five primary projects:

1. Website redesign
2. Graphical Forecast Area (GFA) expansion
3. Helicopter Emergency Medical Services (HEMS) Tool update
4. Automation of Social Media
5. ADDS Lite deployment

Website Design

Over the last five to eight years, the user base of the aviationweather.gov website has been trending from primarily a desktop user to a mobile user. Statistics across all government websites (h ttps://analytics.usa.gov/) indicated that desktop users comprised less than half of the site visits. Although desktop users still account for over 80% of the hits to the tools on aviationweather.gov, mobile users are expected to double over the next five years especially since pilots are utilizing tablets and cell phones more as part of the pre-flight routine.

To make the website more mobile accessible, a variety of new technologies are being researched to find which will give the best user experience. Figure 1 shows an example of the current website on a mobile device on the left and a possible mobile-friendly redesign featuring a responsive layout: one that adapts to the device on the right.

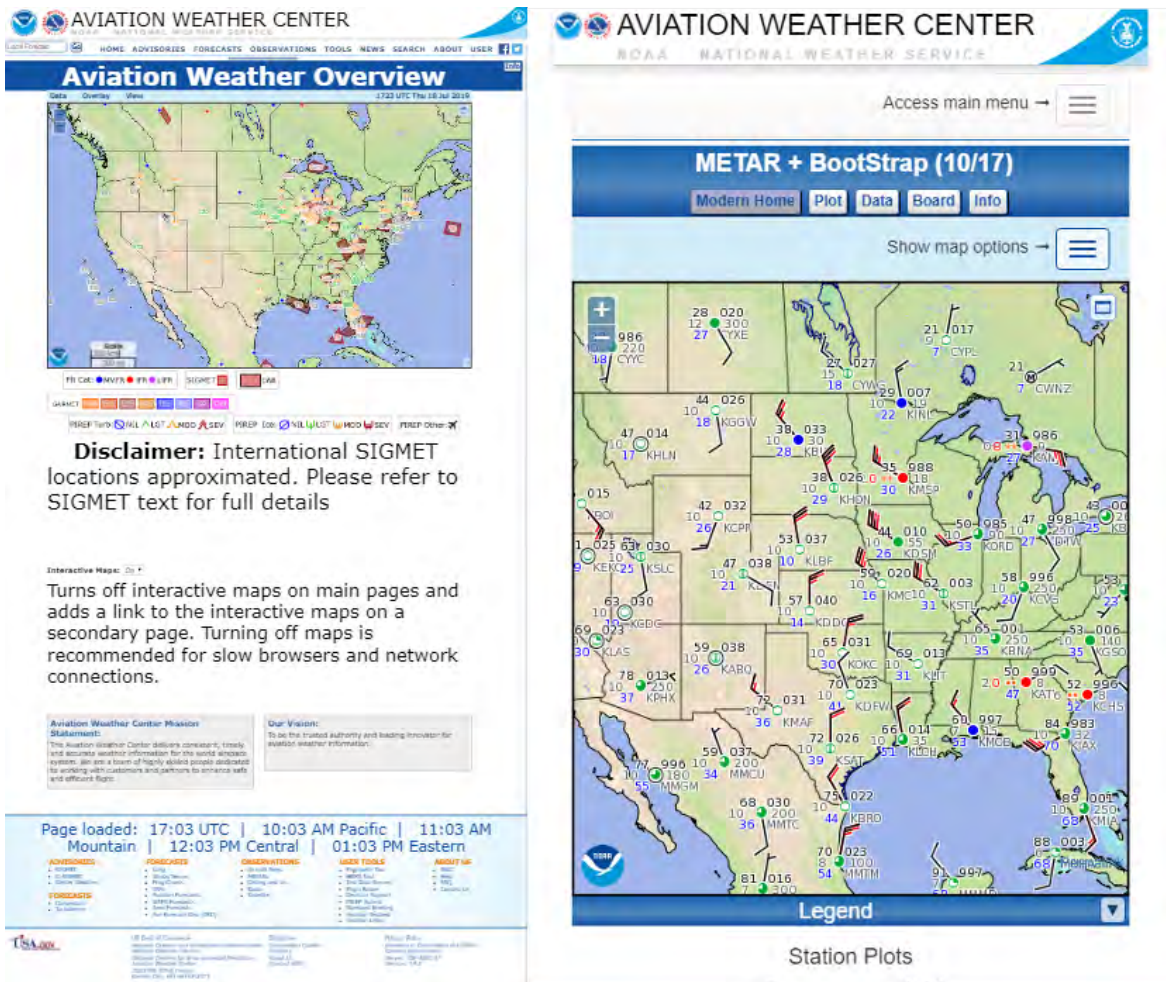


Figure 1. Samples of the current website on a mobile device on the left and a mobile-friendly redesign using BootStrap on the right.

After researching several Javascript frameworks, Twitter's Bootstrap (https://getbootstrap.com/) was selected as the library that would allow the best user experience across all platforms. This decision was based on the platform's maturity, popularity, and availability of documentation.

Another challenge facing the website was the use of outdated dynamic map rendering software (specifically Open Layers version 2). To update to a newer version would require a significant rewrite. As with the mobile-friendly conversion, replacements for Open Layers version 2 were investigated. By in large, the NWS had adopted Leaflet (https://leafletjs.com/); and, after a bit of experimentation it was found to be very capable, light-weight, and highly extensible. A simplified layout featuring a Leaflet interactive map is shown in Figure 2.

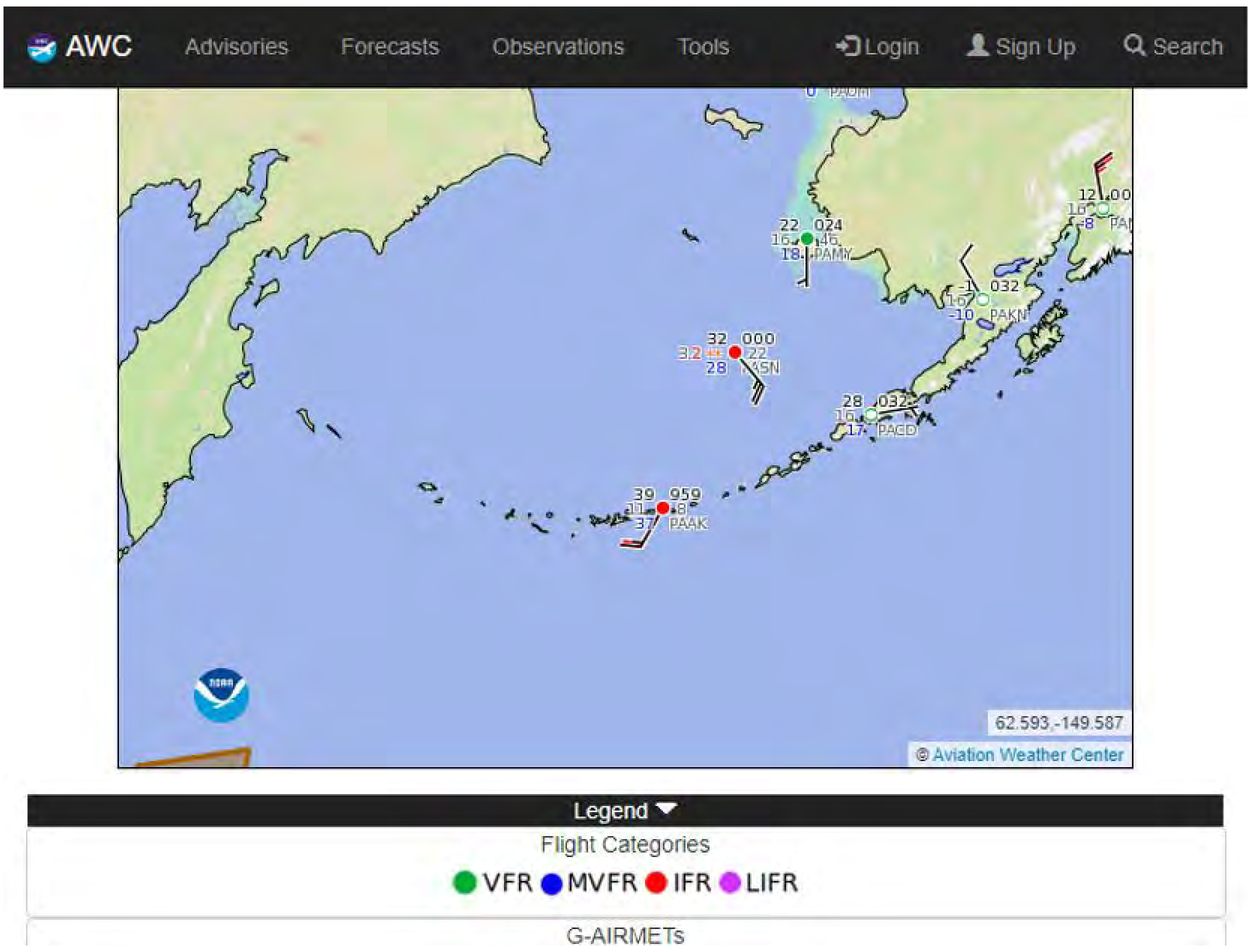


Figure 2. A sample of a dynamic map using Leaflet

Over the last year, a prototype was developed using the Mobile-First Paradigm (https://www.searchenginewatch.com/2019/03/05/mobile-first-design-for-2019/). An example is shown in Figure 3. Note how narrow the presentation can be while still maintaining usability and not requiring excessive pinch-zooming. Another aspect of the redesign is to create a Progressive Web Application (https://en.wikipedia.org/wiki/Progressive_web_application) that leverages the existing AWC GeoJSON scripts to allow for offline availability. So when a pilot is in the cockpit without cellular signal, the page still functions. The technology to accomplish
these tasks is not sophisticated, just modern. By implementing HTML5, CSS3, and the java script capabilities of modern browsers, the website will reach a broader audience and provide a better user experience.

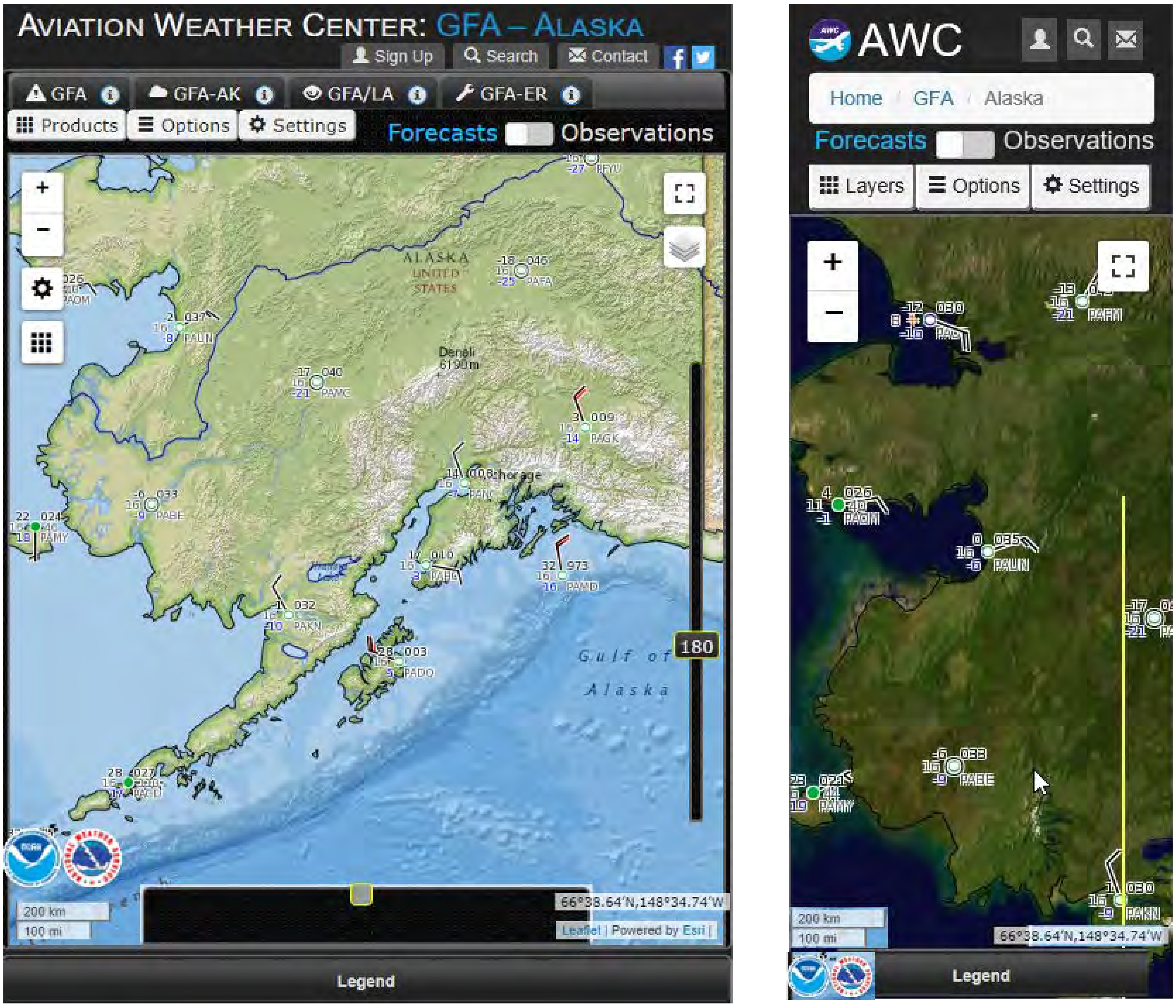


Figure 3. An example of how the website resizes and maintains functionality over different sized displays (e.g. tablet vs phone)

Graphical Forecast for Aviation (GFA) Expansion Project

The GFA Tool went through an upgrade last year where the domain of the tool was expanded into the Gulf of Mexico and the Caribbean Sea. Phase two of that expansion is to extend coverage over the Pacific. The new domain expands on the data that was used in phase one, including use of Local Aviation MOS Product (LAMP) and the National Digital Forecast Database, over the contiguous United States and using the extended Rapid Alpha Process (RAP) model to cover areas outside Continental United States (CONUS). This new domain covers a large part of the eastern Pacific. An example of the new domain is in Figure 4.

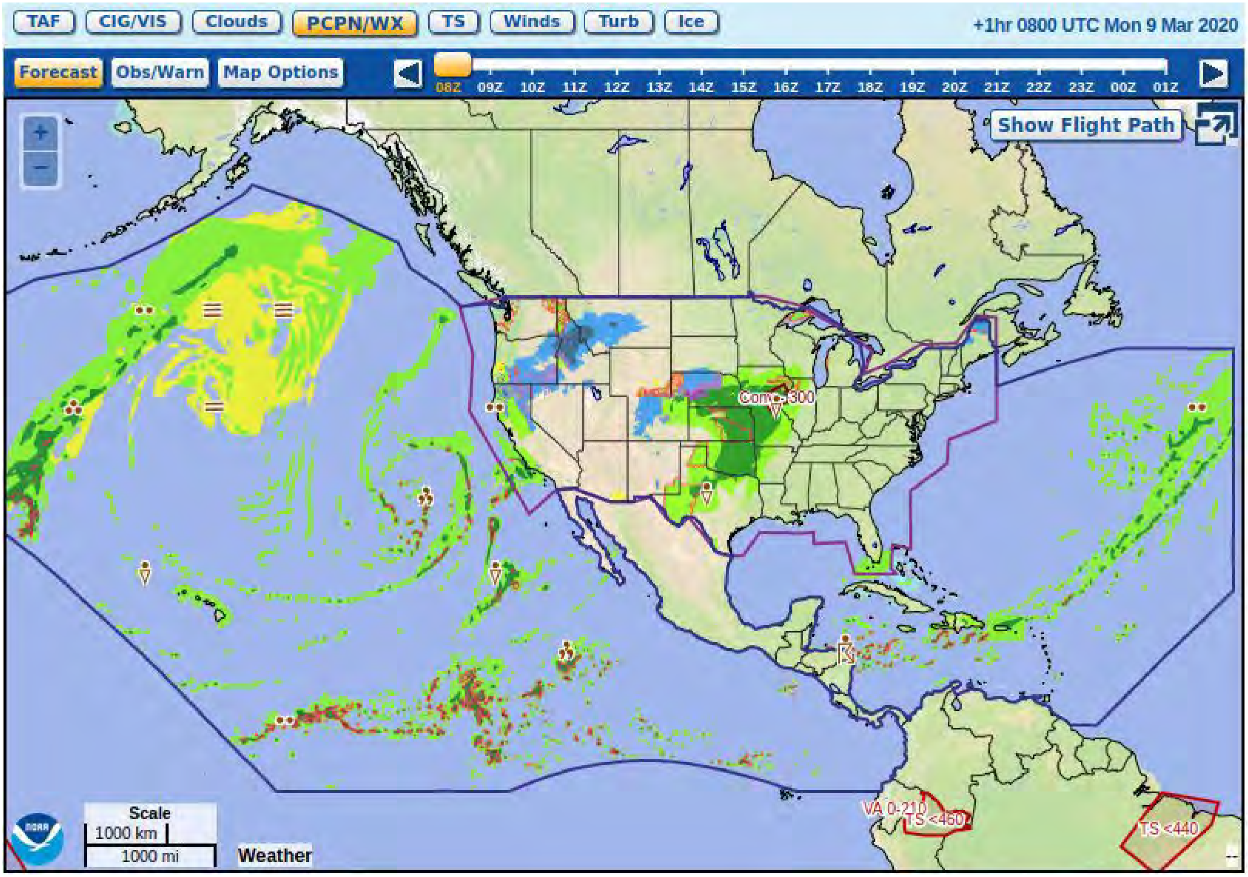


Figure 4. The GFA Tool with the expanded domain over the Pacific.

This has been under evaluation on the AWC Testbed website (testbed.aviationweather.gov) since early summer and is set to be operational in early 2020.

Phase three of the expansion, expected in 2020, is to add coverage for Alaska. Representatives from Alaska participated in the AWC Testbed Summer Experiment in August 2019 to discuss requirements for an Alaska version.

Helicopter and Emergency Medical Services (HEMS) Tool Upgrade

Over the past two years, an upgrade to the HEMS Tool has been in development. Last year, a new set of ceiling and visibility products using the Local Aviation Model Output Statistics (MOS) Program (LAMP) model were added to the tool. This includes not only 15 minute updates to the analysis but forecasts out to six hours into the future.

This year the tool was evaluated by the Aviation Weather Development and Evaluation (AWDE) team. The main focus was updates to the user interface. This included recommendations to change the time slider, update the options menu, and product labeling, legends, and full screen access (see Fig. 5). This also resulted in extensive upgrades to the help and tutorial pages.

This is set to go operational in early 2020.

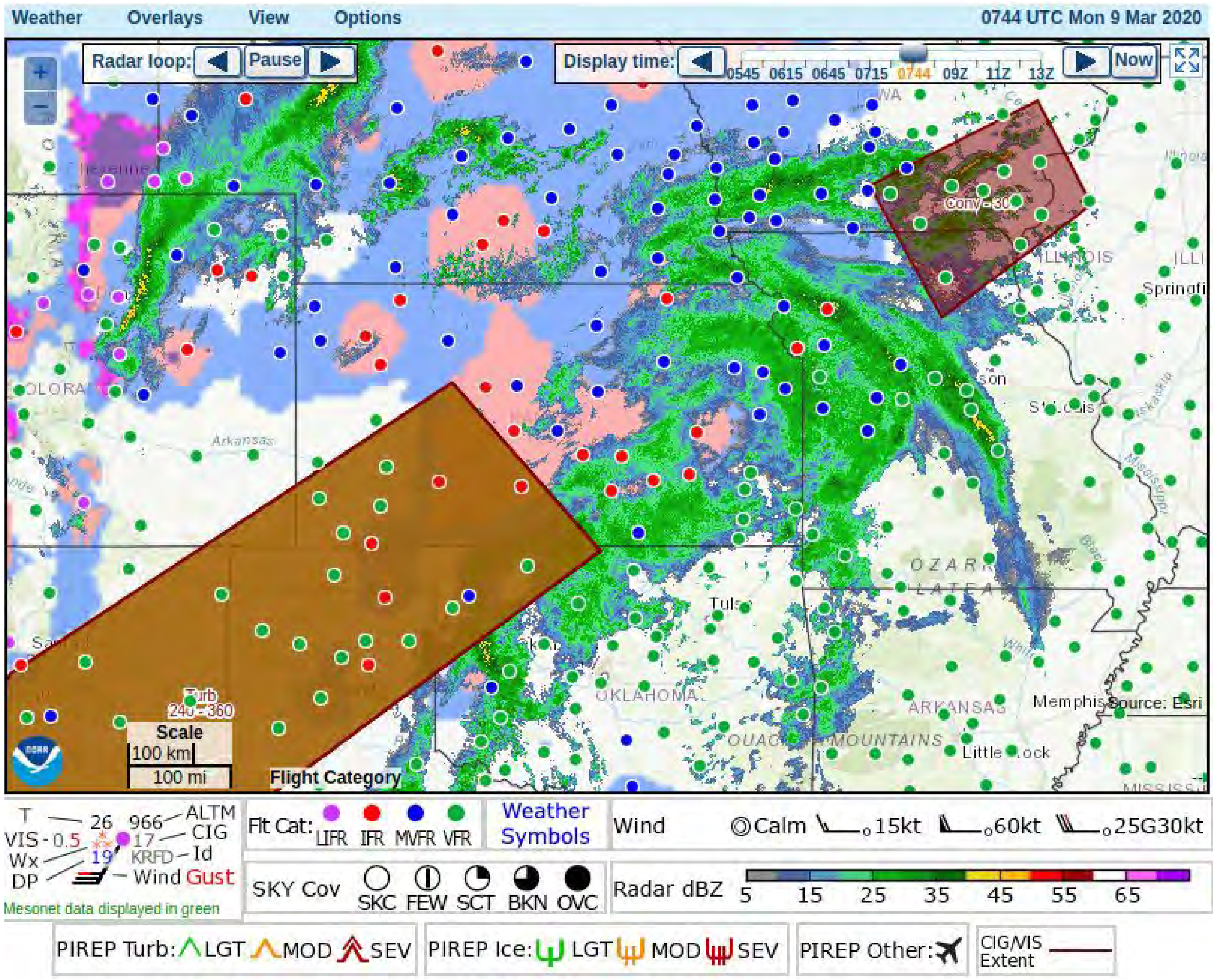


Figure 5. A sample of the updated HEMS Tool

Automation of Social Media

As part of a project to expand the delivery of products to social media, a test project was set up to automatically deliver Significant Meteorological Information (SIGMETs) to Twitter. Over the spring and summer of 2019, the development of automated imagery of various AWC products that mimic what other NWS centers were pushing to Twitter and Facebook was finalized. The second step was setting up the secure transfer of the imagery to Twitter. This was made operational in summer 2019. A sample product is shown in Figure 6.

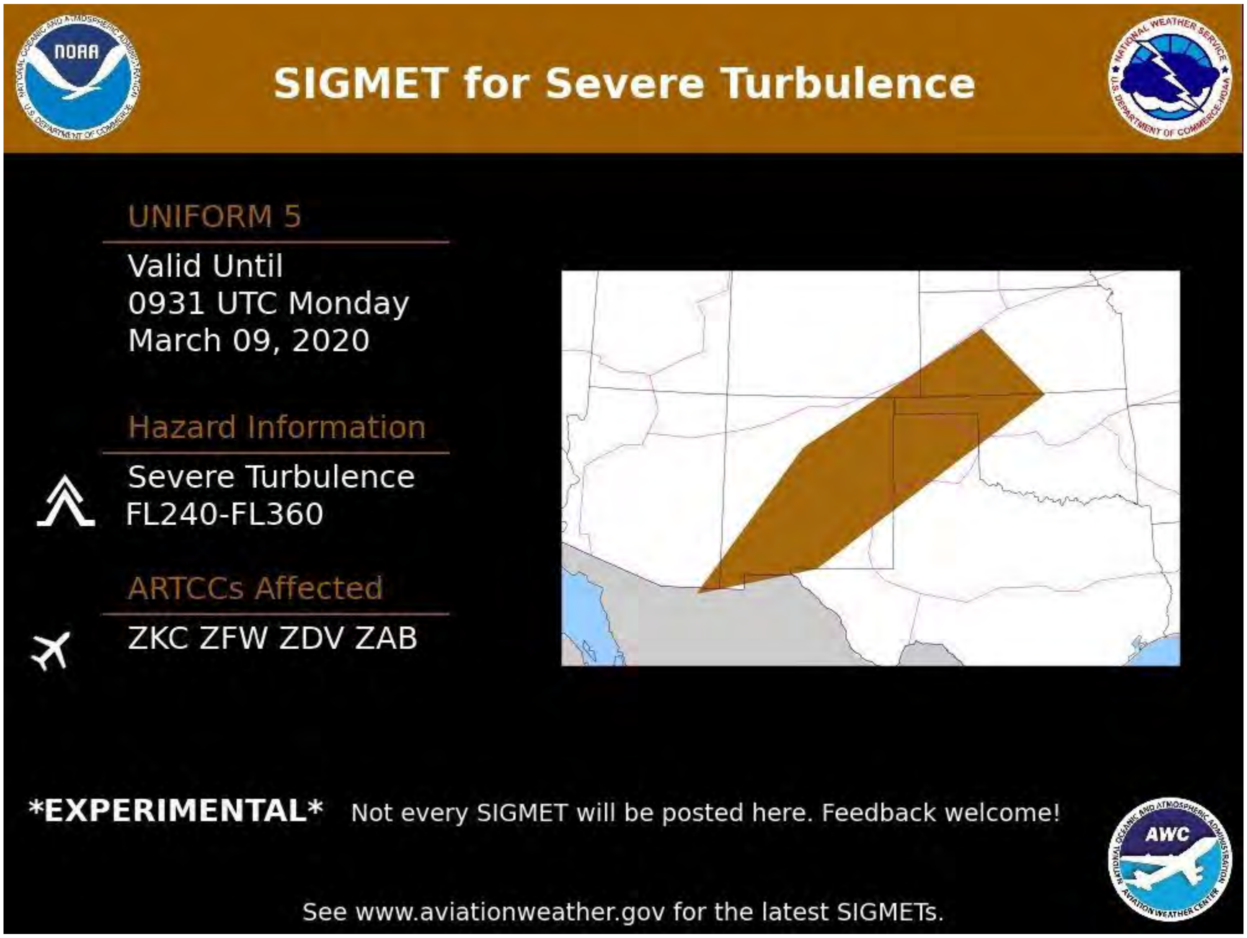


Figure 6. Sample automated SIGMET image that was distributed to AWC's Twitter feed.

ADDS Lite

ADDS Lite refers to the back-end data processing that powers the aviationweather.gov website. Up until two years ago, the back-end infrastructure was a combination of nearly a dozen web projects, each with their own infrastructure. ADDS Lite was developed to simplify the infrastructure, remove duplicate processing and create a common file structure while standardizing the processing across each of the projects and tools. In addition, ADDS Lite would provide an easier setup for the Integrated Dissemination Program (IDP) staff to support. The work was begun in 2016 and most of the legacy website was moved to ADDS Lite in 2018. To complete the product, two new sets of servers would need to be built out, one in College Park and a second in Boulder to provide redundant backup.

The work to build the new ADDS Lite servers in Boulder was started over the summer and finished in September. This included creating about two dozen virtual machines (VMs) to handle the back-end, databasing, and web services. AWC IT staff worked with IDP to create these VMs within IDP's infrastructure rules. In early October the web and IT team went to College Park to train the IDP staff.

Work continued at the end of the year to improve monitoring of the website on Integrated Dissemination Program's (IDP's) Big Brother tool. With this work completing, the work to build out the servers in College Park was scheduled for early to mid-2020.

Other Accomplishments

TFM Convective Forecast (TCF) and Extended TCF (ETCF) - Updates to both products were finalized late in the year to offer more capabilities to the end user. This included access to verification graphics and improving the user interface.

RHEL6 to RHEL7 Transition - As a continuation of the work done within operations in 2018, many of the research, development and testing servers at AWC were upgraded from Red Hat Enterprise version 6 to version 7 over the year.

GOES 16/17 Derived Products - Work was done to test the use of GOES derived products within tools like HEMS and GFA. Initially, Instrument Flight Rules (IFR) probability products were added to HEMS for evaluation during the Summer Experiment. The hope is to add lightning and other derived products in the future.

Test Products added to WIFS - WIFS is an internet distribution service for aviation data aimed at international air operations. Two new products were added to the Testbed website. First, to manage the transition away from alphanumeric codes, Meteorological Terminal Air Report (**METAR**) and Terminal Aerodrome Forecast (**TAF**) products formatted in International Civil Aviation Organization (ICAO) Meteorological Information Exchange Model (**IWXXM**) format were created and tested. Second, to handle the request for higher resolution model data, new 0.125 degree grids were created for icing, turbulence and convective products.

PROJECT PUBLICATIONS: N/A
PROJECT PRESENTATIONS/CONFERENCES:

Vietor, D., 2019: AviationWeather.gov Update. EAA Airventure 2019, Oshkosh WI, 26-30 July.

PROJECT TITLE: Research-to-Operations at the NOAA/Aviation Weather Center (AWC) and Aviation Weather Testbed (AWT) in support of the FAA Aviation Weather Research Program (AWRP).

PRINCIPAL INVESTIGATOR: James H. Henderson

RESEARCH TEAM: Brian Pettegrew

NOAA TECHNICAL CONTACT: Joshua Scheck (NOAA/AWC)

NOAA RESEARCH TEAM: Austin Cross (NOAA/AWC)

PROJECT OBJECTIVE:

The Aviation Weather Center (AWC) and the Federal Aviation Administration (FAA) have a collaborative agreement for the transfer of services from research-to-operations (R2O) into the National Weather Service (NWS) through the Aviation Weather Testbed (AWT) and the Aviation Weather Research Program (AWRP). Through this partnership, the AWC ensures sustainment of a quasi-operational architecture supporting the experimental production and testing of AWRP sponsored research and distribution through Aviation Weather Testbed (AWT) and its website upon request.

The AWC sustains the AWT, supporting applied research and development for continuous improvement of AWC's full operational mission, partnerships in R2O supporting aviation weather safety and related improvements in national traffic flow management (TFM), and assessments or evaluations of internal, external, and AWRP-sponsored research. These R2O initiatives are shared through continued collaboration across the FAA and participating National Oceanic and Atmospheric Administration (NOAA) testbeds.

PROJECT ACCOMPLISHMENTS SUMMARY:

For the reporting period January 1, 2019 - December 31, 2019, CIRA Staff accomplished the following tasks:

1. Facilitated and coordinated an interagency upgrade and transfer of the Graphical Turbulence Guidance (GTG) production from Weather and Climate Operational Supercomputer System (WCOSS) into the Unified Post Processor (UPP)
2. Sponsoring the end-of-life for the National Ceiling and Visibility Analysis at AWC.
3. Supported the evaluation of icing products for the scientific evaluation of the Rapid Refresh Model (RAP) upgrade.
4. Support of the World Area Forecast System (WAFS) upgrades through research and development,
5. Development of WAFS hazard blending schemes as part of the International Civil Aviation Organization (ICAO) Aviation System Block Upgrades and hazard upgrades
6. Creation of a collaborative effort to formalize a R2O process between the FAA and the NWS through the AWT.
7. Global Lightning Mapper (GLM) grids into AWIPS production system

1) GTG Production Switch

The Graphical Forecast Guidance (GTG, Figure 1) is a product operationalized by the NWS through AWRP funded R2O. The algorithm uses RAP model derived fields, producing a forecast of clear-air turbulence (CAT) and mountain wave turbulence (MWT) in units of Eddy Dissipation Rate (EDR), which is the official ICAO unit of turbulence reporting. GTG has been run and supported operationally by NCEP Central Operations (NCO) and by the Aviation Support Branch (ASB) at AWC since November of 2015. This past year, AWC has worked collaboratively with NCEP Central Operations (NCO) and the Environmental Modeling Center (EMC) to integrate this algorithm into the modeling Unified Post Processor (UPP).
As part of this production switch, the AWC was able improve the longevity and usefulness of the GTG product to benefit its aviation partners.

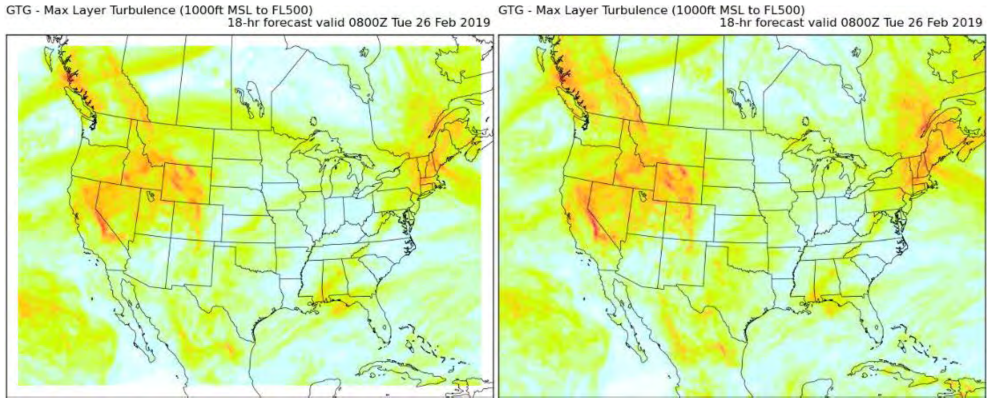


Figure 1. GTG products from the original production (left) to the new production platform (right).

2) End-of-life transition of National Ceiling and Visibility Analysis (NCVA)

The NCVA is a frequently updating analysis of ceiling and visibility conditions derived from surface observations and a satellite cloud mask. This was primarily used as a static graphic on https://www.AviationWeather.gov/cva, seen in Figure 2, and a dynamic analysis on the AWC Helicopter Emergency Medical Services (HEMS) tool. However due to the de-commissioning of older Geostationary Operational Environmental Satellite (GOES) images, software, and IT security concerns, the performance of NCVA has degraded. This will be replaced by the Gridded Localized Aviation MOS Product (GLAMP) Analysis, run and maintained by NCO.

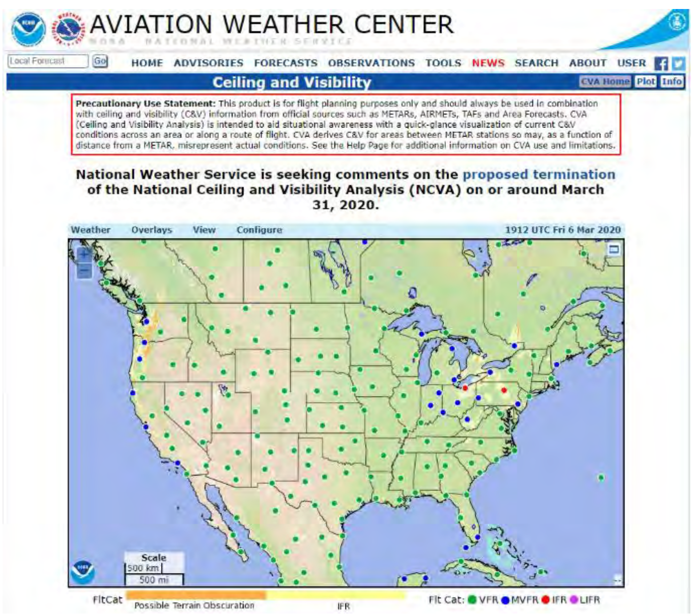


Figure 2: Ceiling and Visibility Analysis page

3) Evaluation of Icing forecasts for RAP upgrade

Testing and evaluation of the RAP version 5 began in July 2019. To support the scientific evaluation of the upgraded RAP model, the AWC ran the Forecast Icing Potential (FIP) algorithm on parallel versions of the RAP to help assess any impacts. These were made available not only to AWC partners in Office of Atmospheric Research (OAR), but were used as part of the AWC evaluation. It was found that the upgrade did not critically affect the FIP algorithm.

In July 2018, the NWS Rapid Refresh (RAP) model underwent significant improvements. This upgrade required many changes to the AWC Graphical Turbulence Guidance (GTG) and FIP products that use the RAP derived model fields as inputs. A couple of the primary GRIB2 encoded fields that required changes

were the accumulated precipitation and the convective precipitation, both fields used by the FIP (see Figure 3).
Because of the renaming of some of these encoded fields, these algorithms required timely upgrades.

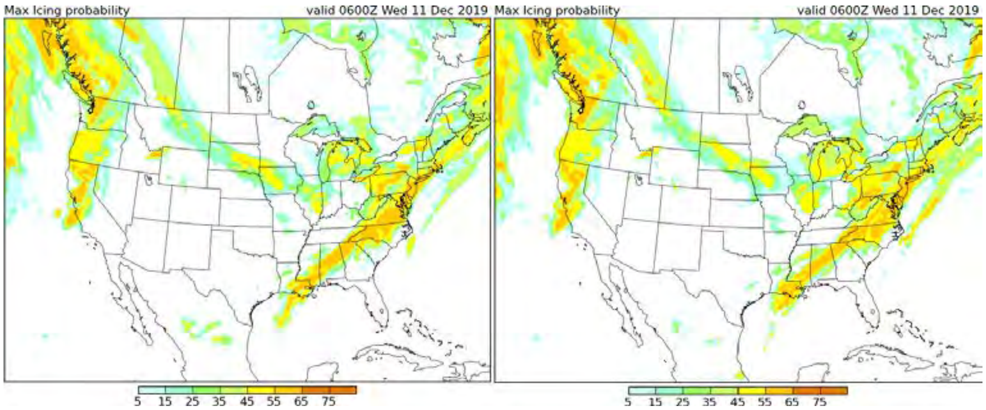


Figure 3: Max Probability of Icing derived from the RAPv4 (left) and RAPv5 (right).

4) WAFS Upgrade Development and Improved Icing Blending Scheme

The International Civil Aviation Organization (ICAO) has set requirements for the WAFS program to upgrade their gridded hazard products for both turbulence and icing. For turbulence, the requirements were to provide a high-resolution global forecast of turbulence in units of Eddy Dissipation Rate.

Additionally, WAFS was required to provide global, high-resolution forecasts of icing severity. Using the EMC's implementation of Icing Severity on the NWS Global Forecast System (GFS), the AWC began investigating and developing a method to blend forecasts from multiple WAFS centers to achieve a consistent global product.

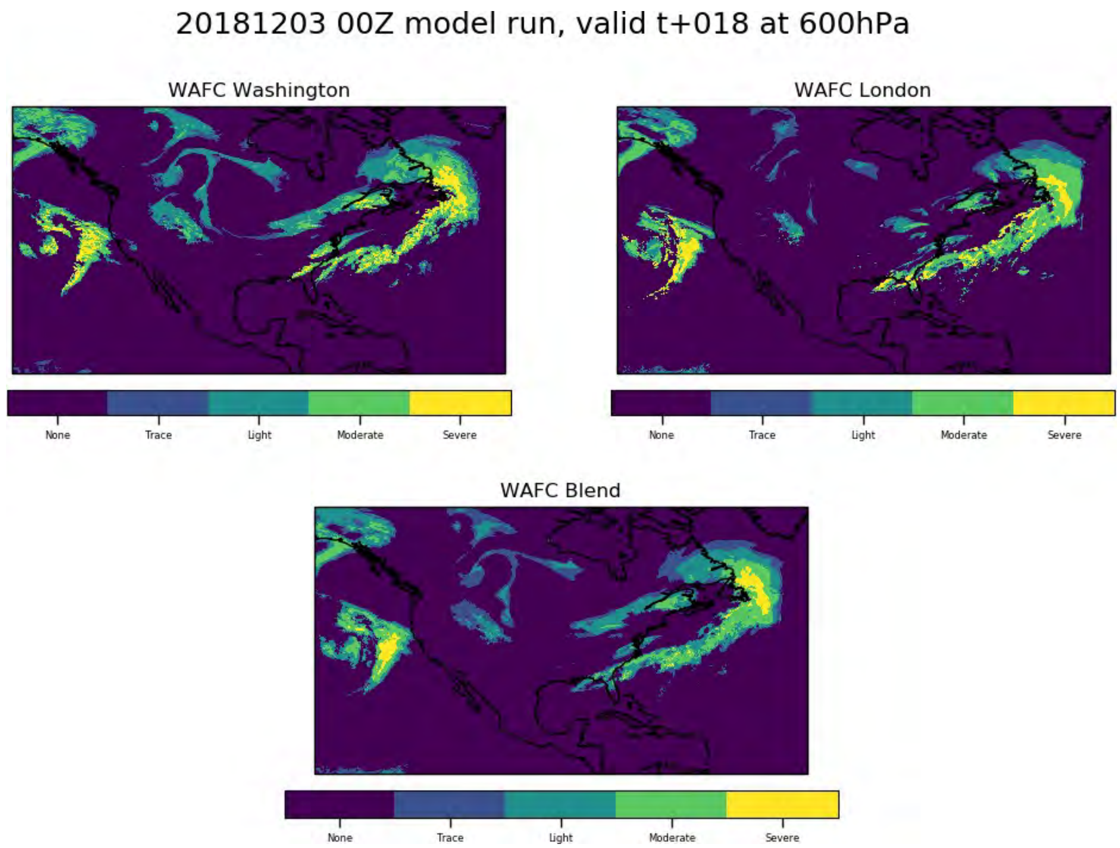


Figure 4: Comparison of Met Office Global Icing Severity Blended with GFS Icing Severity

The blended icing severity product for WAFS is scheduled to be implemented into operations by November 2020, and currently only includes input from the NWS and the Met office in Exeter, UK.

6) Research-to-Operations Improvements

This task is an ongoing research and development effort by the AWT and FAA to address inconsistencies between FAA supported research and development, and the transition process for operational implementation into the NWS. The intent is to work within AWT to organize and structure the R2O process and work with the FAA to integrate their current process within the AWT structure, creating an agile and efficient transition process. Representatives from the FAA and AWC met to construct a formal outline demonstrating an end-to-end R2O process between agencies. Using previous processes, this was built on improved agency coordination and realistic timelines based on governance.

Other research done, has been to continue the development and transition of Geostationary Lightning Mapper (GLM) into an applicable form for AWC forecasters to use.

With the upcoming production platform switch at the AWC, the AWT was able to fully integrate the GLM from GOES 17 into the current GLM data and make it available in grib2 format to support the new AWIPS production platform (Figure 5). AWC users have used the GLM data in operations improving situational awareness for SIGMETs over the US and over the Caribbean.

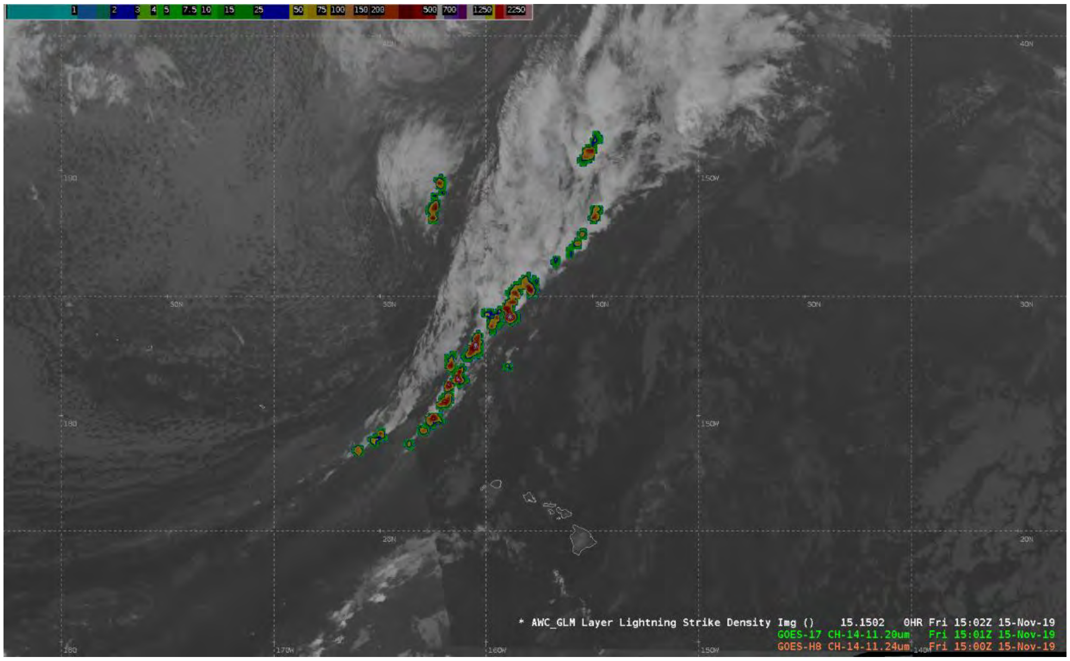


Figure 5: GLM from GOES-17 near HI displayed on AWIPS

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Research-to-Operations at the NOAA/Aviation Weather Center (AWC) and Aviation Weather Testbed (AWT) in support of the FAA Aviation Weather Research Program (AWRP)

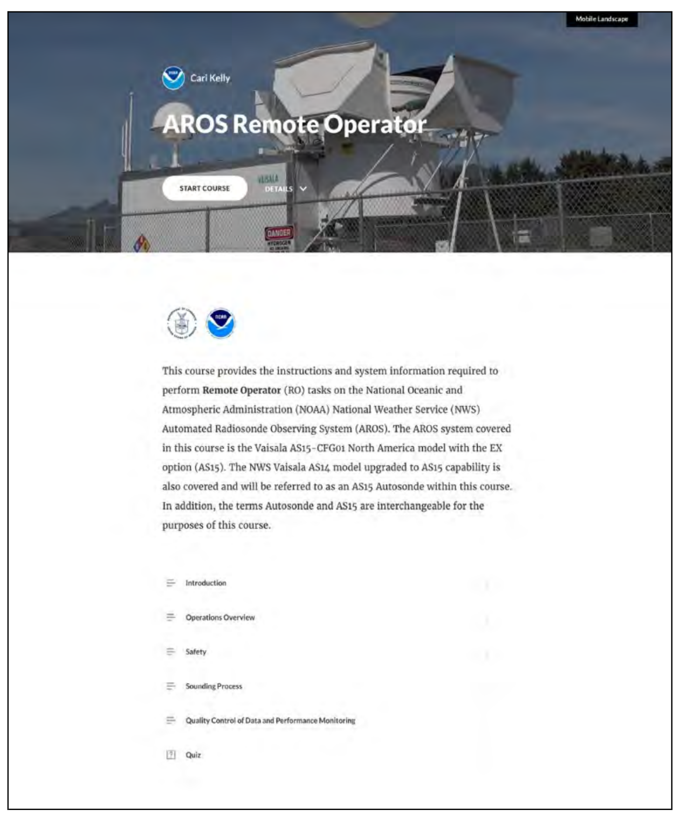
PRINCIPAL INVESTIGATOR: James Henderson

RESEARCH TEAM: Cari Kelly

NOAA TECHNICAL CONTACT: Jim Poole (NOAA/NWSTC)

PROJECT OBJECTIVES:

Cari Kelly designed four important online courses for the Electronics Division of the Office of the Chief Learning Officer at the National Weather Service Training Center in Kansas City. Her skills as an Instructional Developer have saved resources by freeing up full training days in at least four in-house face-to-face courses for NOAA Weather Radio (NWR). She has also developed courses for the deployment of the Automated Radiosonde Observing System (AROS), working remotely with subject matter experts in the Washington DC area. The AROS courses will train NWS personnel working in remote locations.



PROJECT ACCOMPLISHMENTS SUMMARY: SEE ABOVE

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: SHyMet - CIRA support to GOES-R Training: The Satellite Hydro-Meteorology (SHyMet) Education and Outreach Program & GOES-R commitment to the WMO CGMS Intl VLab & GOES-R FDTD Satellite Training Liaison

PRINCIPAL INVESTIGATOR: Bernadette Connell,

RESEARCH TEAM: Dan Bikos, Erin Dagg, Ed Szoke

TECHNICAL CONTACT: Dan Lindsey NOAA/NESDIS/GOES-R

NOAA RESEARCH TEAM: Deb Molenar NOAA/STAR/RAMMB, Kevin Scharfenberg, Brian Motta

PROJECT OBJECTIVES:

The overall objective of the Satellite Hydrology and Meteorology (SHyMet) program is to develop and deliver comprehensive distance-learning courses on satellite hydrology and meteorology, in particular for the enhanced capabilities of the newly launched Geostationary Operational Environmental Satellites (GOES): GOES-R/16 (16 November 2016) and GOES-S/17 (1 March 2018). The development of training materials is an ongoing process that includes establishing foundational materials, providing applications training to ensure relevancy of products and usage in the forecast process, and encouraging continued use and deeper understanding of imagery and products over time. This project leverages the structure of the Virtual Institute for Satellite Integration Training (VISIT) program. This work was done in close collaboration with experts at CIRA, the Cooperative Institute for Meteorological Satellite Studies (CIMSS), COMET, satellite liaisons, the NOAA Satellite Training Advisory Team (STAT), and the National Weather Service (NWS) Office of the Chief Learning Officer (OCLO) which includes the Training Center (NWSTC), the Warning Decision Training Division (WDTD), and the Forecast Decision Training Division (FDTD).

Specific Objectives:

1-- Interact with experts, training partners, and NOAA NESDIS and NWS Program Offices to discuss training objectives, set goals, and contribute content to meet high priority applications-based GOES-R training for user readiness.
2-- Evaluate current content of SHyMet Courses (Intern, Forecaster, Tropical, and Severe Thunderstorm) and prioritize for updates to reflect new GOES 16 & 17 imagery and products and operational applications.
3-- Attend meteorological and educational workshops, conferences and symposiums as the opportunities arise to present materials related to SHyMet/GOES-R, to exchange information on blended learning, and to actively solicit user needs from the community.

PROJECT ACCOMPLISHMENT SUMMARY:

1-- Interact with experts, training partners, and NOAA NESDIS and NWS Program Offices to discuss training objectives, set goals, and contribute content to meet high priority applications-based GOES-R training for user readiness.

Figure 1. From left to right: Example content from the Day-Snow-Fog Quick Brief on the left and the associated Job Aid on the right. The Job Aid incorporates the concepts of facilitated hands-on learning by investigating the product with real-time or case study data.

- During the past year, emphasis was put on creating Quick Briefs and Job Aides for designated products and coordinating user led / instructor facilitated application Webinars. The CIRA researchers participated in bi-weekly NWS OCLO Training Team calls.

- The SO_2 RGB Quick Guide developed in a previous year had very limited background information to utilize in the development of training materials. There was no formal GOES-R algorithm development associated and this RGBs that was developed by the Japan Meteorological Association (JMA) for use with the AHI sensor. The use of the SO_2 RGB, particularly with high amounts of SO_2 exploded from volcanoes, proved very useful during the past year, in particular for the eruption of the Russian Raikoke Volcano in June 2019 that affected Alaska Aviation. Data from this eruption and other volcanoes were collected for additional understanding and the development of training.

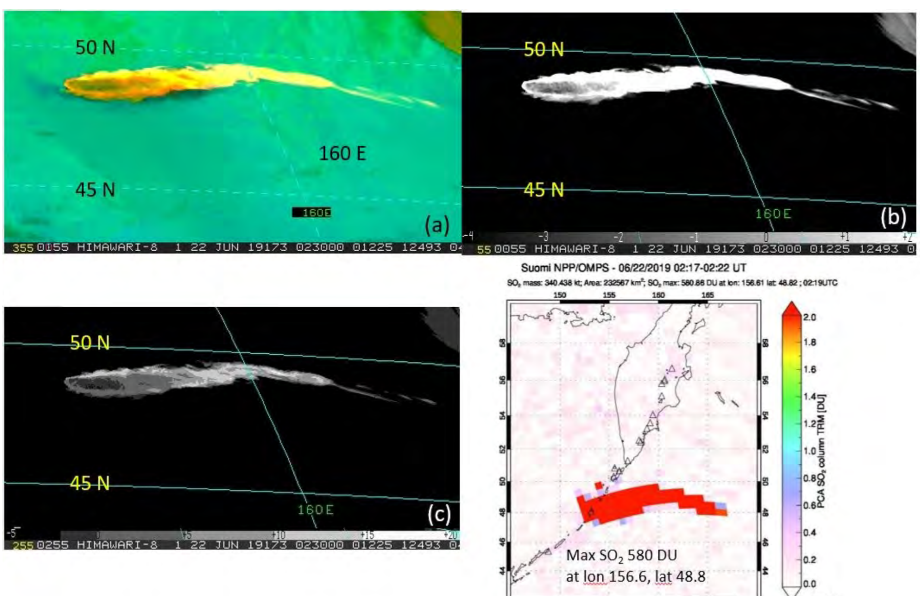


Figure 3. The volcanic plume from the Raikoke volcanic eruption on 22 June 2019 at 02:30 UTC for the Himiwari-8 imagery. The same channels used in this RGB are available on GOES 16 & 17. a) the SO2 RGB, b) the red component of the SO2 RGB with a normal BTD for 6.9 – 7.3 µm stretched from -4 to +2, c) the BTD for 6.9 - 7.3 µm stretched between -5 and +20, and d) SO2 retrieval in DU from Suomi NPP/OMPS at ~02:20 UTC.

2-- Evaluate current content of SHyMet Courses (Intern, Forecaster, Tropical, and Severe Thunderstorm) and prioritize for updates to reflect new GOES 16 & 17 imagery and products and operational applications.

- CIRA is coordinating with CIMSS and OCLO to develop the course outline for a Satellite Introduction course that will replace the SHyMet Intern.

- CIRA is coordinating with CIMSS and OCLO to develop the course outline for a Satellite Severe Thunderstorm course that will update/replace the content of the existing SHyMet course with the same name. It is anticipated that the course will debut Spring 2020.

New training sessions developed the past year (2019) in collaboration with the VISIT Program include:

-- “Integrating GOES into Mesoanalysis”.

-- “Severe Weather Applications of the GOES Split Window Difference Product”.
-- “Storm Signatures Observed in Satellite Imagery”.

Sessions updated during the past year (2019) include:
-- “Tracking the Elevated Mixed Layer with a new GOES-R Water Vapor Band”.
-- “Can Total Lightning Help with Warnings for Non-Supercell Tornadoes?”

3-- Attend meteorological and educational workshops, conferences and symposiums as the opportunities arise to present materials related to SHyMet/GOES-R, to exchange information on blended learning, and to actively solicit user needs from the community.

-- See the presentations and workshops listed below. The SatFC-G was actively promoted to the Academic and International communities in presentations at conferences, meetings, and in workshops.

-- The 2019 WMO/Eumetcal Online Course for Trainers on Blended Learning took place 1 April – 2 June. B. Connell was a facilitator for the course and E. Sanders was a participant.

PROJECT PUBLICATIONS:

Gitro, C.M., D. Bikos, E.J. Szoke, M.L. Jurewicz Sr., A.E. Cohen, and M.W. Foster, 2019: A Demonstration of Modern Geostationary and Polar-Orbiting Products for the Identification and Tracking of Elevated Mixed Layers. *J. Operational Meteor.*, **7** (13), 180-192.

PROJECT PRESENTATIONS/CONFERENCES:

Bikos, D., S. Lindstrom, E. Szoke, B. Connell, E. Sanders, and B. Motta 2019: VISIT / SHyMet Training on GOES-16/17 Imagery and Products. Poster, National Weather Association (NWA) Annual Meeting, 7-12 September, Huntsville, Alabama.

Bikos, D., E. Szoke, B. Connell, and E. Sanders 2019: Recent CIRA VISIT and SHyMet Training Activities on GOES-R Series Applications. Poster, AMS/EUMETSAT Joint Satellite Conference, 28 September – 4 October, Boston, Massachusetts.

Connell, B., E. Sanders, and L. Veeck, 2019: “Building Short Examples to Highlight Successful Learning and Meet WMO Competency Guidelines for Satellite Skills for Operational Meteorologists.” Joint Satellite Conference, 30 September – 4 October 2019, Boston, Massachusetts. Presentation.

Szoke, E., D. Bikos, K. Hilburn, R. Cox, D. Barjenbruch, and P. Schlatter, 2020: Is There a Total Lightning Precursor Signal for Non-Supercell Tornadoes. Talk, 16th Annual Symposium on New Generation Operational Environmental Satellite Systems at the AMS 100th Annual Meeting, 14 January 2020, Boston.

PROJECT TITLE: AQPI Economic Impacts Study

PRINCIPAL INVESTIGATORS: R. Hill

RESEARCH TEAM: H. Cutler, M. Shields, J. Van de Lindt, K. Crofton, O. Nofal

NOAA TECHNICAL CONTACT: Dave Turner

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVE:

Estimate the potential economic savings due to improved precipitation forecasts due to the implementation of the AQPI project in Santa Clara County, California

PROJECT ACCOMPLISHMENTS SUMMARY:

This study estimates the economic benefits of the Advanced Quantitative Precipitation Information (AQPI) project. We have put together a team of economists and civil engineers that has created a modeling structure to understand how improved AQPI precipitation forecasts can be leveraged into a series of mitigation policies to offset the adverse economic impacts of potential flooding. Our test cast is for Santa Clara County in northern California. We are nearing completion of the basic engineering and economic models and will soon estimate losses under a variety of potential scenarios.

The civil engineering team--led by Professor John van de Lindt--has created a simulation model where the characteristics of commercial and residential buildings in terms of building materials and elevations are used to develop a family of “fragility curves” that describe potential structural damage to flooding. We can model how a flood is transmitted throughout the community, causing damage to commercial and residential buildings, which is subsequently used as an input to a computable general equilibrium (CGE) model to estimate the impact on economic activity.

The economics team has constructed the CGE model for Santa Clara County. A CGE model is an economic impact model that describes how utility maximizing households, profit maximizing firms and the local government interact to create economic activity in a city/municipality. Part of the data used in our model is a data set supplied by Santa Clara County Assessor’s Office. This data set contains records for almost all commercial and residential buildings in the county. Specifically, we have data for the value of a building, the size and value of the parcel the building resides on, the type of construction material used for the building and the number of stories for each building. These data along with U.S. Census Bureau data permits us to construct a spatial CGE model where we identify the location of all firms and households that are in and out of the flood plain in Santa Clara County.

Our primary objective is to develop a series of mitigation policies that can be implemented due the improved precipitation forecasts coming from the AQPI model. Since the AQPI system can generate more accurate forecasts with advanced warning, we are exploring the potential short- and long-term benefits of a variety of near-term mitigation strategies, such as water pumps, sand bagging, moving critical equipment to higher ground, etc. that can attenuate the economic damages from flooding.

The CGE model is complete and the engineering simulation model is near complete. We should able to compute preliminary simulations by the end of April. We believe we have a good prototype model to analyze the impact of the AQPI system for the other eight counties in northern California.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Estimating the Economic Value of Improved Weather Forecasts Resulting from NOAA - GSD Research and Technology Transfer

PRINCIPAL INVESTIGATORS: R. Hill

RESEARCH TEAM: H. Cutler, M. Shields, B. Hartman, Y. Hu, J. Hwayoung, T. Lu

NOAA TECHNICAL CONTACT: Dave Turner

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVE:

Document the economic value of improved weather forecasts for three select economic activities in the US economy

PROJECT ACCOMPLISHMENTS SUMMARY:

Each year the US federal government makes significant investments in improving weather forecasting models. Although the primary purpose is saving lives, forecasts are also used by a variety of decision makers on myriad economic problems. Accordingly, improved weather forecasts can help with decision-making, providing increases in economic efficiency. In this project we estimate the value of improved HRRR forecasts in three important activities: 1) commuting, 2) electricity generation using wind-power, and 3) production agriculture. Overall, we find that improved weather forecasts provide substantial economic savings in the US. Specifically:

- We find that HRRR2 generates substantial positive economic impacts in these areas relative to HRR1
- We find that HRRR3 generates mixed economic impacts in these areas relative to HRRR2

<u>Theoretical Framework</u>

Consider an economy that consists of several industries. Define a production function for any industry *j* as, $Y_j=A_j(i)F(K_j,L_j)$, where K is industry capital stock (e.g., buildings and equipment), L is industry labor, and $F(\bullet)$ is the technology that converts capital and labor into output. GDP or total economic output (Y_t) at time *t* is $Y_t = \Sigma_{j,t}Y_{j,t}$. For our study, is A(i)--which economists call Total Factor Productivity (TFP)--is an important parameter. This scaling variable represents the *efficiency* of the production technology, with output increasing in its value. Although research shows many factors can influence the magnitude of TFP, here we emphasize information (i). Let the accuracy of information range from 0 (completely imperfect) to 100 (perfect), and normalized such that A(100)=1. Assuming better information increases production efficiency (i.e., $\delta A/\delta i>0$), we know that $\delta Y_j/\delta i = \delta Y_j/\delta A_j*\delta A_j/\delta i > 0$; better information increases industry output, all else equal.

Although “better” information allows the more efficient allocation of time and resources, information is costly to procure and apply. As a result, decision-makers collect and implement information only when its expected benefits exceed its costs. Improvements in HRRR are valuable in instances where the newer version provides better “actionable” information than the previous version. Actionable information is that which leads to important behavioral *changes* that impact economic outcomes. For example, farmers may care about temperature forecasts only if the predicted temperature will damage their crops AND they are able to take some action to mitigate the adverse impacts. The difference between the value of production with "limited" information and "better" information is the value of information.

- We compare expected economic outcomes under two different forecasts
    - HRRR(V) is "better" when (Y|HRRR(V)) > (Y|HRRR(V-1)), where V=2 or 3
    - HRRR(V) is "worse" when (Y|HRRR(V)) < (Y|HRRR(V-1))
- Value of updated forecast model is the difference between "HRRR(V) better" and "HRRR(V) worse"

Key Assumptions

In order to implement our analysis, we make several important—yet strong—assumptions.

1. HRRR forecasts are a "public good" and available to everyone at no cost. All decision-makers have access to timely forecasts and incorporate the information into their decisions.
2. Weather-related decisions are based solely on HRRR forecasts or proprietary forecasts informed by HRRR forecasts
3. Decisions are made "with commitment" based on 12-hour ahead forecasts. Forecast changes closer to the "event" do not change behavior

Data

- Geographic unit of analysis
    - *Commuting*: City boxes based on "minimum bounding boxes" containing municipal boundaries (155 largest US cities) (precipitation)
    - *Wind*: METAR buffer zones containing wind turbines (wind speed)
    - *Agriculture*: US Counties with a METAR station (temperature)
- Forecasts
    - Hourly, 12-hour ahead forecasts for 3x3 km grids for CONUS (NETCDF)
- Observations
    - Precipitation: Stage-IV precipitation accumulation (4x4km resolution)
    - Temperature and wind speed: METAR stations (point observations)
- We limit our time-frame to periods where there are two versions of HRRR running simultaneously
    - HRRR1 and HRRR2: June 2015 to August 2016
      HRRR2 and HRRR3: July 2017 to June 2018

Application 1: The economic value of improved precipitation forecasts due to improved commuting decisions

Commuters are one important user group, making daily decisions about when to leave for work based, in part, on expected road conditions. When workers account for potential weather delays, economic losses due to missed work time are reduced. We quantify some of the economic benefits of updated weather forecasting models by looking at how improved forecasts impact commuter decisions about when to depart for work.

We begin by comparing the accuracy of 12-hour ahead "rush hour" forecasts from three generations of National Oceanic and Atmospheric Administration (NOAA) models for approximately 200 MSAs. We exploit the fact that when NOAA introduces updated models, both the current and new version run for several months. We compare forecasts from each model to observed weather data. Model "improvements" occur when the updated model provides a more accurate forecast than the previous version, for example, predicting observed rainfall when the previous model did not.

Previous research shows that even slight precipitation can increase individual commuting times by several minutes. We leverage this work to estimate the number of minutes of work that are saved when commuters have better weather forecasts that allow them to arrive at work in a timely fashion by departing from home earlier. We aggregate average work-time saved per commuter across all commuters in an MSA, and then across all MSAs in each of the eight BEA regions. This provides an estimate in the number of full-time equivalent (FTEs) workers “saved” in a year for each region. For example, we estimate that commuters that follow HRRR2 would provide 2.6 million hours (1,491 FTEs) of additional work than they would have had they followed HRRR1. Economic impacts are then estimated via reductions in labor supply in computable general equilibrium models built specifically for each region under each forecasting regime. Overall, we find that improved precipitation forecasts provide a fairly small reduction in economic losses due to missed work time, but the value of these gains still exceeds the annual investment in the specific forecast modeling endeavor.

Table 1 summarizes the results for the transition from HRRR1 to HRRR2. We report on savings in 1) total economic output and 2) federal tax revenue for each of eight BEA regions. We provide an “upper bound” estimate--which documents the total potential savings if commuters use HRRR2 instead of HRRR1 and do not make up any lost work time (for example, a worker arrives late to the job, but leaves as scheduled). The lower bound estimate assumes workers stay late and make up 75 percent of missed work time. Aggregating across the eight regions, total output savings in the upper bound case are $111.67 million. This supports $15.21 million in federal tax revenue. For the lower bound estimate, output and federal tax revenue savings are $27.9 million and $3.8 million, respectively. The difference between HRRR2 and HRRR3 (not reported here) are quite small, with HRRR2 slightly outperforming HRRR3.

TABLE 1: Impacts on Commuting HRRR2 versus HRRR1

	Total Output (mil of $)		Federal Tax Revenue (mil of $)	
BEA Regions	Upper Bound	Lower Bound	Upper Bound	Lower Bound
Southwest	$10.16	$2.54	$0.48	$0.12
Great Lakes	18.27	4.57	2.54	0.63
Southeast	22.25	5.56	2.19	0.55
Middle East	40.87	10.22	7.49	1.87
Far West	4.95	1.24	0.58	0.15
Rocky Mountain	1.96	0.49	0.16	0.04
New England	8.76	2.19	1.11	0.28
Plains	4.45	1.11	0.67	0.17
Total	$111.67	$27.92	$15.21	$3.80

Application 2: Estimating the cost savings in power generation due to updated wind forecasting models

In the US, wind power is an important, low-cost contributor to the electricity grid, and its share of total production is steadily increasing. However, because wind is intermittent, wind power generation can be highly variable. Accordingly, an increased reliance of wind power can make it more difficult for utilities to optimize their production decisions across their portfolio of sources. Thus, accurate 12-hour ahead wind forecasts are important for utilities that use wind power as a source of electricity generation.

We estimate how improvements in wind forecasts help utilities better manage their internal production resources. Our first step determines if forecasts of predicted electricity output are more accurate as the HRRR model evolves. We exploit the fact that when the HRRR model is updated, both the current and new versions run for several months. In this analysis we compare wind forecasts from each model (e.g., HRRR2 versus HRRR3) to recorded wind observations from weather stations located near wind turbines. Forecast accuracy is said to improve as the difference between the predicted and actual wind speed declines.

The second step assigns economic values to wind forecast errors. Here we draw on industry data to estimate cost increases when there are forecast errors. The costliest error occurs when utilities expect to produce more wind power than they actually do. Because electricity demand must be met, utilities must turn to the spot-market when they do not generate enough themselves. This is expensive, as spot-market prices tend to be much higher than the costs of production from most utility-owned sources.

Overall, we find that improved wind forecasts have led to significant cost savings for utilities, but further improvements in wind forecast modeling can still provide significant positive economic impacts. Tables 2 and 3 compare HRRR1 and HRRR2. In Table 2 we identify all cases where HRRR2 outperforms HRRR1, while Table 3 shows the converse. We focus on cases where the models “overpredict” generated power; such errors necessitate utilities correct for these errors by turning to the spot market. The first row of each table shows the “actual” power produced, calculated using: 1) observed wind speed in each location, 2) installed capacity in each location, and 3) wind power curves that convert wind speed into power.[1] The second and third rows show the 12-hour ahead forecasted wind power based on the two models. The second data column shows the amount of over-prediction, which must be purchased from the spot market due to a shortfall in production. The third data column shows the “costs” of these mistakes, assuming a spot market price of $50 per megawatt. The last column shows the new gains from the “better” model.

[1] We adjust the potential wind power downward to account for the fact that some turbines may not be available due to maintenance.

Overall, we find that in instances where HRRR2 outperforms HRRR1, utilities potentially saved $107.87 million. In the instances where HRRR1 outperformed HRRR2, the "costs" of HRRR2 were about $47.3 million. The difference is: HRRR2 plus $60.56 million versus HRRR1 for the specified time period. Following the same methodology, the net benefit for HRRR3 compared to HRRR2 is $4.16 million (not detailed here).

Table 2: Benefit: HRRR2 "better" than HRRR1

	electricity generation (megawatt)	Buying from wholesale market (megawatt)	Cost ($50/megawatt)	Net gains from HRRR2
"Actual"	579,260			
Based on HRRR1	3,328,407	2,749,147	$137,457,349	
Based on HRRR2	1,170,927	591,668	$29,583,385	$107,873,964

Table 3: Cost: HRRR2 "worse" than HRRR1

	electricity generation (megawatt)	Buying from wholesale market (megawatt)	Cost ($50/megawatt)	Net gains from HRRR1
"Actual"	770,698			
Based on HRRR1	1,478,557	707,859	$35,392,968	
Based on HRRR2	2,424,744	1,654,046	$82,702,296	$47,309,328

Application 3: Estimating the Reduction in Freeze and Frost Losses to Agriculture associated with Improved Weather Forecasts

Each year, US agricultural producers suffer millions of dollars in losses due to freeze and frost. When such events are predicted, producers can take a variety of actions to prevent crop loss, including sprinkling, wind machines/helicopters, covering crops, and fog or smoke clouds. Crop protection measures must be put into effect ahead of the freeze or frost, thus making weather forecasts important in the producer's decision to protect their crops. Because such measures are expensive, we focus on high value agriculture crops.

We use federal crop insurance indemnity payments as a proxy for losses, using the United States Department of Agriculture's Cause of Loss dataset. Federal crop insurance policies are purchased by producers and pay indemnities when the farmers yield, or revenue falls below pre-specified levels and cover many of the specialty crops that are prone to freeze or frost losses. We narrow down the thousands of observations of freeze and frost indemnity payments into only instances where the weather forecast would potentially make an impact on the producer's decision and crop losses. For example, when temperatures get below a threshold, crop loss will still occur even when preventative measures are taken.

Once we narrow the dataset down to the events where the weather forecast was theoretically important in producer decision making, we narrow it further to identify those events where the currently running HRRR model missed the freeze forecast and the newer model--which was running on NOAA computers but not available to the public--correctly predicted the freeze. If this was the case, we assumed that if farmers had this correct information, they could have reacted to protect their crops from freeze damage. We aggregate these potential reductions in crop losses across the 8 BEA regions, and, using CGE models for each region, evaluate the economic benefits from the improved weather forecasts.

In Tables 4 and 5 we report on instances where one version of HRRR correctly predicts a freeze/frost event and the other does not. We set the threshold at 35 degrees Fahrenheit as the temperature at which a risk-averse producer would take a preventative action. We calculate averted crop losses and enter this into the appropriate regional CGE model as an increase in export demand. The model then translates this additional output into 1) employment, 2) domestic supply, 3) household income and 4) federal tax revenue. Effects include both direct and multiplier impacts. In Table 4, we show that HRRR2 "saved" about 74 jobs, $8.4 million in domestic supply, $7.7 million in household income and $1.9 million in federal tax revenue. For HRRR2 versus HRRR3, there were substantially fewer incidents where the two models had potentially economically meaningful differences in forecasts. In those instances, HRRR3 outperformed HRRR2, saving 47 jobs and $1.27 million in federal government revenue.

Table 4. HRRR2

	Employment	Domestic Supply (mil of $)	Household Income (mil of $)	Govt Rev (mil of $)
Rocky Mountain	0.3	0.0	0.0	0.0
Far West	-22.2	-1.8	-2.6	-0.1
Great Lakes	27.2	3.5	3.7	0.8
Middle East	43.0	4.3	3.0	0.8
Plains	6.1	0.4	0.5	0.0
Southwest	16.2	1.6	2.6	0.3
Southeast	3.2	0.3	0.5	0.1
Total	73.7	8.4	7.7	1.9

Improvement over HRRR1: 35 Degrees

Table 5. HRRR3 Improvement over HRRR2: 35 Degrees

	Employment	Domestic Supply (mil of $)	Household Income (mil of $)	Govt Rev (mil of $)
Rocky Mountain	45.73	3.73	5.30	1.24
Far West	0.71	0.07	0.11	0.02
Great Lakes	0.71	0.06	0.06	0.01
Total	47.15	3.86	5.47	1.27

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Presented to Jennifer Mahoney (NOAA, Boulder) November 2019

PROJECT TITLE: CIRA - AOML Research Team (CART)

PRINCIPAL INVESTIGATOR: Steven Miller

RESEARCH TEAM: Peter Marinescu, Kate Mugrave

NOAA TECHNICAL CONTACT: Lidia Cucurull, Deputy Director, Quantitative Observing System Assessment Program (QOSAP)

NOAA RESEARCH TEAM: Led by Lidia Cucurull, supported by CIMEL, CIRES (and CIRA) staff

PROJECT OBJECTIVES:

Colorado State University proposes to the National Oceanic and Atmospheric Administration's Office of Oceanic and Atmospheric Research Atlantic Oceanographic and Meteorological Laboratory (NOAA/OAR/AOML) a new program to support broad-spectrum research studies and new scientific inquiries (including Post-Doctoral associates, Research Associates, Research Scientists, and Visiting Scientists), in close coordination with AOML leadership, under the auspices of the Cooperative Institute for Research in the Atmosphere (CIRA). The team of CIRA-associated research staff comprise the CIRA-AOML Research Team (CART).

CIRA's goals emphasize basic and applied research, interfacing with graduate education, and mentoring of newly graduated professionals. Major objectives of the Institute that resonate with the interests/objectives of AOML include satellite remote sensing applications with specific focus on tropical regions and associated weather systems. CIRA is currently listed as one of the principal affiliates of AOML's Hurricane Research Division (HRD; https://www.aoml.noaa.gov/hrd/advancedprograms/) and the CART program helps to formalize this partnership moving forward.

This proposal encompasses a broad scope of satellite algorithm development, calibration/validation, radiative transfer model development, and data assimilation activities which resonate with CIRA's research themes established under its recently selected Cooperative Agreement with NOAA.

PROJECT ACCOMPLISHMENTS SUMMARY:

Technical work on this project has not yet commenced, as we have focused initially on filling the initial postdoc position. Dr. Peter Marinescu was identified as a well-qualified candidate for the position given his background in both observations and numerical modeling.

His initial role in CART will be to study application of various satellite remote sensing instruments and the assimilation of their observations into numerical weather prediction (NWP) models. The individual in this position will work on satellite calibration and validation activities, with an overarching goal of optimizing the current and future architecture of NOAA's observing systems. There will be an initial focus on assessment of data from the Atmospheric Dynamics Mission-Aeolus (ADM Aeolus). Here, the individual in this position will develop Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs) to evaluate the impact of Aeolus-derived winds in NWP models including the Hurricane Weather Research and Forecasting (HWRF) model. Similar experiments, based on other observations and models, will also be considered.

A very positive initial face-to-face meeting between Miller/Marinescu and Lidia Cucurull's group was conducted, and Peter is excited to begin work with the team beginning 1 April 2020.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: CIRA Support to JPSS Proving Ground Risk Reduction Training Activities

PRINCIPAL INVESTIGATOR: Bernadette Connell

RESEARCH TEAM: Jorel Torres, Erin Sanders, Dan Bikos

NOAA TECHNICAL CONTACT: Mitch Goldberg, JPSS Program Science Office

NOAA RESEARCH TEAM: Deb Molenar, Brian Motta, and Kevin Scharfenberg

PROJECT OBJECTIVES:

This project supports a full-time Satellite Liaison with part time contributions from research staff at the Cooperative Institute for Research in the Atmosphere (CIRA). As a team, they form links between the Joint Polar Satellite System (JPSS) program and National Oceanic Atmospheric Administration (NOAA) operational end users primarily at National Weather Service (NWS) Offices and National Centers. This project takes advantage of the expert knowledge of researchers in the fields of education, meteorology, and remote sensing to promote effective learning and knowledge retention strategies for the user while ensuring that the training reflects the strengths and limitations of the imagery and products for proper interpretation and usage in the operational setting. The linkage between research and operations allows for continual feedback between the groups that is beneficial for all involved: improvements in algorithms and products on the research side with increased understanding of imagery and products in the operational setting.

The Liaison (Jorel Torres) and research team provide training for operational NWS forecast staff on imagery and products from Visible Infrared Imaging Radiometer Suite (VIIRS), Advanced Technology Microwave Sounder (ATMS), and Cross-track Infrared Sounder (CrIS) sensors, as well as the NOAA Unique CrIS ATMS Products (NUCAPS), and Numerical Weather Prediction (NWP) data assimilation. Priority areas include current JPSS Program initiatives such as River and Ice Flooding, Fire and Smoke, NUCAPS, Arctic, Aviation, Hydrology, and Training. The projects are coordinated with the JPSS Program Office and the NWS Office of the Chief Learning Officer (OCLO), in particular the Forecast Decision Training Division (FDTD) of OCLO.

Specific Objectives:

1. JPSS Initiatives: Participate in JPSS initiative teleconferences and continue to review and assess both user needs and developer capabilities and identify training development opportunities.

2. Collaboration with Training Partners: Interact and collaborate with the Satellite Training Advisory Team (STAT) and training partners: the NWS OCLO, NWS Science and Operations Officers (SOOs), the Virtual Institute for Satellite Integrated Training (VISIT) and the Satellite Hydrology and Meteorology (SHyMet) training programs, the Short-term Prediction Research and Transition Center (SPoRT), COMET, and Satellite Liaisons on the creation of training materials.

3. JPSS Training Development: Develop and provide Quick Guides and Quick Brief training materials for NWS AWIPS-based visualization and analysis of SNPP/JPSS data for targeted, applications-based, operational decision-making. Create blog posts to highlight the use of JPSS imagery and products, particularly for significant weather and environmental events.

4. Participate in JPSS/PGRR annual reviews, science weeks, and professional meetings: Attend professional meetings to present on training activities. Participate in short courses and related training events as an organizer and presenter.

PROJECT ACCOMPLISHMENTS SUMMARY:

1. JPSS Initiatives:
   - The satellite liaison, J. Torres, participated in JPSS Initiative teleconferences: River and Ice Flooding, Fire and Smoke, NUCAPS, Arctic, Aviation, Hydrology, and Training. The conference calls bring researchers together to discuss progress and issues associated with their research projects or the transition of products to operations. On average there are a total of 11 initiative calls per quarter; some initiatives have calls every month and others have a call once per quarter.
   - The liaison was able to further facilitate introductions between developers and users of satellite products (VIIRS Snow Cloud Discriminator, VIIRS Day Land Cloud Fire RGB, Fire Temperature RGB, Modified NUCAPS), and provide online resources.

2. Collaboration with Training Partners Highlights:
   - The primary user this project targets for training is the NWS forecaster. The NWS Office of the Chief Learning Officer (OCLO) oversees training of its employees and has several divisions devoted to this task: the NWS Training Center (NWSTC), the Warning Decision Training Division (WDTD), and the Forecast Decision Training Division (FDTD). The Satellite Training Advisory Team (STAT) consists of Science Operations Officers (SOOs), satellite liaisons, representatives from the NWS OCLO, and training developers. During the past year, the project trainers participated in weekly STAT calls to discuss the development of new training materials, and track participation and feedback on the Satellite Foundational Course for JPSS (SatFC-J) which launched on March 27, 2019.
   - The liaison initiated a Google Drive archive of VIIRS NCC (December 2015 to present) and NUCAPS (April 2016 to present) data in AWIPS format to allow for case study access.
   - The liaison provided case data for: COMET with JPSS and GOES AWIPS product imagery and subject matter expertise for the development of two training modules on the topics of wildfire and severe weather; CIMSS with NOAA-20 NUCAPS data files for case studies to help users predict future NUCAPS overpasses for the CONUS and OCONUS domains; the NWS Satellite Applications Workshop with NUCAPS data for two case studies presented at the workshop.
   - CIRA staff initiated discussions with Nate Eckstein, Jeff Osiensky (Alaska Aviation Weather Unit/Anchorage Volcanic Ash Advisory Center), Doug Wesley (AAWU), and Jamie Kibbler (Washington Volcanic Ash Advisory Center) on available low earth orbiting SO2 products that they currently use and how they relate to a new RGB product available for GOES. This is in response to significant volcanic eruptions during the past summer and to prepare for possible future SO2 services as part of our VAAC tasks.

3. JPSS Training Development:
   - Beginning in November 2019, the liaison offered bi-weekly VIIRS Near-Constant Contrast (NCC) teletraining for users. This teletraining is 20 minutes and highlights the utility of VIIRS NCC in the operational forecasting environment, focusing on product applications and limitations. http://rammb.cira.colostate.edu/training/visit/training_sessions/viirs_ncc_imagery_in_awips/
   - The blog is intended to open the doors of communication between the Operational, Academic and Training Meteorology communities. The blog averages around 270 views per month and is located on the VISIT program website: http://rammb.cira.colostate.edu/training/visit/blog/. There were 22 blog entries over the year with topics that focus on operational applications of JPSS and GOES-16 imagery and products, including fires, flooding, fog, snow, and severe weather.

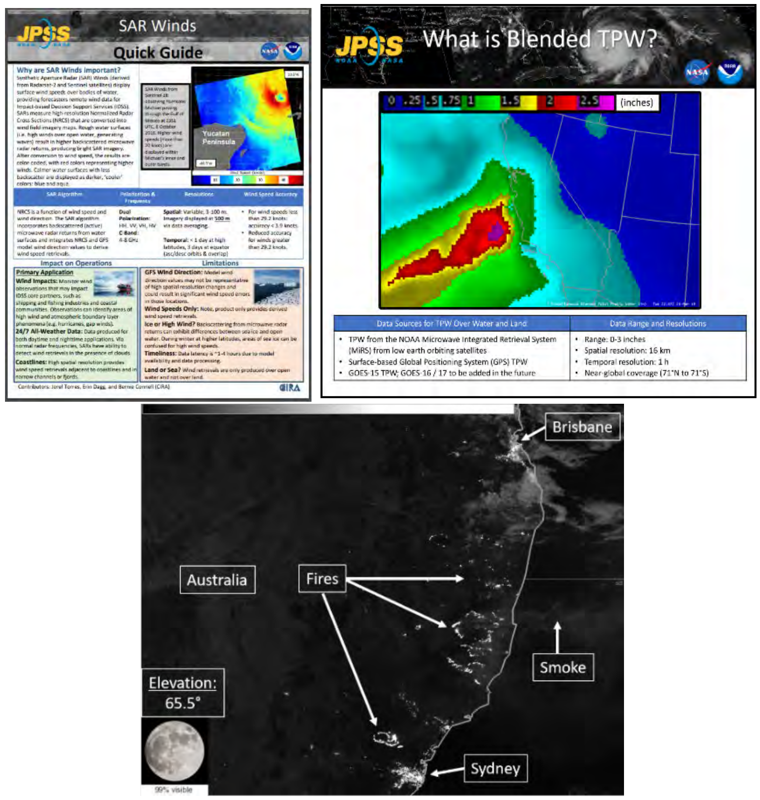


Figure 1: (left) SAR Winds quick guide, (center) slide from Blended TPW quick brief, and (right) NCC imagery from a blog post on the Australian Wilfires.

- Quick guides and quick briefs completed during the past year are accessible online: http://rammb.cira.colostate.edu/training/visit/quick_guides/
    - o Quick Guide: Synthetic Aperture Radar (SAR) Winds
    - o Quick Briefs: VIIRS Near-Constant Contrast (NCC), Blended Total Precipitable Water (TPW), VIIRS Day Land Cloud Fire RGB, VIIRS Fire Temperature RGB (in review)

4. Participate in JPSS/PGRR annual reviews, science weeks, and professional meetings:
- Presentations are listed in the following section.
- Participation in short courses and other training events as an organizer and presenter:
    - o 2019 NOAA/NASA Satellite Meteorology Summer Workshop: JPSS Workshop. 11 July 2019. Fort Collins, CO. http://rammb.cira.colostate.edu/training/visit/links_and_tutorials/2019_noaa_nasa_jpss_workshop.asp
    - o 2019 Joint Satellite Conference: Significant Hazards Satellite Applications Short Course. 29 September 2019. Boston, MA. http://rammb.cira.colostate.edu/training/visit/links_and_tutorials/2019_JSC_Workshop.asp
    - o AMS 100th Annual Meeting Short Course: From GOES-R and JPSS Satellite Data to Disaster Response: Every Decision Counts. 12 January 2020. Boston, MA. http://rammb.cira.colostate.edu/training/visit/links_and_tutorials/2020_AMS_Boston.asp

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES:

Torres, 2019: "JPSS Products in AWIPS and SatFC-J". Three presentations for the Boulder NWS WFO Spring (3 and 11 April) Workshops and the Grand Junction NWS WFO Spring (15 May) Workshop.

Torres, 2019: “JPSS: Impact on NWP, Product Applications and SatFC-J”. *JPSS Program Leadership Meeting*. Boulder, CO, 11 June 2019. Oral Presentation.

Torres, J., 2019: “JPSS Educational Resources”. *2019 NOAA/NASA Satellite Meteorology Summer Workshop*. Fort Collins, CO, 11 July 2019. Oral Presentation.

Torres, J., B. Connell, E. Sanders and D. Bikos, 2019: “An Overview of the Satellite Foundational Course for JPSS (SatFC-J)”. 2019 *National Weather Association (NWA) Annual Meeting*. Huntsville, AL, 12 September 2019. Poster Presentation.

Torres, J., D. Bikos and E. Szoke, 2019: “Polar-orbiting and Geostationary capabilities and observations in support of Active Fires”. 2019 *National Weather Association (NWA) Annual Meeting*. Huntsville, AL, 12 September 2019. Poster Presentation.

Torres, J., 2019: “Satellite Training Resources”. *2019 Joint Satellite Conference: Significant Hazards Satellite Applications Course*. Boston, MA, 29 September 2019. Oral Presentation.

Torres, J., B. Connell, E. Sanders and D. Bikos, 2019: “An Overview of the Satellite Foundational Course for JPSS (SatFC-J)”. *2019 Joint Satellite Conference*. Boston, MA, 3 October 2019. Oral Presentation.

Torres, J. and B. Connell, 2020: “JPSS Products, Applications and Training Resources”. *2020 AMS 100th Annual Meeting*. Boston, MA, 15 January 2020. Oral Presentation.

Torres, J., 2020: “The Utility of JPSS and GOES Fire Weather Products and Applications in the Operational Forecasting Environment”. *2020 AMS 100th Annual Meeting*. Boston, MA, 16 January 2020. Oral Presentation.

Torres, J., 2020: “JPSS and GOES Satellite Training and Data Resources for NOAA and non-NOAA Users”. *Alaska Center for Climate Assessment and Policy (ACCAP) - Virtual Alaska Webinar Symposium (VAWS) Webinar*. 28 January 2020. Remote Presentation.

PROJECT TITLE: Hydrometeorological and Water Resources Research

PRINCIPAL INVESTIGATORS: V. Chandrasekar, Haonan Chen, Lynn Johnson

RESEARCH TEAM: Haonan Chen, Lynn Johnson

NOAA TECHNICAL CONTACT: Robert Cifelli, NOAA/ESRL

PROJECT OBJECTIVES:

1. Design and development of a real-time quantitative precipitation estimation (QPE) system for the Advanced Quantitative Precipitation Information (AQPI) program

2. Development of a flexible Bayesian approach to bias correction of radar-derived precipitation estimates over complex terrain

PROJECT ACCOMPLISHMENTS SUMMARY:

<u>Project 1: Design and development of a real-time quantitative precipitation estimation (QPE) system for the Advanced Quantitative Precipitation Information (AQPI) program</u>

The National Oceanic and Atmospheric Administration (NOAA) and collaborating partners are building the AQPI system aimed at improving prediction of hazardous weather and flooding events in the San Francisco Bay Area. As part of the AQPI program, high-frequency (i.e., X-band) high-resolution gap-filling radars are being deployed over the Bay Area to augment observations from the NEXRAD network, improve QPE, and resolve the detailed precipitation microphysics. In this project, a real-time QPE system is designed for the AQPI radar network, and the polarimetric radar rainfall estimation algorithms are developed. The AQPI QPE system integrates both the new radar observations and existing NEXRAD radar product to produce seamless high-resolution QPE (250 m by 250 m by 2 min) for the entire Bay Area. The preliminary rainfall products are evaluated through cross-comparison with independent rain gauge observations. Results show that the rainfall products generated by the AQPI QPE system have superior performance to the operational radar-based QPE currently available in this particular domain.

Project 2: Development of a flexible Bayesian approach to bias correction of radar-derived precipitation estimates over complex terrain

In this project, a Bayesian framework based on local rain gauge observations is developed to correct the biases and reduce uncertainties associated with operational radar rainfall products in complex terrain. The proposed Bayesian framework is designed with high flexibility. In addition to radar rainfall intensities, it can incorporate factors such as terrain topography and wind information. This Bayesian-based correction technique is also not limited to rainfall estimates at hourly scale. It can be easily extended to other regions and to different temporal scales. A demonstration study in the Russian River basin in northern California is conducted. The results show that the proposed Bayesian technique performs much better than conventional local-bias and mean-field-bias correction approaches. After incorporating the terrain elevation information in the Bayesian framework, the radar QPE bias correction performance is further enhanced. This project also provided operational implications of this bias correction approach, and the probabilistic distribution curves of bias corrected radar QPE at calibration gauge sites are almost identical to rain gauge measurements.

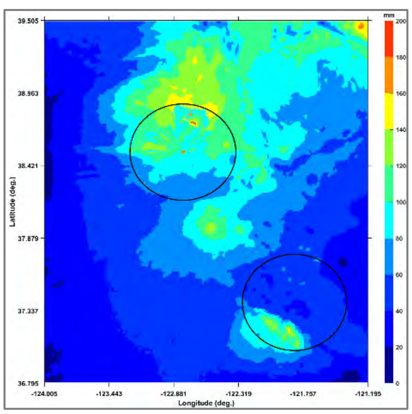


Figure 1. 48-hr rainfall accumulations from the AQPI radar QPE system during 13-14 Feb 2019. (for Project 1)

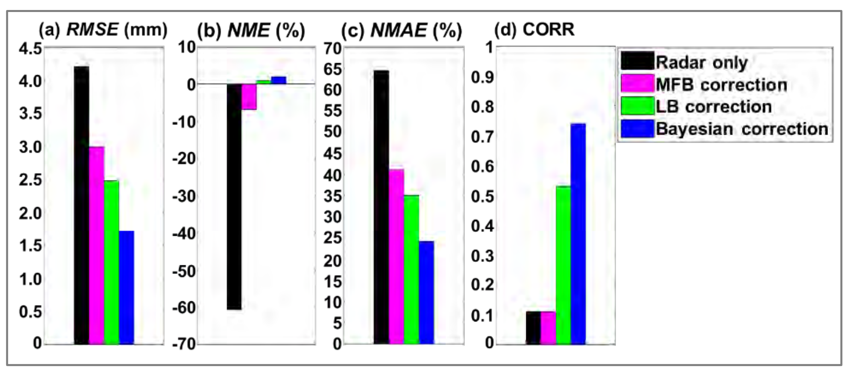


Figure 2. Quantitative evaluation results of hourly rainfall estimates from radar before and after bias correction using different techniques for the 7 Feb 2017 precipitation event: (a) RMSE (mm), (b) NME (%), (c) NMAE (%), and (d) CORR. (for Project 2)

PROJECT PUBLICATIONS:

Chen, H., R. Cifelli, V. Chandrasekar, and Y. Ma, 2019: A flexible Bayesian approach to bias correction of radar derived precipitation estimates over complex terrain: Model design and initial verification. *Journal of Hydrometeorology*, 20, 2367–2382.

Chen, H., V. Chandrasekar, H. Tan, and R. Cifelli, 2019: Rainfall estimation from ground radar and TRMM precipitation radar using hybrid deep neural networks. *Geophysical Research Letter*, 46, 10669-10678.

Barcaroli, E., A. Lupidi, L. Facheris, H. Chen, and V. Chandrasekar, 2019: A validation procedure for a polarimetric weather radar signal simulator. *IEEE Transactions on Geoscience and Remote Sensing*, 57(1), 609-622.

Derin, Y., E. Anagnostou, A. Berne, M. Borga, B. Boudevillain, W. Buytaert, C.-H. Chang, H. Chen, G. Delrieu, Y. Hsu, and Coauthors, 2019: Evaluation of GPM-era global satellite precipitation products over multiple complex terrain regions. *Remote Sensing*, 11, 2936.

Gou, Y., H. Chen, and J. Zheng, 2019: An improved self-consistent approach to attenuation correction for C-band polarimetric radar measurements and its impact on quantitative precipitation estimation. *Atmospheric Research*, 226, 32-48.

Chen, H., R. Cifelli, Y. Ma, and V. Chandrasekar, 2019: Representing radar rainfall uncertainties in complex terrain using a Bayesian modelling approach. *The 99th AMS Annual Meeting*, Phoenix, AZ, 6-10 January 2019.

Chen, H., R. Cifelli, and V. Chandrasekar, 2019: Improving quantitative precipitation estimation in complex terrain over the San Francisco Bay Area using gap-filling radar network. *The 99th AMS Annual Meeting*, Phoenix, AZ, 6-10 January 2019.

Chen, H., V. Chandrasekar, and R. Cifelli, 2019: A deep learning approach to dual-polarization radar rainfall estimation. *URSI Asia-Pacific Radio Science Conference (AP-RASC)*, New Delhi, India, 09-15 March 2019.

Chen, H., and R. Cifelli, 2019: Investigating the precipitation microphysical variability induced by orographic enhancement in Northern California. *12th International Precipitation Conference*, Irvine, CA, 19 – 21 June 2019.

Chen, H., R. Cifelli, and V. Chandrasekar, 2019: Integrating multi-scale data for seamless QPE in the AQPI system. *American Geophysical Union Fall Meeting*, San Francisco, CA, 9-13 December 2019.

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Hydrometeorological and Water Resources Research

PRINCIPAL INVESTIGATORS: V. Chandrasekar, Haonan Chen, Lynn Johnson

RESEARCH TEAM: Haonan Chen, Lynn Johnson

NOAA TECHNICAL CONTACT: Robert Cifelli, NOAA/ESRL

PROJECT OBJECTIVES:

1 - Hydrologic Research and Applications Development - Objective: Provide expert guidance and consultation on hydrologic applications for the HMA Team.

2 - Advanced Quantitative Precipitation Information (AQPI) System Project - Objective: Develop AQPI system to provide high resolution (space and time) forecasts of floods and water supplies for the 9-county San Francisco Bay area.

3 - National Water Model Assessment for Reclamation's Water Management Needs - Objective: Provide both a quantitative and reflective assessment of NOAA's National Water Model (NWM).

4 - Russian River Tributaries Water Budget Model - Develop a collaborative GeoDSS River Basin Management Decision Support System.

5 - Russian River Risk-Based Optimal Reservoir Operating Decisions Using Ensemble Forecasts – Objective: Develop a method for determining an optimal operating strategy for a reservoir system using ensemble forecasts and considers multiple objectives.

6 - Assimilation of Lake and Reservoir Levels into the WRF-Hydro National Water Model to Improve Operational Hydrologic Predictions - Objective: Improve the representation of reservoir mass balance and storages in the operational NOAA National Water Model (NWM).

PROJECT ACCOMPLISHMENTS SUMMARY:

1) Hydrologic Research and Applications Development:

- Provided guidance and leadership in carrying forward the hydrological research agenda defined by the HMA Team, including publication in technical reports, peer-reviewed journals, and conferences.
- Supported the HMA Team Leader in identifying and tracking candidate (and past) tools, techniques and knowledge transfers to NWS and key stakeholders.

2) Advanced Quantitative Precipitation Information (AQPI) System Project: (Figure 1):

a) Distributed Hydrologic Modeling (DHM) for Flood Operations:

- Developed descriptions of AQPI hydrologic products (Figure 2).
- Conducted quantitative assessment of NWM performance using retrospective simulation outputs for USGS stream gages in SF Bay AQPI region (Figure 3).
- Conducted assessments of tributary hydrologic products with AQPI users and other for usability for flash flood operations (Figure 4).
- Presented highlights of project (oral) at AGU Conference in San Francisco in December 2019.
- Drafting journal paper on assessment of distributed hydrologic modeling.

b) AQPI Coastal Flooding Forecast:

- Coordinated with USGS CoSMoS coastal flood modelers on interfacing with tributary hydrology model.
- Developed case study for coupled tributary DHM with coastal hydrodynamic model (Figure 5).

c) AQPI Benefits:

- Defined approach to documentation of AQPI benefits, involving development of case studies for various applications for flood warning, linkage to local agency models, linkage of tributary hydro model to coastal hydrodynamic model, and others in preparation.
- Local Agency Model Support - Santa Clara Valley Water District
- AQPI Benefits paper published in Journal of Flood Risk Management.
- Coordinated with CSU Economics Dept. on detailed study of APQI benefits characterization on property damages and county-wide economic impacts.

3) National Water Model Assessment for Reclamation's Water Management Needs

- Participated with research team in reviewing technical approach and progress, and developing supportive materials for reflective assessment.
- Conducted review of USBR reservoir projects' forecast needs per water management objectives (Figure 6).

4) Russian River Tributaries Water Budget Project (Figure 5):

- A hydrologic water budget model has been developed for Feliz and Austin Creek watersheds within the Russian River basin by combining the RDHM streamflow simulation model with the GIS-based Geo-MODSIM network streamflow model (Figure 7). A journal paper has been published the ASCE Irrigation and Drainage Engineering Journal (January 2020) and second paper is being submitted to Agricultural Water Management.

5) Forecast-Based Operations Optimization (FBO-O) Project (Figure 8):
- Work to date by PhD student Matt Peacock has focused on setting up the framework for a dynamic programming optimization model for the Russian River basin using the generalized dynamic programming software package CSUDP developed at Colorado State University.

6) Assimilation of Lake and Reservoir Levels into the WRF-Hydro National Water Model (Figure 7):
- Coordinated with NCAR project team to provide progress reports for case study on Russian River reservoir operations.
- Developed concepts of operation for integration of reservoirs into the NWM.
- Poster presentation (lead by Jungho Kim) at AGU 100 Fall Meeting. Washington, D.C. December 10-14.
- Submitted Final Report to project sponsor NOAA/OAR/ FY2016 Joint Technology Initiative.

Figures

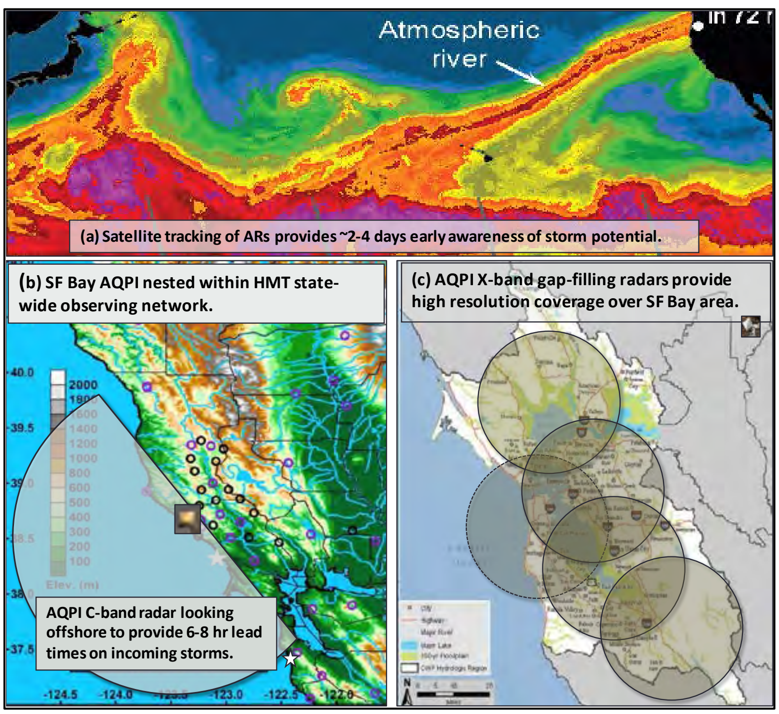
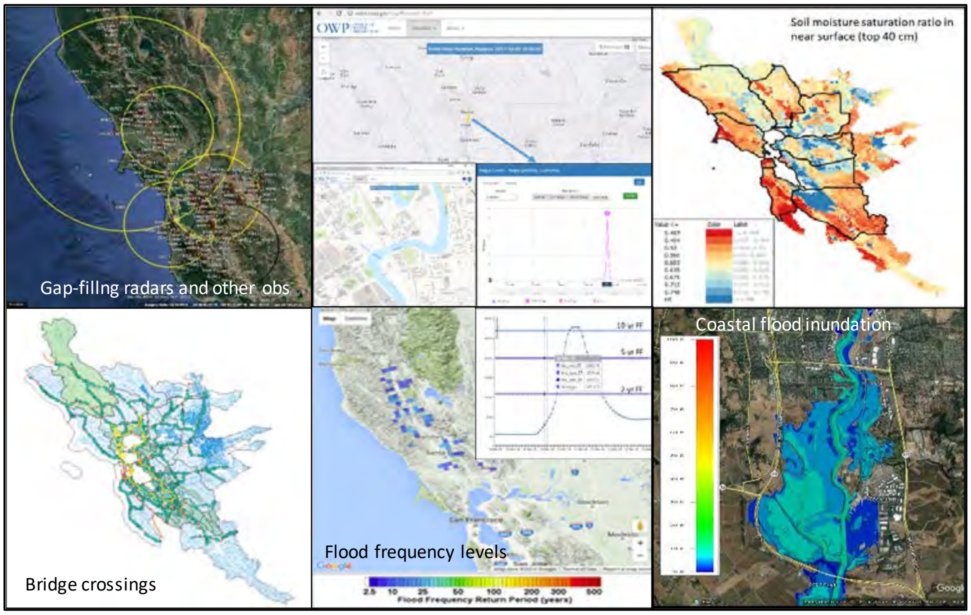


Figure 1. AQPI system involves (a) satellite detection and tracking of atmospheric river events over the Pacific Ocean, (b) C-band weather radar will look offshore at incoming storms, and (c) x-band radars will provide coverage over the SF Bay area.



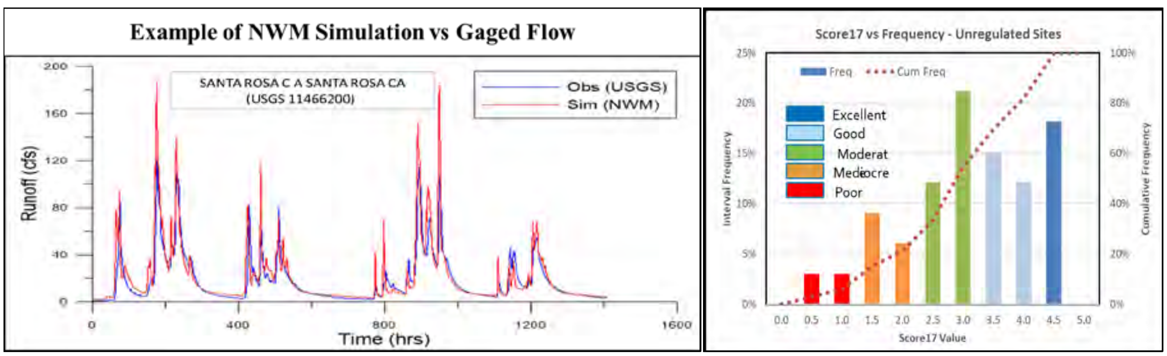


Figure 3. NWM performance assessment.

Question Subtopic	Weighted Score	Comments
Precipitation	4.2	Precipitation information rated Very Useful.
Soil Moisture Content	3.4	Soil moisture rated Somewhat Useful.
Surface Runoff	2.6	Grid runoff rated Not Useful to Somewhat Useful.
Discharge	4.2	Cumulative discharge rated Useful.
Recurrence Intervals	3.8	Recurrence interval rated Very Useful by most, but some rated is Not Useful.
Hydrograph Time Series	5.0	Time series unanimous Very Useful.

Usefulness Ratings		
Not at all	Some what	Very much
1	3	5

Figure 4 Tributary Hydrology Model Assessment Summary – Watershed DHM Products

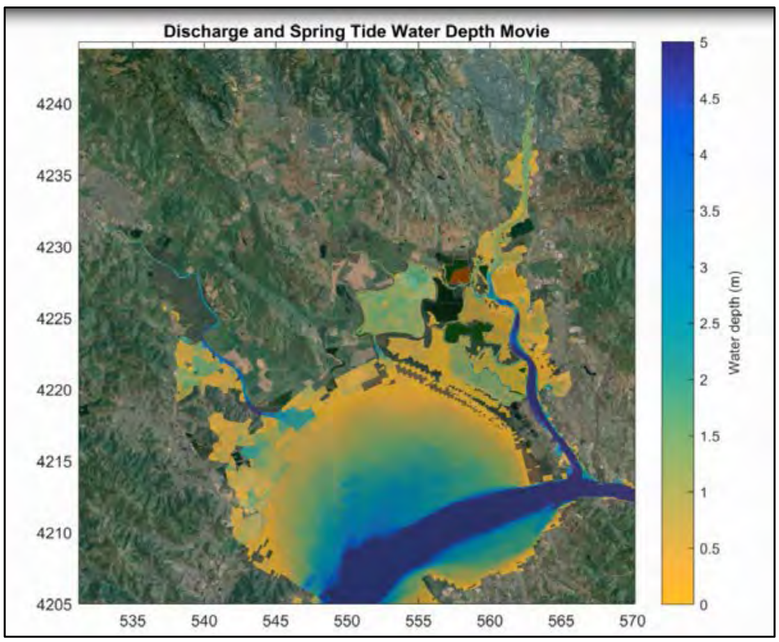


Figure 5. Coastal flood inundation mapping for Napa River estuary.

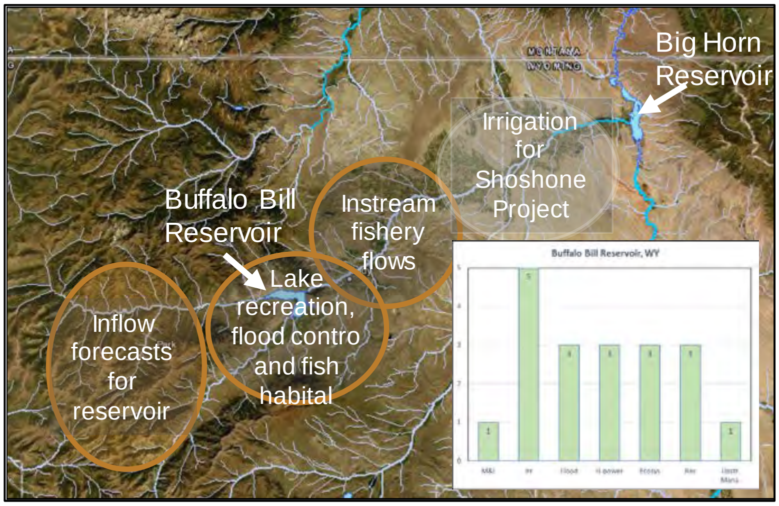


Figure 6. USBR reservoir operations purposes for Buffalo Bill Reservoir, WY.

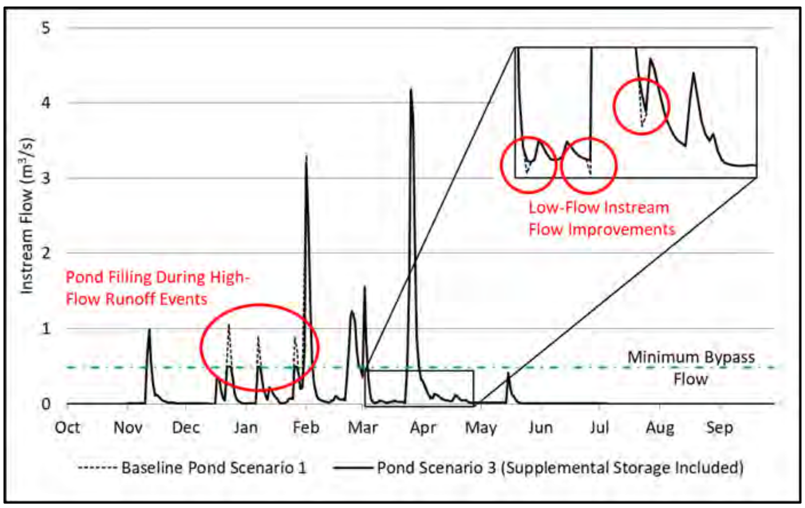


Figure 7. Modeled instream flow downstream of agricultural diversion and instream flow demand for the baseline Pond Scenario 1 and Pond Scenario 3 (Supplemental Storage Included). The modeled operations show the filling of supplemental storage during initial high-flow runoff events and improved instream flowrates during low-flow conditions related to frost protection demands.

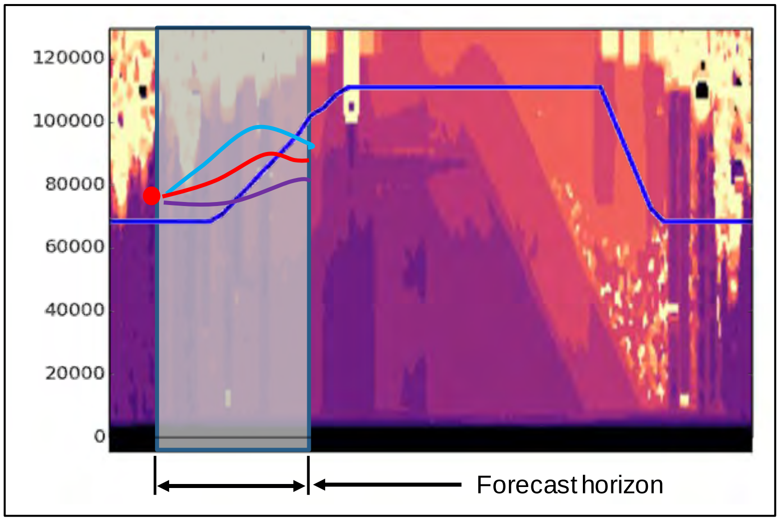


Figure 8. Q-learning algorithm chooses an action based on an explore/exploit parameter that is possible for all actions that can be

PROJECT PUBLICATIONS:

Geospatial DSS for Maintaining Agricultural Diversions under Environmental Flow Requirements. (with C. Fields, J. Labadie). Journal of Irrigation and Drainage Engineering, Volume 146 Issue 2. February. https://doi.org/10.1061/(ASCE)IR.1943-4774.0001441.

Benefits of an Advanced Quantitative Precipitation Information System. (with R. Cifelli, A. White). Journal of Flood Risk Management (Wiley Online Library). January. https://doi.org/10.1111/jfr3.12573.

Hybrid Machine Learning Framework for Hydrological Assessment. (with Kim, J. (Lead Author), H. Han, L. E. Johnson, S. Lim, and R. Cifelli. J. Hydrology, 577, 123913. October. https://doi.org/10.1016/j.jhydrol.2019.123913.

Assessment of antecedent moisture condition on flood frequency: An experimental study in Napa River Basin, CA, (with Kim, J. (Lead Author), R. Cifelli, A. Thorstensen, and V. Chandrasekar.) December. J. Hydrology. Regional Studies, 26, 100629, October. https://doi.org/10.1016/j.ejrh.2019.100629.

Geospatial Decision Support System for Ameliorating Adverse Impacts of Irrigated Agriculture on Aquatic Ecosystems. (with C. Fields (Lead author), J. Labadie, F. I.W. Rohmat). Submitted to Agricultural Water Management, An International Journal (Elsevier). (In review)

Assessment of Flood Forecast Products for a Coupled Tributary - Coastal Model. (with R. Cifelli, J. Kim, T. Coleman, and G. Pratt, L. Herdman, R. Martyr-Koller, J. Finzi-Hart4, L. Erikson, P. Barnard, M. Anderson). Submitted to International Journal of Disaster Risk Reduction (Elsevier). (https://www.journals.elsevier.com/international-journal-of-disaster-risk-reduction). (In review).

An Experiment on Reservoir Representation Schemes to Improve Hydrologic Prediction in a Regulated River System. (with J. Kim (Lead author), L. Read, L. E. Johnson, D. Gochis, R. Cifelli, H. Han). Submitted to Hydrological Sciences Journal (In review).

National Water Model Retrospective Simulation Assessment: AQPI Case Study – Tributary Hydrologic Model. (with J. Kim). Draft report for Advanced Quantitative Precipitation Information System Project. September. 81 pp.

PROJECT PRESENTATIONS/CONFERENCES:

Fishing for Applications of S2S Forecasting. (with A. Ray). AMS 2020, Boston, Session: Challenges in Communication & Decision Support Throughout the R2O Nexus.

AQPI: Systems Requirements for Hydrological Functions. (with R. Cifelli, G. Pratt, J. Kim). Poster at American Geophysical Union Annual Meeting, San Francisco, CA. December 13.

Assessment of the NOAA Operational Short-Range Streamflow forecast: A Case Study for February 2019 events in San Francisco Bay Area. (with J. Kim, R. Cifelli). Poster at American Geophysical Union Annual Meeting, San Francisco, CA. December 9.

PROJECT TITLE: Improving Convection-Permitting Ensemble Based Uncertainty Communication for Decision Support Using the Weather Archive and Visualization Environment (WAVE)

PRINCIPAL INVESTIGATOR: Ken Fenton

RESEARCH TEAM: Jebb Stewart

NOAA TECHNICAL CONTACT: Daniel Nietfeld (OAR/ESRL/GSD/EDS)

NOAA RESEARCH TEAM: NOAA: Melissa Petty (OAR/ESRL/GSD); NCAR: Julie Demuth; CIRES: Matthew Wandishi and Jennifer Henderson

PROJECT OBJECTIVES:

The objective of this project is to develop an enhanced Weather Archive and Visualization Environment (WAVE) system to help better assess and communicate hazardous weather risks for improved impact-based decision support services (IDSS). The project will accomplish this objective through three means:

1--Conducting social science research with forecasters and core partners to understand their critical weather decisions and informational needs;

2--Using this knowledge to guide research on forecaster-oriented verification of convective allowing model ensemble output;

3--Using knowledge from both research efforts to guide the development of WAVE.

PROJECT ACCOMPLISHMENTS:

1—Social Science Research:

The social science research was conducted during two rounds of data collection, which consisted of in person interviews with National Weather Service (NWS) Weather Forecast Office (WFO) forecasters, and state and local emergency mangers (EMs). Overall, feedback from 44 interviews was aggregated and pointed toward the need for skillful, high spatial and temporal resolution guidance about the timing of hazardous weather. The first round of interviews informed the development of the verification graphics, which were presented to the second round of interview participants. The findings from the second round of interviews showed that the verification timing graphics were on the right track, but several adjustments will be necessary to make these more useful to forecasters and EMs.

2—Verification of Convective Allowing Model Ensemble Output:

The findings from the social science research was used to develop verification graphics that focused on the performance of an ensemble to identify the start time of an event. The High-Resolution Rapid Refresh Ensemble (HRRRE) was selected for this prototype work, however, the work is applicable to any ensemble. In addition, the initial focus was placed on winter and fire weather, in particular, the verification of the onset of snow events and winds exceeding Red Flag parameters. The earliest, mean, and latest onset times of snow and winds exceeding selected thresholds were verified against Meteorological Terminal Aviation Routine Weather Reports (METARs) and the Unrestricted Mesoscale Analysis (URMA). The verification results were created both in map form and as distributions of the timing errors. The intent of the verification is to give the forecaster an idea of the average and distribution of the onset timing errors from the ensemble over the past 30 days. In 2020, modifications will be made to the verification displays and to make the verification period user selectable.

3—Development of WAVE

Graphics showing the onset and cessation timing of weather events were added to WAVE to support the field research and verification efforts. Maps showing the event timing were created for the watch/warning/advisory areas of the WFOs that were visited as well as dynamically placed maps based upon the largest fires on a given day. The maps are being updated in real time and will be added to the main WAVE web page in 2020.

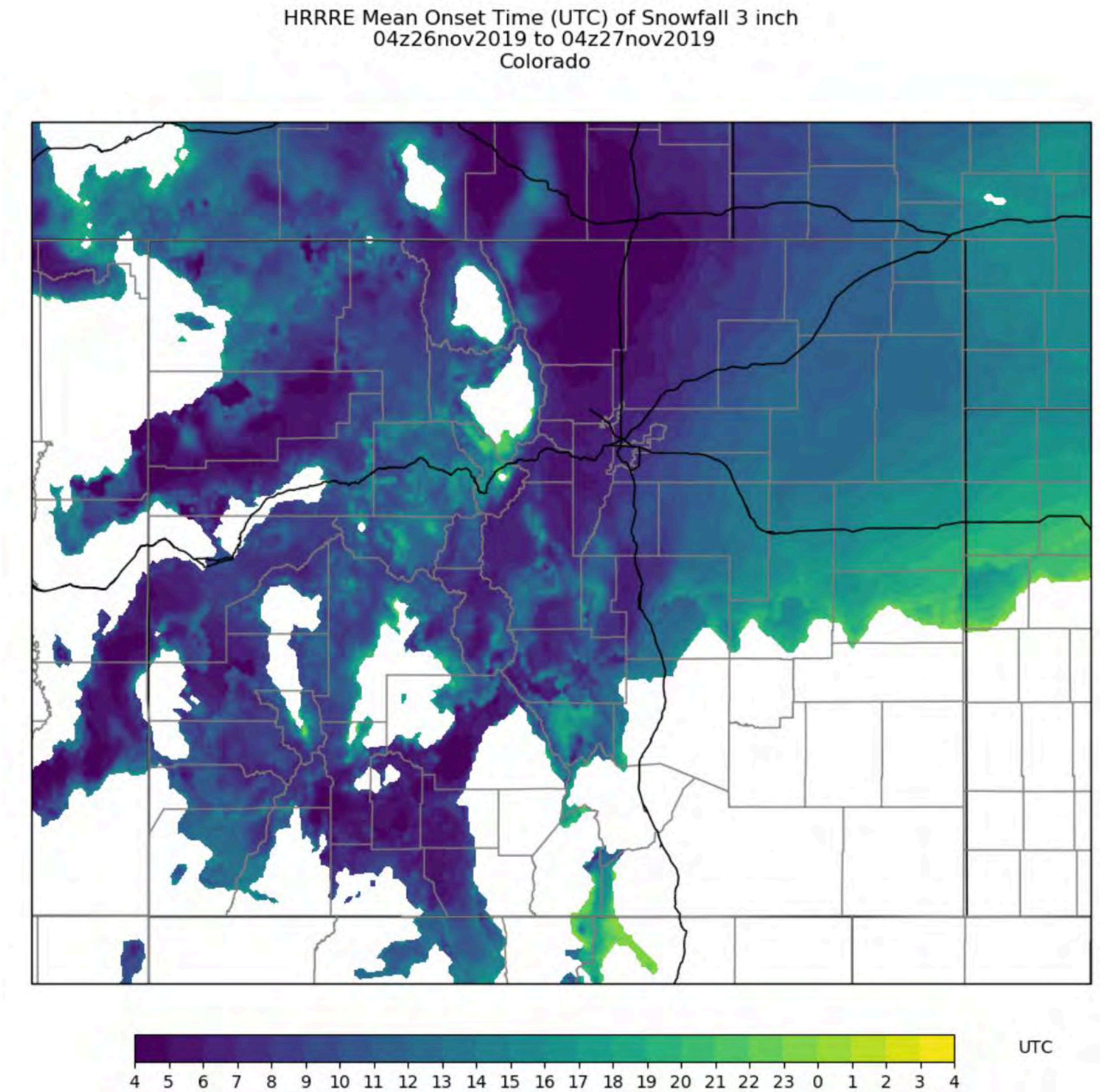


Figure 1. Sample graphic showing the mean onset time from the HRRRE for a three inch snowfall event over Colorado.

PROJECT PUBLICATIONS: N/A

PROJECT PRESENTATIONS/CONFERENCES: N/A

PROJECT TITLE: Intelligent post-processing of convection-allowing model output to inform Weather Prediction Center outlooks and forecasts

PRINCIPAL INVESTIGATOR: Russ Schumacher

RESEARCH TEAM: Aaron Hill, Jacob Escobedo

NOAA TECHNICAL CONTACT: Chandra Kondragunta,

NOAA RESEARCH TEAM: Mark Klein, Jim Nelson

PROJECT OBJECTIVES:

As outlined in the original proposal, the specific objectives of this project are as follows:

- Quantify the advantages of applying advanced post-processing methods to CAM (convectional-allowing model) guidance for informing WPC outlooks and forecasts. The explicit representation of convection in models has been demonstrated to produce more realistic spatial distributions of extreme precipitation, and our preliminary results show that applying machine learning algorithms to CAM output can improve probabilistic forecasts even further. We will thoroughly evaluate the advantages and disadvantages of incorporating CAM output into our CSU-MLP model(s).

- Evaluate the developed forecast systems in the Flash Flood and Intense Rainfall (FFaIR) experiment and in an operational environment at the WPC and Hydrometeorology Testbed. The FFaIR testbed allows for robust evaluation of a forecast system by forecasters and researchers in a realistic real-time environment. We have previously demonstrated machine-learning-based forecast products at FFaIR, and received valuable feedback from participants that have led to improvements in the forecasts themselves and in how they are presented to forecasters.

- Implement an operational version of this forecast system at WPC. Assuming the evaluations are successful, we will work with WPC to implement an operational version of the forecast system after incorporating relevant feedback and suggestions.

PROJECT ACCOMPLISHMENTS SUMMARY:

The proposed work plan for tasks through the end of the reporting period is reproduced from the original proposal in the table below, and the current status of these tasks is given in the right-hand column.

Time	**Tasks and milestones**	**Accomplishments/completion**
Months 1-3 (Sep-Nov 2018)	Train GEFS/R-based day-1 first-guess model; disaggregate into 6-hour periods; obtain HREFv2 archive	**Day-1 model: complete** **Disaggregation: complete for NSSL-based model; in progress for GEFS/R-based model** **HREFv2 archive: complete**
Months 1-7 (Sep 2018-March 2019)	Evaluation of NSSL-WRF-based model; comparison to other model guidance	**In progress (~85% complete)**

Months 7-9 (March-May 2019)	Routinely prepare forecasts and make gridded files available to WPC/HMT staff	**Complete**
Months 10-11 (June-July 2019)	Provide forecasts for evaluation during FFaIR; participate in FFaIR	**Complete**
Months 12-15 (Aug-Nov 2019)	Formalize evaluation of forecasts from FFaIR, receive and respond to feedback from FFaIR participants	**Complete**
Months 13-17 (Dec 2019-Apr 2020)	Experiment with and evaluate improvements to day-1 model	**In progress (~50% complete)**

The primary accomplishment of the reporting period was the evaluation of Colorado State University-Machine Learning Probabilities (CSU-MLP) forecast products during the Flash Flood and Intense Rainfall (FFaIR) testbed experiment in summer 2019. Two primary products were routinely generated and delivered to the Hydrometeorology Testbed at the Weather Prediction Center for use by the FFaIR participants. Each of these was a day-1 probabilistic forecast of excessive rainfall; FFaIR participants were able to use these products as part of their creation of experimental Excessive Rainfall Outlooks (EROs) for day 1. The first CSU-MLP forecast product was trained using the global Reforecast-2 ensemble, and then used the operational GEFS as its daily input data. The design of this model is essentially identical to the day-2 and 3 models we have developed and transitioned to WPC operations under previous support, just with a shorter lead time. The second model uses the National Severe Storms Laboratory (NSSL) version of the WRF model, which uses a horizontal grid spacing of 4 km and thus explicitly represents convection, for the training dataset.

The products were successfully delivered daily during FFaIR and were used as part of the testbed experiment. PI Russ Schumacher and postdoc Aaron Hill both attended and participated in FFaIR for one week. There were some particularly successful forecasts made by the CSU-MLP system during FFaIR. One notable example was on 8-9 July 2019 (Figure 1). This day saw two different regions with extreme rainfall, one in North Dakota and one in Nebraska. The GEFS-based CSU-MLP system correctly showed high probabilities of excessive rainfall in both of these areas, particularly in Nebraska.

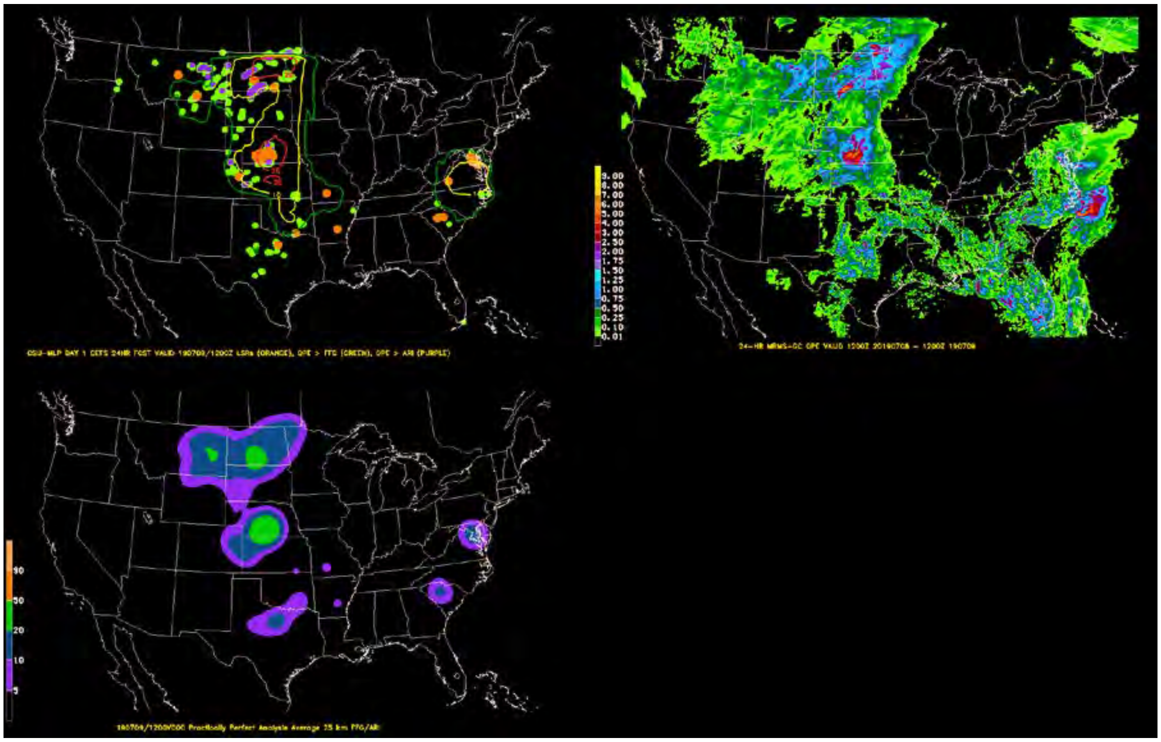


Figure 1: (a) GEFS-based CSU-MLP forecast (color contours) and observations of excessive rainfall (colored dots). Forecast was from 0000 UTC 8 July for the 24-h period ending 1200 UTC 9 July 2019. (b) Analyzed precipitation from the MRMS for this time period. (c) "Practically perfect" probabilistic forecast based on the observed excessive rainfall.

Of course, not every forecast was so skillful, but the models generally performed well over the course of the FFaIR time period. Evaluation of the FFaIR forecasts (courtesy of Sarah Trojniak and Mike Erickson of HMT/WPC) shows that both CSU-MLP systems were less skillful, generally by a small increment, than the experimental and operational WPC ERO. This is expected behavior, as the human forecasters have numerous other information sources, as well as their expertise, to incorporate when generating their forecasts. But the fact that the CSU-MLP forecasts are competitive with these products suggests that they are likely to be useful guidance for forecasters.

Formal evaluation of the forecasts during FFaIR were disseminated in the final report from HMT/WPC. The results of these evaluations are being used to help improve the products going forward, in close collaboration with WPC staff. We also continue to routinely make available gridded model output for the models mentioned above, for evaluation at WPC and HMT. The NOAA transition plan for this project was completed and signed by all necessary parties in June 2019.

Ongoing and future work is focused on the NSSL-WRF based model for day-1 forecasts. Postdoctoral researcher Aaron Hill has made substantial progress on this work, with one recent line of inquiry focused on the length of the training period that is required for skillful forecasts. Preliminary results suggest that training periods of less than a year may be adequate which would enable the use of other modeling systems that have shorter periods of record. These analyses are still ongoing and will be reported when more robust results are obtained.

Another accomplishment in the reporting period was that a manuscript was accepted for publication on the extension of the methods used for excessive precipitation forecasting (supported by this and a previous JTTI grant) to severe weather (hail, winds, tornadoes). We have been in discussion with staff at the Storm Prediction Center to identify potential uses of these forecasts at the SPC.

PROJECT PUBLICATIONS:

Hill, A.J., G.R. Herman, and R.S. Schumacher, 2020: Forecasting severe weather with random forests. *Monthly Weather Review,* in press.

PROJECT PRESENTATIONS/CONFERENCES:

Aaron Hill: "Heavy Precipitation and Flash Flood Forecasts Using Random Forests and Convection-Allowing Models", 30th Conference on Weather Analysis and Forecasting/26th Conference on Numerical Weather Prediction, American Meteorological Society, Boston, Massachusetts, January 2020

Russ Schumacher: "If a Flood Falls in a (Random) Forest, Does It Get Counted? Advances and Challenges in Predicting Excessive Precipitation Using Machine Learning", 30th Conference on Weather Analysis and Forecasting/26th Conference on Numerical Weather Prediction, American Meteorological Society, Boston, Massachusetts, January 2020

PROJECT TITLE: JPSS PGRR VLAB CIRA Support to JPSS Proving Ground Risk Reduction Training Activities

PRINCIPAL INVESTIGATOR: Bernadette Connell

RESEARCH TEAM: Erin Sanders, Luciane Veeck, Rosario Alfaro

NOAA TECHNICAL CONTACT: Mitch Goldberg, JPSS Program Science Office

NOAA RESEARCH TEAM: Mike Davison, Jose Galvez, Kevin Scharfenberg, Natalia Donoho

PROJECT OBJECTIVES:

The World Meteorological Organization (WMO) Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) is a collaborative effort joining major operational satellite operators across the globe with WMO regional training centers of excellence in satellite meteorology. Those regional training centers serve as the satellite-focused training resource for WMO Members. Through its cooperative institute for Research in the Atmosphere (CIRA) at Colorado State University (CSU), NOAA/NESDIS sponsors Regional Training Centers of Excellence (CoE) in Argentina, Barbados, Brazil, and Costa Rica.
The top-level objectives of the VLab are:

1-- To provide high quality and up-to-date training and supporting resources on current and future meteorological and other environmental satellite systems, data, products and applications;
2-- To enable the regional training centers to facilitate and foster research and the development of socio-economic applications at the local level through the National Meteorological and Hydrological Services.

Enhanced training and coordination of training that is specifically targeted for the JPSS series satellites and accomplished under this project will prepare forecasters, researchers, and managers on how to utilize imagery and products to provide services and training in these areas. Other CIRA RAMMB projects are leveraged to meet the VLab top level objectives.

Specific Objectives:

4. Represent CIRA and NOAA training interests in National and International Training and Coordination Groups.

5. Provide training opportunities for the International Community.

6. In support of NOAA commitments to the WMO VLab, provide travel support for VLab trainers, and coordinate Spanish translation for JPSS-related training materials.

PROJECT ACCOMPLISHMENTS SUMMARY:

4. Represent CIRA and NOAA training interest in National and International Training and Coordination Groups:

- Participated in WMO virtual and in-person meetings associated with VLab, VLMG, and the WMO Coordination Group on Satellite Data Requirements (SDR).
- Coordinated and collaborated with NOAA through participation in NOAA GEONETCast Americas (GNC-A) Coordination Group webinars, the JPSS Training Initiative, the Satellite International Training Working Group (SITWG) calls, and AmeriGEO calls.
- Coordinated with the JPSS, GOES-R, and GNC-A program offices, the NWS Office of International Affairs (IA), the NWS/WPC International Desk, the Meteorological and Hydrological Service (SENAMHI) of Peru and many others to develop and deliver a 2.5-day training on New Generation Geostationary and Polar Orbiting Satellite Imagery and Products to meet GEO priority areas. The workshop was held during AmeriGEO Week in Lima, Peru 19-23 August, 2019.

5. Provide training opportunities for the International Community:

- During January through December 2019, the WMO/NOAA/CIRA VLab Regional Focus Group (RFG) conducted 12 monthly bilingual (English/Spanish) virtual sessions. http://rammb.cira.colostate.edu/training/rmtc/fg_recording.asp
- The 2019 WMO/Eumetcal Online Course for Trainers on Blended Learning took place 1 April – 2 June. B. Connell and L. Veeck were facilitators for the course and E. Sanders was a participant.
- B. Connell, L. Veeck, and E. Sanders developed and co-hosted the "WMO VLab Train the Trainers Workshop: How Can We Better Utilize Blended Learning in Continuing Professional Development?" held on 28-29 September 2019 prior to the Joint Satellite Conference in Boston, MA. https://vlab.moodlecloud.com/course/view.php?id=3

Figure 1. (Left) Participants from the Argentina Meteorological Service highlight their storyboard for JPSS Training. (Right) Participants at the Workshop prior to the Joint Satellite Conference, 28-29 September 2019, Boston, MA.

6. Provide travel support for VLab trainers, and coordinate Spanish translation for JPSS-related training materials.

- CIRA provided partial travel support for: 1) two trainers, one from the Argentina WMO VLab Center of Excellence (CoE), and the other from the Costa Rica WMO VLab CoE, to attend the Joint Satellite Conference and WMO VLab Trainer Workshop in Boston, MA, on September 28 – October 4, 2019; 2) The WMO Technical Support Officer (TSO) attended the Community for the Advancement of Learning in Meteorology and related disciplines (CALMET) Conference in Darmstadt, Germany on September 17-20, 2019.
- Rosario Alfaro translated slides and text into Spanish for SatFC-J Modules 1-4. Recordings are in review for the first three modules.

PROJECT PUBLICATIONS:

Connell, B., M. Davison, J. Gálvez, K-A. Caesar, V. Castro, T. Mostek, E. Sanders, L. Veeck, M. Garbanzo, M. Campos, N. Rudorff, 2020: “Enhancing long-term impacts of training through international collaboration: the case of the VLab Regional Focus Group of the Americas and Caribbean.” WMO Global Campus Innovations Publication. (Accepted; expected to appear in 2nd quarter 2020)

PROJECT PRESENTATIONS/CONFERENCES:

Connell, B., E. Sanders, and L. Veeck, 2019: “Building Short Examples to Highlight Successful Learning and Meet WMO Competency Guidelines for Satellite Skills for Operational Meteorologists.” Joint Satellite Conference, 30 September – 4 October 2019, Boston, MA.

Connell, B., E. Sanders, M. Davison, J. Gálvez, V. Castro, T. Mostek, K-A. Caesar, L. Veeck, M. Garbanzo, M. Campos, N. Rudorff, 2019: “Insights from 15 Years of Conducting the WMO VLab Regional Focus Group Monthly Sessions for the Americas and the Caribbean”, Joint Satellite Conference, 30 September – 4 October 2019, Boston, MA.

B. Connell coordinated and collaborated with many NOAA and SRG individuals to develop the agenda, develop or adapt training materials, and deliver a 2.5-day training: “New Generation Geostationary (GOES-16/17) and Polar Orbiting (JPSS - Suomi NPP and NOAA-20) Satellite Imagery and Products to meet GEO priority areas.” 21-23 August, 2019, Lima, Peru.

PROJECT TITLE: Multi-disciplinary Investigation of Concurrent Tornado and Flash Flood Threats in Landfalling Tropical Cyclones

PRINCIPAL INVESTIGATORS: Russ Schumacher, Jennifer Henderson

RESEARCH TEAM: Erik Nielsen, Allie Mazurek

NOAA TECHNICAL CONTACT: Kandis Boyd

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

As outlined in the original proposal, the specific objectives of this project are as follows:

- Quantitatively analyze the meteorological processes supporting tornadoes at the same location as locally large rainfall rates. Building upon our current VORTEX-SE research, we will use the multi-radar/multi-sensor (MRMS) estimates of rainfall and low-level rotation, along with observations, model analyses, and numerical model simulations, to thoroughly document the meteorological situations in which concurrent tornado and flash-flood (TORFF) threats arise in landfalling tropical cyclones (TCs), and compare these to other TORFF scenarios.

- Understand NWS forecast and warning challenges for multiple hazards during landfalling TCs, in comparison with other weather situations. Through in-person interviews with NWS forecasters we will examine forecasters processes, timings of products, and issues communicating uncertainty in messaging with the public. This work builds on our previous VORTEX-SE project studying TORFFs in the southeast, which reveals that local Weather Forecast Office (WFO) policies and practices can unintentionally amplify of one type of warning over the others.

- Understand public risk assessment and vulnerabilities for multi-hazard scenarios through the analysis of Twitter data. Though an analysis of Twitter narratives for individuals identified as affected by both hazards, we will examine their information sources, risk perceptions, and potential vulnerabilities.

PROJECT ACCOMPLISHMENTS SUMMARY:

The proposed work plan for tasks through the end of the reporting period is reproduced from the original proposal in the table below, and the current status of these tasks is given in the right-hand column.

Time	**Tasks and milestones: meteorological research**	**Accomplishments/ completion**	**Tasks and milestones: social sciences research**	**Accomplishments / completion**
Months 1-6	Update database of TORFF events in SE US, including LTCs	**Complete through 2018**	Work with collaborators at CSU to refine twitter streams to identify a subset to analyze	**Complete through 2019**
	Begin processing MRMS data	**Complete**		
	Continue monitoring TORFF in real time	**Complete**	Contact WFO collaborators to schedule in-person interviews	**Complete**
Months 7-12	Complete observation-based analysis (with MRMS and other data)	**Complete**	Conduct interviews.	**Complete**
	Begin conducting and analyzing	**Complete**	Analyze Twitter streams and	**In progress (see text below)**

Months 13-18	numerical simulations Complete analysis of numerical simulations, begin work to synthesize results with findings of social-science research, present results at AMS annual meeting	**Some items complete, some still in progress**	transcripts of WFO partner interviews. Synthesize qualitative datasets for collaboration with physical science team. Work to synthesize results with physical science research. Present at AMS annual meeting. Work with CU to collect Twitter data from a second LTC. Contact relevant WFO collaborators and conduct interviews.	**In progress (see text below)** **Some items complete, some still in progress**

Three cases have been the primary focus of physical-science analysis in this project: Hurricanes Harvey (2017), Florence (2018), and Imelda (2019) as they all produced a considerable number of overlapping TORFF warnings, as well as observations of tornadoes and flash flooding. We have analyzed several MRMS products for these events that relate to precipitation and low-level rotation (indicative of the potential for tornadoes), including quantitative precipitation estimates (QPE) on short timescales, rotation tracks, azimuthal shear, and various polarimetric variables that indicate precipitation production and other storm-scale processes.

Analysis of the MRMS products in landfalling tropical cyclones produced some unexpected issues in terms of quantitatively assessing tornado-scale rotation features. For example, the rotation-track products show artifacts when the TC is near a radar, where the tracks appear to emanate outward from the radar, presumably because the radial velocity changes sharply when a TC exists near the radar. These features will require some attention to address prior to these data being used in quantitative analysis. We have also conducted numerical simulations of Harvey and Imelda, with Florence simulations underway. These simulations allow for analysis of physical processes in a dynamically consistent framework, to go along with the observations.

Postdoctoral researcher Erik Nielsen had two manuscripts published in early 2020 that connect to this project as well. The first examines how frequently observed instances of extreme short-term rain rates (>75 mm, or 3 inches, in one hour) are associated with storm-scale rotation. The second is a case study that integrates observations and simulations of the April 2016 Houston, TX “Tax Day” flood, which was also a TORFF event. Both were published in Monthly Weather Review, and the paper on the Houston case was featured as a “Paper of Note” in the Bulletin of the American Meteorological Society.

Professional development has been provided for CU Boulder Ph.D. student Melissa Bica, from Computer Science, and undergraduate student Joy Weiner, who has been assisting with Twitter data collection and analysis. Bica joined co-PI Spinney in collecting data from NWS offices and conducting a focus group with NWS partners related to Florence. This was her first qualitative data collection trip. Data collected for this grant comprises a chapter in Bica's dissertation work.

Professional development is also being provided for co-PI Spinney, who graduated with her Ph.D. in May 2019 and who then became a postdoc on the project; she has been assisting with project design, co-leading interview data collection, and co-leading Twitter data analysis. She attended the VORTEX-SE workshop for the first time in September 2019, and gave a poster presentation of results, which exposed her to a new group of scholars outside her normal set of colleagues.

For the CSU/CIRA portion of the project, postdoctoral researcher Erik Nielsen and graduate student Allie Mazurek (who started August 2019) are now fully contributing to the project and will have many opportunities for upcoming training and professional development. Nielsen attended and presented at the VORTEX-SE workshop in September 2019, and he contributed to the data collection at NWS WFOs in August 2019.

Dissemination of results to date has largely occurred through completion of Melissa Bica's dissertation chapter in Q4, which is under review at the Computer Human Interaction Society, as well as through ongoing conversations with participating WFOs. Data has also been disseminated through near-real-time maps of TORFF warning overlaps, which are available on the web at http://schumacher.atmos.colostate.edu/weather/TORFF_rt/

PROJECT PUBLICATIONS:

Nielsen, E.R., and R.S. Schumacher, 2020: Dynamical mechanisms supporting extreme rainfall accumulations in the Houston "Tax Day" 2016 flood. *Monthly Weather Review*, 148, 83-109.

Nielsen, E.R., and R.S. Schumacher, 2020: Observations of extreme short-term precipitation associated with supercells and mesovortices. *Monthly Weather Review*, 148, 159-182.

PROJECT PRESENTATIONS/CONFERENCES:

January 2020: Erik Nielsen, "Investigation of the Dynamics of Extreme Rainfall in Landfalling Tropical Cyclones", Tropical Meteorology and Tropical Cyclones Special Symposium, 100th American Meteorological Society Annual Meeting, Boston, MA

January 2020, Jennifer Spinney, "Keeping Calm in the Chaos: An Examination of Forecaster Sense-Making and Partner Response to TORFFs during Hurricane Florence". 15th Symposium on Societal Applications, 100th American Meteorological Society Annual Meeting, Boston, MA

PROJECT TITLE: Support of the Virtual Institute for Satellite Integration Training (VISIT)

PRINCIPAL INVESTIGATORS: Dan Bikos and Bernadette Connell

RESEARCH TEAM: Edward Szoke, Erin Sanders, Kevin Micke, Sharon King

NOAA TECHNICAL CONTACT: Kevin Scharfenberg (NOAA/NWS/OCLO/FDTD)

NOAA RESEARCH TEAM: Debra Molenar (NOAA/NESDIS/STAR/RAMMB), Kevin Scharfenberg and Brian Motta (NOAA/NWS/OCLO/FDTD)

PROJECT OBJECTIVES:

The primary objective of the VISIT program is to accelerate the transfer of research results based on atmospheric remote sensing data into National Weather Service (NWS) operations. This work is a collaboration between CIRA, the National Weather Service (NWS), and other Cooperative Institutes. The transfer of research results into NWS operations is accomplished through a variety of distance learning methods. Asynchronous training delivery methods include online videos, quick guides, quick briefs, job aids and blog entries, these exist on web-pages and may be taken anytime. Synchronous training delivery methods include live webinars and teletraining, these utilize a combination of a conference call and software and occur live at a scheduled time. The combination of synchronous and asynchronous distance learning methods (Fig. 1) reaches out to as broad an audience as possible given the busy schedule of NWS forecasters. There have been over 3,500 asynchronous training completions over the past year and over 50,000 VISIT training completions since April 1999. CIRA is also actively involved in tracking of participants, and the collection and summarization of course feedback material. For more information on the VISIT program, see: http://rammb.cira.colostate.edu/visit/

Specific Objectives:
1--Develop, deliver, and track usage of teletraining, recorded modules, quick guides, quick briefs, job aids, and blog entries that target the utilization of new satellite products available on AWIPS.
2--Conduct regularly scheduled virtual “FDTD GOES Applications Webinars”.
3--Attend meteorological and education conferences and symposiums and participate in other relevant organizational meetings; provide partial support to the WMO Space Program through the Virtual Laboratory for Education and Training (VLab) and its Management Group (VLMG).

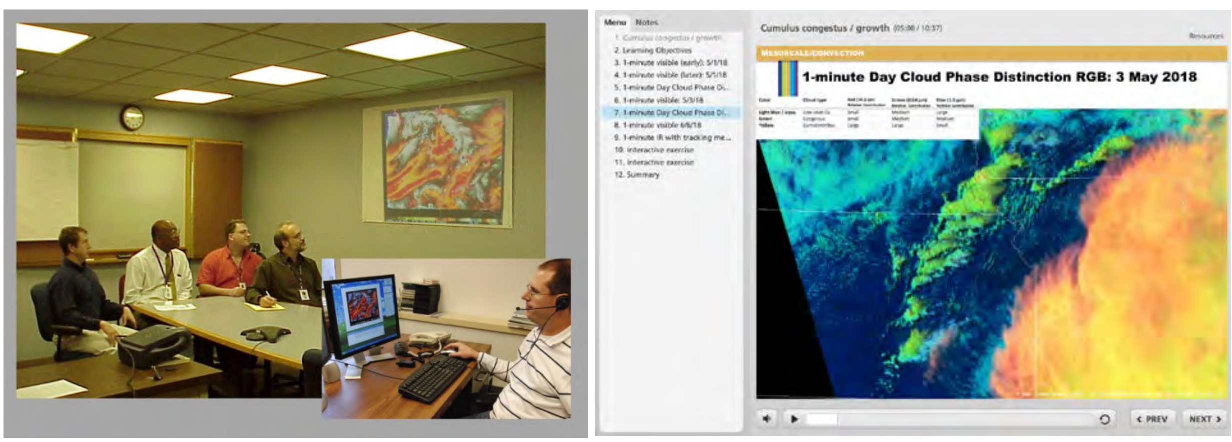


Figure 1. Examples of synchronous training - Live VISIT teletraining (left), and asynchronous training - audio / video playback VISIT training module from SatFC-G course (right).

PROJECT ACCOMPLISHMENTS:

1--Training sessions:

New VISIT training sessions developed in 2019, most of them contribute to an updated SHyMet Severe course that will debut Spring 2020.
-- “Integrating GOES Into Mesoanalysis”.
-- “Severe Weather Applications of the GOES Split Window Difference Product”.
-- “Storm Signatures Observed in Satellite Imagery”.
Updated in 2019:
-- “Tracking the Elevated Mixed Layer with a new GOES-R Water Vapor Band”.
-- “Can Total Lightning Help with Warnings for Non-Supercell Tornadoes?”

As directed by the Satellite Training Advisory Team (STAT), CIRA has contributed to the development of Level 2 applications training. The following is a list of completed CIRA authored Quick Guides (QG) and Quick Briefs (QB).

- Completed (Between April 2019 and February 2020):

-- Day Cloud Convection RGB (QB).
-- Day Snow/Fog RGB (QB).
-- Blended TPW (QB).

VISIT blog:

-- The blog is intended to open the doors of communication between the Operational, Academic and Training Meteorology communities. The blog averages around 270 views per month and is located here: http://rammb.cira.colostate.edu/training/visit/blog/. There were 22 blog entries during the time period of interest with topics that focus on operational applications of GOES-16/17 and JPSS imagery and products.

VISIT training metrics April 1, 2019 – February 18, 2020:

-- Live teletraining: 29 sessions delivered to 100 participants.
Audio / video playback (through NOAA's Learning Management System as well as directly through CIRA's web interface): 3,589 participants.

2-- FDTD GOES Application Webinars / VISIT Satellite Chat:

-- CIRA coordinates with CIMSS and with the Forecast Decision Training Division (FDTD) to deliver webinars that are led by NOAA/NWS staff to promote peer to peer (SOOs or forecasters training other SOOs or forecasters) training. Webinars are recorded and made available (at http://rammb.cira.colostate.edu/training/visit/satellite_chat/) so that the community may benefit from these presentations when unable to attend live (example shown in Fig. 2):

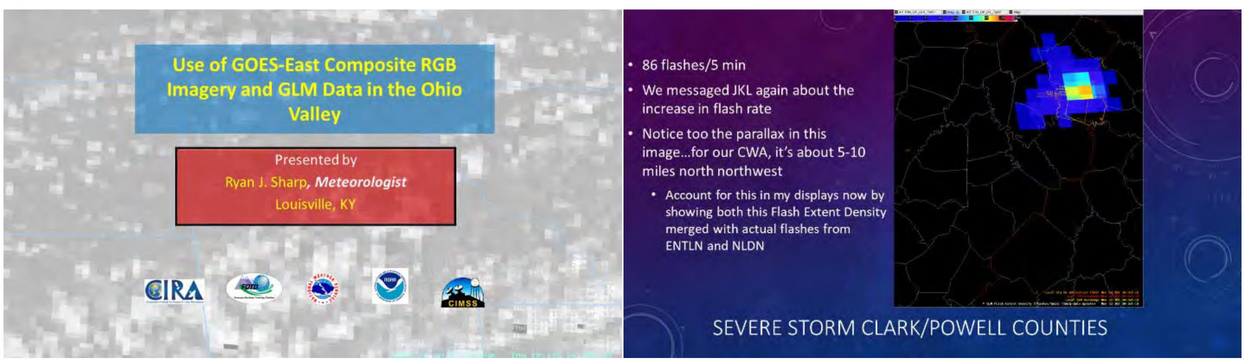


Figure 2. Live FDTD GOES Applications Webinar recording made available on VISIT web-pages.

Examples of webinar topics include GOES-16/17 operational applications towards severe thunderstorm signatures, volcanic ash, smoke, hazardous emissions from a refinery accident, GLM DSS and warning decision making, river flooding, and pyrocumulus to severe thunderstorm transition. Imagery and products from the ABI include single band, band difference products, RGB products in addition to lightning data from the GLM.

In the past year, 9 webinars have been offered with a total of 91 office participants (about 10 offices per webinar). WFO participation in the webinars is given in Fig. 3

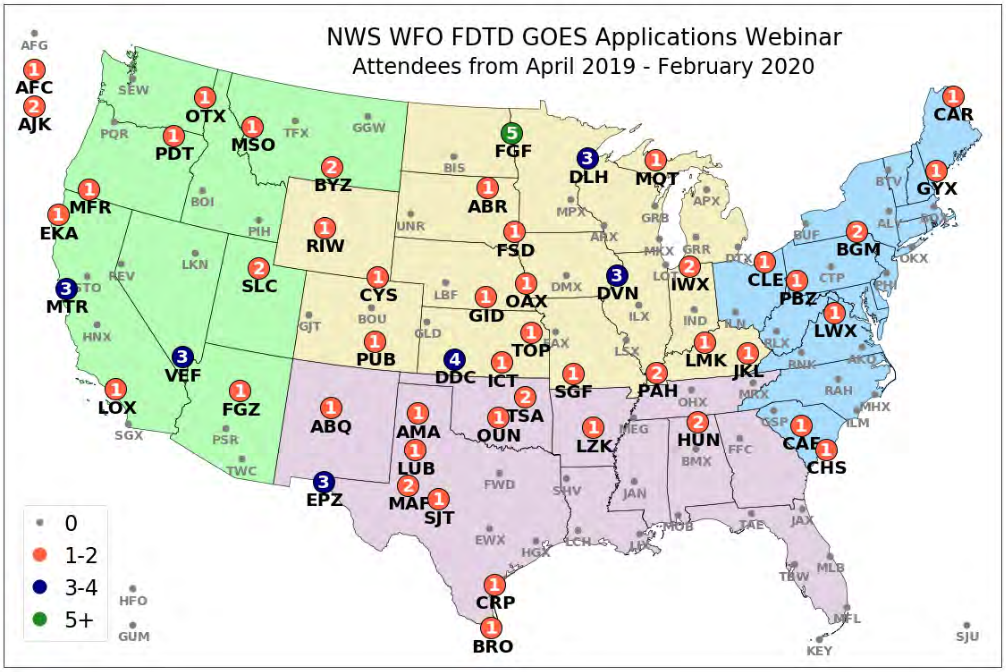


Figure 3. NWS WFO participation in FDTD GOES Applications Webinars April 2019 – February 2020.

3-- Support the WMO Space Program through the Virtual Laboratory for Education and Training (VLab) and its Management Group (VLMG):

This project provided partial support for WMO VLab activities that encourage the exchange of training approaches, content, and information with International Partners. One highlight of support includes the continued collaboration to conduct monthly virtual Regional Focus Group sessions and the resulting continued participation from WMO Region III and IV countries. The GOES-R and JPSS programs also support WMO VLab training activities and additional highlights can be found in those sections of the CIRA Report

During January through December 2019, CIRA/WMO VLab Regional Focus Group (RFG) conducted 12 monthly bi-lingual virtual sessions. A total of 31 different countries participated throughout the year, with a median of 13 countries represented in each session. The number of participants each session varied, ranging from 22 to 69. The RFG weather and climate briefings have connected instructors, researchers, forecasters, and weather enthusiasts and enabled them to view geostationary and low earth orbiting imagery and products, and to share information on weather patterns, hurricanes, severe weather, flooding, volcanic eruptions, and other significant events. Typically, the sessions include a climatic and synoptic overview of the Americas and the Caribbean presented by collaborators Mike Davison or José Galvez from the NWS/NCEP/WPC International Desk. The GOES and POES imagery from SLIDER are then used to look more closely at weather features. Additional content is provided by WMO Centers of Excellence in Barbados, Costa Rica, Brazil, and Argentina and by participating countries

PROJECT PUBLICATIONS:

Gitro, C.M., D. Bikos, E.J. Szoke, M.L. Jurewicz Sr., A.E. Cohen, and M.W. Foster, 2019: A Demonstration of Modern Geostationary and Polar-Orbiting Products for the Identification and Tracking of Elevated Mixed Layers. *J. Operational Meteor.*, **7** (13), 180-192.

PROJECT PRESENTATIONS/CONFERENCES:

Bikos, D., S. Lindstrom, E. Szoke, B. Connell, E. Sanders, and B. Motta 2019: VISIT / SHyMet Training on GOES-16/17 Imagery and Products. Poster, National Weather Association (NWA) Annual Meeting, 7-12 September, Huntsville, Alabama.

Bikos, D., E. Szoke, B. Connell, and E. Sanders 2019: Recent CIRA VISIT and SHyMet Training Activities on GOES-R Series Applications. Poster, AMS/EUMETSAT Joint Satellite Conference, 28 September – 4 October, Boston, Massachusetts.

Bikos. D. 2019: Himawari-8 Using New Spectral Bands for Meteorological Applications. Oral, Invited lecturer as part of the COMET course for forecasters from the Korean Meteorological Agency, 12 November, Boulder, Colorado.

Connell, B. L. Veeck, and E. Dagg developed and co-hosted the “WMO VLab Train the Trainers Workshop: How Can We Better Utilize Blended Learning in Continuing Professional Development?”, 28-29 September 2019, (prior to the Joint Satellite Conference), Boston, Massachusetts.

Connell, B., E. Sanders, and L. Veeck, 2019: “Building Short Examples to Highlight Successful Learning and Meet WMO Competency Guidelines for Satellite Skills for Operational Meteorologists.” Joint Satellite Conference, 30 September – 4 October 2019, Boston, Massachusetts. Presentation.

Connell, B., E. Sanders, M. Davison, J. Gálvez, V. Castro, T. Mostek, K-A. Caesar, L. Veeck, M. Garbanzo, M. Campos, N. Rudorff, 2019: “Insights from 15 Years of Conducting the WMO VLab Regional Focus Group Monthly Sessions for the Americas and the Caribbean”, Joint Satellite Conference, 30 September – 4 October 2019, Boston, Massachusetts. Presentation.

Szoke, E., 2019: “GOES-R Proving Ground and HRRR”. Four presentations: for the Boulder NWS WFO Spring (3 and 11 April) and Winter (16 October) Workshops and the Grand Junction NWS WFO Spring (15 May) Workshop.

Szoke, E, 11 May 2019: E. Szoke gave a weather talk at the Boulder WFO sponsored Media Workshop held on the Denver Metro campus.

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Torres and C. Seaman, 2019: An Update on CIRA’s GOES-16/17 Proving Ground Efforts. Poster, 44th National Weather Association (NWA) Annual Meeting, 9-12 September 2019, Huntsville, Alabama.

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Torres and C. Seaman, 2019: Some Lessons Learned from the CIRA GOES-R Proving Ground Effort. Talk, AMS 2019 Joint Satellite Conference, 29 September – 4 October 2019, Boston.

Szoke, E., D. Bikos, K. Hilburn, R. Cox, D. Barjenbruch, and P. Schlatter, 2020: Is There a Total Lightning Precursor Signal for Non-Suercell Tornadoes. Talk, 16th Annual Symposium on New Generation Operational Environmental Satellite Systems at the AMS 100th Annual Meeting, 14 January 2020, Boston.