Annual Report for

THE CSU-CHILL RADAR FACILITY

Cooperative Agreement No. ATM-9500108

Submitted to

The National Science Foundation

Division of Atmospheric Sciences

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DEPARTMENT OF ATMOSPHERIC SCIENCE
DEPARTMENT OF ELECTRICAL ENGINEERING
COLORADO STATE UNIVERSITY
FORT COLLINS, COLORADO

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1. Introduction

Activities at the CSU-CHILL National Radar Facility from 1 January 1997 to 31 December 1997 are summarized in this annual report. This report is the third report submitted under our second Cooperative Agreement with the National Science Foundation, which commenced on 1 May 1995. During this past year reliable radar operations were again performed. The facility supported another successful REU project in 1997 as well as the Polarimetric Radar Observations of Winter Storms (PROWS) project, both funded by NSF. Additionally, CHILL staff spent considerable time readying the facility for a remote deployment to Wisconsin to support WISP-98. A radar site was located near Green Bay, WI. However funding for the project was subsequently declined. A new antenna pad design was obtained for the WISP deployment. The new pad design will be used in future deployments of CHILL which will result in approximately a $15K savings for each deployment.

Another highlight in 1997 was the establishment of a contract with Lassen Research for delivery of a new state of the art signal processor. This $100K upgrade will be paid for by a 60/40 contribution from CSU/NSF respectively. We will realize a factor of two increases in data processing speeds with the new processor, thereby allowing faster scanning of storms to sample storm dynamics while collecting the full suite of multiparameter variables.

We also acquired the HOT 10 cm Doppler radar from the Illinois State Water Survey. This radar was transferred to CSU in February 1997. HOT will be used with CHILL to develop a dual-Doppler radar observational network along the Front Range of Colorado. This network would be similar to the old NSSL Norman-Cimmaron dual-Doppler network in that S-band radars will be used to mitigate the effects of attenuation. However this network will have a tremendous advantage in that one radar in the pair would be a multiparameter radar (CSU-CHILL), therefore allowing simultaneous observations of storm microphysics (from multiparameter variables) in the context of dual-Doppler derived air-flow fields. Given our recent work on short pulse transmission capabilities coupled with our present signal processor upgrade, we will effectively realize a factor of two increase in scan rate at CHILL while collecting the full suite of multiparameter variables. This is important since it means that multiparameter data can be collected in a simultaneous mode with Doppler velocity data at scan rates adequate for sampling storm evolution in many situations (10-12 degrees per second).

data to document the in-cloud microphysical changes accompanying the initial electrification of the cloud. Successful operations were conducted on at least two afternoons. Data are presently being analayzed in both those projects.

Finally, "target of opportunity" CSU-CHILL data were collected during the severe flash flood that struck Ft. Collins on the evening of 28 July 1997. An initial analysis of this event is included in the Fall 1997 CSU-CHILL newsletter (Appendix D of this report). A more complete analysis is currently being prepared for submission to the Bulletin of the American Meteorology Society.

b. Educational Support

The CSU-CHILL facility continued to provide educational support to both engineering and meteorological interests during 1997. The radar was available for tours on 11 April 1997 as a component of a CSU science open house for high school students. A total of approximately 50 students visited the radar on this date. Due to this success, the open house organizers have requested that the facility be made available again for this same purpose in the spring of 1998. On 5 September 1997, the students enrolled in the CSU Electrical Engineering 100 course (numbering ~80) visited the radar to obtain an introduction to meteorological weather radars. On 24 June 1997 several science teachers participating in NCAR's LEARN Project visited the CSU-CHILL facility. The radar tour augmented classroom presentations that they had received at NCAR. Direct classroom use of the radar data was made in EE514 (Random Signal Analysis), taught by Prof. V. Chandrasekar. A portion of the final examination for this course was based on sample CSU-CHILL time series recordings.

In ATS, near real time radar data images available via the internet were used in Prof. Steven Rutledge's ATS 350 class. This class reaches an undergraduate audience of approximately 100 students. Tours of the facility were also conducted for ATS 652, a graduate-level course in Remote Sensing. Many students in Atmospheric Sceince and Electrical Engineering conntinue to focus their thesis and dissertation topics around CSU-CHILL data. See Appendix A for details.

c. Technical Developments

One of the major technical efforts during 1997 was the selection and contracting for a new signal processor for the CSU-CHILL radar. The current SP20 system was delivered 10 years ago and while performing reliably, it did not have the processing capability to pursue the faster scanning modes outlined in the five year plan for the radar. The new system is another Lassen Research design involving digital IF techniques and SHARC dsp chips. Algorithm development on the new system will be much easier due to the advances in dsp design and support software. A digitizing/processing unit for each radar channel will be installed near the radar receivers. These units will digitize the 10 MHz IF signal, apply digital bandpass filtering to match the receiver response to the transmitted spectrum, and perform the quadrature detection. They also manage the dual gain digitizers to extend the dynamic range of the system to 100 dB, although the current LNA/mixer setup will limit the dynamic range to 95 dB. Each module contains three SHARC chips which will do most of the signal processing chores including clutter filtering and covariance calculations. The data are then passed to a commercial DSP card which will complete the calculations. One of the significant features of the new processor is that it will process a high quality sample of each transmitted pulse. The real-time analysis of this will be used to correct the I/Q time series for phase and amplitude errors which will vary slightly from pulse to pulse.

During 1997, the simultaneous transmit mode was tested for the first time. In this mode, both transmitters fired simultaneously, and the received signal was alternately selected from one receiver or the other (STAR mode). This method did not take advantage of the possibility of zero lag covariances which should give improved phidp and rhohv measurements, but it did give some insights as to the artifacts which may arise with simultaneous transmit when there is significant depolarization or high differential phase shift during propagation. There is further discussion on the analysis of these data sets in the Electrical Engineering section of the annual newsletter.

During the PROWS winter study, a technique for automatically transferring images from the CSU-CHILL real-time display system to the Wide World Web page on a routine basis was developed. This allows up to four parameters from a selected sweep to be transferred. The speed of the transfer between the VAX and Sun workstations limits the number of images transferred per hour. Typically images sets were selected for transfer every 15 or 30 minutes. The web images are set up with hot links to other radar fields from the same sweep, and also to the same image from previous and subsequent volumes. This technique proved to be quite useful in that allowed scientists to keep track of operations from their offices or even from home.

As previously mentioned, another major development begun in 1997 was the acquisition of another 10 cm Doppler radar from the Illinois State Water Survey. The radar was dismantled in Illinois and shipped back to Greeley. It is currently being refurbished and tested prior to installation at an identified site approximately 45 km north CSU-CHILL near the town of Nunn. There it will provide a permanently installed dual-doppler system in conjunction with the CSU-CHILL radar .

The "Nunn radar" is similar to CSU-CHILL in design except that it operates at a single polarization. The antenna has a 1.6 degree beamwidth. The 20 foot dish is enclosed in a fiberglass radome. All of the radar equipment is housed in a 40 foot semi trailer. The rotary power regulator has been wired up and tested. The transmitter also has been tested. The frequency chain and the receiver system are being rebuilt. A switchable attenuator will be installed in the receiver to implement the same instantaneous automatic gain system currently used on CSU-CHILL. The system will be upgraded to record data on 8mm tapes. This radar came with a basic SP20 signal processor. When the new signal processor is installed on CSU-CHILL, parts of the data system no longer needed will be transferred to the Nunn radar.

d. Atmospheric Sciences Activities

Mr. L. Carey, a Ph.D. candidate continues to explore mechanisms to explain the sudden onset of positive CG flashes associated with severe storms that produce bursts of large hail. CSU-CHILL data are being used to provide detailed information on the hail phase of the severe storms. Additionally, phi dp data are being used to identify regions of high electric fields in the storm anvils, which align ice crystals in the vertical, producing negative k_{dp} values in these regions. Mr. Carey will complete his Ph.D. in April 1998.

T. Lang and J. Ryan are using CSU-CHILL data collected during the STERAO-A project as part of their research to examine relationship between lightning and production of NOx. T. Lang is a first year Ph.D. student. J. Ryan will complete his M.S. in September 1998. Lt. C. Butler from the USAF is a second year student in the M.S. program. Lt. Butler is heavily involved in our present USWRP-funded project to explore the use of multiparameter radar to improve radar-based estimates of particle type, visibility, snowfall rate and liquid-equivalent precipitation. She will complete her M.S. degree in May 1998.

e. Electrical Engineering Activities

Analyses of particle image data collected with the 2D video disdrometer leased from Joanneum Research (Graz, Austria) continued in 1997. These analyses were based on both warm season precipitation sampled in 1996, as well as winter precipitation observed during the PROWS97 project. Polarimetric radar signatures are being compared with the detailed particle characterizations provided by the video disdrometer. Dr. Scott Bolen completed his Ph. D dissertation in 1997 under the direction of Prof. V. Bringi. In the course of his research, several methods for relating multiparameter radar rainfall estimates to the underlying raingage observations made at the earth's surface were explored. An optimal method of associating these two data sets was formulated and has been accepted for publication in the Journal of Atmospheric and Oceanic Technology.

Additional analyses are being done of test time series data collected in the Simultaneous Transmit / Simultaneous Receive (STAR) CSU-CHILL operating mode. Preliminary analyses of these data have been encouraging in that the STAR mode data are quite similar to those collected using conventional alternating H and V transmit polarization sequence. These analyses have also highlighted the need for the development of a remote monitor system that can measure the actual polarization state of the signal transmitted in the STAR mode. (See Technical Developments section for details).

3. Activities Planned for 1998

a) Project Support

The CSU-CHILL facility is currently scheduled to support one NSF-sponsored project in present year: REU98. This is a continuation of the summer season project that Prof. V. Chandrasekar has conducted in the past. In addition, investigators have expressed initial interest in the series of 20 hr projects summarized below:

Prof. V. Chandrasekar is interested in radar support during research aircraft flights by the Wyoming King Air near Fort Collins. Nolen Doesker of the Office of State Climatologist is interested in conducting a hail verification project with local high school students. CHILL data would be used to target areas for post-station data collection. Larry Carey will conduct a project to explore effects of clutter on rain measurements from specific differential phase, k_{dp}. Andy Detwiler of SDSMT is also interested in doint test flights with the T-28 in the vicinity of CHILL.

b) Facility Upgrades

The new signal processor is scheduled for delivery in September 1998. Parts of the system will be delivered in June to allow the development of data archival software at Greeley. Data will come out of the new processor via ethernet. It will be captured by a Sun workstation and archived on disk. Data will be moved to tape in the background or after operations are complete. The disks currently on the system can hold several days of operations before filling up. Test data will be collected during the winter of 1998-1999 and the system should be ready for normal operations in the Spring of 1999. Faster scanning through use of shorter transmit pulses and/or simultaneous V+H transmission is one of the first new techniques which will be pursued with the new processor.

In order to determine the exact transmit polarization during simultaneous mode, it is necessary to have a remote monitor downrange of the antenna to sample the waves and report back to the radar. One of the transmitters will be upgraded with the addition of an I/Q Vector Modulator. This will allow the transmit amplitude and phase to be fine tuned based on the information from the remote polarization monitor to produce a variety of transmit polarizations. The two most interesting transmit polarizations are slant +/- 45 degree linear and circular polarization. The remote monitor will consist of a receive horn with linear OMT oriented at 45 degrees. One of the two OMT ports will be selected and routed to a power meter. This will allow the transmitters to be adjusted for either +45 or -45 degrees by minimizing the power at one or the other port. Circular or H or V polarization would produce equal power at each port. A circular horn may also be available to aid in setting circular polarization. There will be another linear horn at the monitor which can transmit a slant 45 degree test signal which will be used to measure the system phase difference between the H and V channels. This information will be used when transmitting simultaneously to translate the H and V signals received to co and cross polar channels with respect to the transmit mode. In this manor if slant +45 is transmitted, one can reconstruct what slant + and - 45 degree receivers would see and an LDR signal can be calculated. This will tend to aleiviate the problem of measuring LDR with linear HV polarization in areas of low signal.

4. Publications and Reports in 1997

Abou-El-Magd, A. M., 1997: Identification and classification of mixed phase precipitation using multiparameter radar and in-situ measurements, Ph.D. dissertation, Electrical Engineering, Colorado State University, Fort Collins, CO (Advisor: Prof. V. Chandrasekar).

Abou-El-Magd, A. M., V. Chandrasekar, V. N. Bringi and W. Strapp, 1997: Simultaneous radar and in-situ aircraft observations of convective storms, *Proc. IGARSS 97,* IEEE, 1457-1459.

Beaver, J. D. and V. N. Bringi., 1997: The application of S-band polarimetric radar measurements to Ka-band attenuation prediction. *Proc. IGARSS 97,* IEEE, 893--909.

Beaver, J., 1997: The application of S-band specific differential phase to Ka-band attenuation predictions. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc., 47-49.

Bolen, S., 1997: Space-time analysis of radar rainfall fields. Ph.D. dissertation, Electrical Engineering, Colorado State University, Fort Collins, Colorado. (Advisor: Prof. V. N. Bringi).

Bolen, S., V. N. Bringi and J. Beaver, 1997: A new approach to compare polarimetric radar data to surface measurements. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc., 121-122.

Bolen, S., V. N. Bringi and V. Chandrasekar, 1997: An assessment of multiparameter radar rain rate algorithms using an optimal area approach, *Proc. IGARSS 97,* IEEE, 1114-1116.

Bolen, S., V. N. Bringi, and V. Chandrasekar, 1997: An optimal area approach to intercomparing polarimetric radar rainrate algorithms with gauge data. *J. of Atmos. and Oceanic Tech.*, 1997, In press.

Bringi, V. N. and V. Chandrasekar, 1997: The CSU-CHILL fully polarimetric weather radar facility: Providing research experience to undergraduates, *Proc. IGARSS 97*, IEEE, 954-956.

Brunkow, D. A., P. C. Kennedy, S. A. Rutledge, V. N. Bringi, and V. Chandrasekar, 1997: CSU-CHILL radar status and comparisons of available operating modes. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc.

Carey, L. D., and S. A. Rutledge, 1997: Electrical and multiparameter radar observations of a severe hailstorm. *Journal of Geophysical Research*, in press.

Huang, G., V. N. Bringi and J. Beaver, 1997: Application of the polarization power matrix in analysis of convective storm data using the CSU-CHILL radar. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc., 48-49.

Huang. G., 1997: The two transmitter/two receiver CSU-CHILL radar system: Calibration issues and sample data analysis. M. S. thesis, Colorado State Univ., Electrical. Engineering., Fort Collins, CO. (Advisor: Prof. V. N. Bringi).

Hubbert, J. C. and V. N. Bringi, 1997: The effects of 3-body scattering on differential reflectivity. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc.

Hubbert, J. C., V. N. Bringi, V. Chandrasekar, M. Schonhuber, H. E. Urban, and W. L. Randeu, 1997: Convective storm cell intercepts using a mobile 2D-video distrometer in conjunction with the CSU-CHILL radar. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc., 436-437.

Ibrahim, I. A., A. Abou-El-Magd, P. C. Kennedy, and V. Chandrasekar, 1997: Multiparameter radar observations and modeling of winter storms. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc., 53-54.

Ibrahim, I. A., V. Chandrasekar, V. N. Bringi, M. Schoenhuber, H. E. Urban, W. L. Randeu, 1997: Multiparameter radar and insitu observations and modeling of winter storms. *Proc. Radio Science Symposium*, Montreal, Canada, URSi.

Kennedy, P. C., S. A. Rutledge, and V. N. Bringi, 1997: Hail precursor signatures observed in multiparameter radar data. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc.

Lang, T. J., 1997: Relationship between storm structure and lightning activity in Colorado convection observed during STERAO-A. M.S. thesis, Atmospheric Science, Colorado State University, Fort Collins, CO. (Advisor: Prof. S. A. Rutledge).

Lang, T. J., S. A. Rutledge, J. E. Dye and P. Laroche, 1997: An investigation of the relationship between the microphysics of convective storms and their lightning activity. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc.

Liu, H. and V. Chandrasekar, 1997: Radar precipitation estimation using neural networks. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc., 202-203.

Mudukotore, A., V. Chandrasekar and R. J. Keeler, 1997: Pulse compression for weather radars, *IEEE Transactions on Geoscience and Remote Sensing*, in press.

Tawfik, B. B. S., M. J. Gaitan-Gonzalez, and H. Liu, 1997: Wavelet analysis of multiparameter radar images. Preprints, *28th Conf. on Radar Meteorology*, Austin, TX, Amer. Meteor. Soc., 59-60.

Xiao, R., V. Chandrasekar and H. Liu, 1997: Development of a neural network for radar snowfall estimation. *IEEE Transactions on Geoscience and Remote Sensing* , in press.

Zhao, L., 1997: Weather radar signal analysis and phase coding to recover second trip echo. M. S. thesis, Electrical Engineering, Colorado State University, Fort Collins, CO (Advisor: Prof. V. Chandrasekar).

5. Report on Cost Sharing Activities

The following describes cost sharing expenditures at CSU through the third year of the Cooperative Agreement.

	Cumulative through 4/30/97	YEAR 3 5/1/97- 1/31/98	Cumulative through 1/31/98
Materials, parts, supplies, paint	7,739	1,066	8,805
Salaries and services	110,468	43,841	154,309
Telephone and postage	3,456	41	3,497
Vehicles and fuel	844	0	844
Equipment	15,541	23,834[b]	39,375
Indirect cost @ 45%[a]	55,128	20,227	75,355
TOTAL	193,176	89,009	282,185
Estimate 2/1/98 - 4/30/98		14,864[c]	14,864
TOTAL	$193,176	$103,873	$297,049

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a) Indirect cost base excludes equipment.

b) Initial payment for the dual-channel digital signal receiver and digital

signal receiver.	19,674
Video radar acquisition board	4,160
Total	$23,834

c)

Salaries -- S. Rutledge 1 month	13,364
estimated materials, parts, supplies, telephone, postage	1,500
Total	$14,864

6) Statement of Unobligated Funds

Unobligated funds are approximately 10K at the time of this report.

7) Changes in Project Support Personnel

There are no changes in Senior Personnel.

8. Current and Pending Support

A. Current Support for Steven A. Rutledge as of 02/15/98

Agency	Project Title	K$/ YR	Role	Period Covered	Commitment (months)
National Oceanic and Atmospheric Administration (USTPO)	Further Analysis of the Shipboard Radar Data from COARE: Rainfall, Convection organization and surface fluxes.	110	PI	1/1/97 to 1/1/99	1 academic
National Science Foundation	The CSU-CHILL Radar Facility	500	CO-PI	5/1/95 to 4/30/00	1 summer 1 academic
National Science Foundation	Dynamical and Electrical Studies of Convective Cloud Systems	120	PI	2/1/98 to 1/30/01	1 summer
National Aeronautics and Space Administration	Validation Studies and Algorithm Refinement in Support of TRMM	145	CO-PI	6/1/97 to 9/30/99	1 academic
National Science Foundation	Improving Nexrad-based estimates of precipitating rates and hydrometer classification	110	PI	10/01/96 to 9/30/99	
National Oceanic and Atrmospheric Administration	Analysis and Modeling of the Transport of Lightning-Generated Nox and Other Chemical Species in Convective Cloud Systems	80	PI	1/1/97 to 6/30/00	
Colorado State University	Resident Instruction Support				7 academic

B. Current Support for V. N. Bringi as of 02/15/98

Agency	Project Title	K$/ YR	Role	Period Covered	Commitment (months)
National Science Foundation	Continuation of CaPE Radar Analysis	105	PI	4/1/95 to 8/1/98	
National Aeronautics and Space Administration	K-band Propagation Studies Usning the CSU-CHILL Radar	80	PI	5/1/93 to 3/31/98	1 summer
National Science Foundation	Improving NEXRAD Extimates of Precipitation	110	PI	9/1/96 to 8/31/99	.5 summer
National Science Foundation	The CSU CHILL Radar Facility	500	CO-PI	5/1/95 to 4/30/00	1 summer

B. Pending Support for V. N. Bringi as of 02/15/98

AFOSR	The CSU-CHILL Radar Facility for Polarimeteric Studies of Precipitation and Bistatic Methods	PI	2/1/98 to 1/31/01	1 summer
National Science Foundation	Coordinated Analysis of Fully Polarimetric CSU-CHILL Radar Signatures With Surface and Airborne Hydrometeor Images	PI	2/1/98 to 1/31/01	1 summer

Appendix A

Graduate Theses/Dissertation in 1997

Completed / in-progress graduate students:

1) Department of Atmospheric Science:

Completed:

T. Lang (M.S.)	Relationship between storm structure and lightning activity in colorado convection observed during STERO-A.

In-Progress:

L. Carey (Ph.D.)	Lightning and multiparameter radar characteristics of severe hail storms
T. Lang (Ph. D.)	Lightning and Severe Convection
J. Ryan (M.S.)	Lightning and NOx production in deep convection
C. Butler (M.S.)	Multiparameter radar and microphysical observations in winter storms

2) Department of Electrical Engineering:

Completed:

Scott Bolen(Ph. D)	Space Time Analysis of Radar Rainfall Field
Abou El-Magd (Ph. D)	Identification and Classification of Mixed Phase Precipitation Using Multiparameter Radar and Surface Measurements
Li Zhao (M.S.)	Weather Radar Signal Analysis and Phase Coding Scheme to Recover Second Trip Echoes
G. Huang (M.S.)	Two Transmitter/Two Receiver CSU-CHILL Radar System: Calibration Issues and Sample Data Analysis

In Progress:

I. Ibrahim(Ph. D)	Identification and Classification of Multiparameter Radar Data in Winter and Springtime Storms
B. Benbella(Ph. D)	Wavelet and Multiresolution Analysis of Radar Rainfields
H. Liu(Ph. D)	Development of Neural Network and Neuro-Fuzzy Systems for Multiparameter Radar Data
Ji Ran(M.S.)	Development of a Neural Network for Multiparameter Radar Rainfall Estimation
G. Huang(Ph. D)	No title as yet

Appendix B

Letters Associated with Radar Users

11 September 1997
Dr. Harold Duke
USDA - ARS
AERC - CSU
Ft. Collins, CO 80532-1325

Dear Harold:

This letter serves to close out our files on the efforts to collect CSU-CHILL multiparameter radar data over your Wiggins area crop yield test site during the 1997 growing season. According to our records, radar data were collected for your 20 hour project on a number of occasions. I believe reasonably good radar coverage was obtained during the rain events of 19 and 28 July at Wiggins. Please advise me of the dates and times of greatest interest to you. I will then attempt to have radar-based rainfall estimates generated for these periods. Let me know which format (.GIF images, ASCII data files, etc.) you would prefer for these radar data.

Feedback from radar facility users is always of interest A brief summary of your impressions of the radar support for this project (i.e. conduct of operations, performance of the radar equipment and staff, data quality, etc.) will be quite useful. If you prefer, such a summary may be sent directly to Dr. Ken Van Sickle at NSF.

I am glad that the CSU-CHILL Facility was able to collect data in support of your research project. I hope that the overall results of your field program will prove to be useful.

Sincerely,

Pat Kennedy
CSU-CHILL Facility Manager
(970) 491-6248

11 September 1997
Mr. Larry Carey
Department of Atmospheric Science
Colorado State University
Ft. Collins, CO 80523

Dear Larry:

This letter serves to close out our files on the efforts to collect CSU-CHILL multiparameter radar data for your summer 1997 20 hour project (Multiparameter Radar Study of Positive CG Producing Severe Hailstorms). According to our records, the primary radar operational dates for this project were:

2 June	Long-lived +CG producing case
11 June	Widespread convection
13 June	Hail and heavy rain along US-34 between Loveland and Greeley
14 June	Squall line developing along Ft. Collins area foothills
16 June	Fairly long-lived storm remaining below severe limits

A UF data tape has already been supplied to you for the 2 June case. Please advise me if there are additional radar data tapes that you're interested in, or if any questions arise regarding the data.

Sincerely,

Pat Kennedy
CSU-CHILL Facility Manager
(970) 491-6248

11 September 1997
Dr. Walt Petersen
Department of Atmospheric Science
Colorado State University
Ft. Collins, CO 80523

Dear Walt:

This letter serves to close out our files on the efforts to collect CSU-CHILL multiparameter radar data for your summer 1997 20 hour project examining the early stages of convective cloud electrification. According to our records, radar data were collected for your 20 hour project as follows:

6 June Scan tests
17 June Scan tests; poor CU development
8 July Isolated "single flash" storm SE of the radar
17 July poor CU development
24 July Repeated cell development along foothills near ATS
28 July Morning convective activity near ATS

UF data tapes have already been supplied to you for several of the above operations. Please advise me if there are additional radar data tapes that you're interested in, or if any questions arise regarding the data.

Sincerely,

Pat Kennedy
CSU-CHILL Facility Manager
(970) 491-6248

Appendix C

Summary of Greeley Data Collection Activities Through 01/15/97

Project	Period	Outcome
1991		
WISP91 (NSF)	January-March	Nick Powell - CSU Atmospheric Science M.S. thesis completed.
Kostinski (20 hr)	April	Subsequently funded NSF proposal.
Srivastava (20 hr)	April-June	Profiler-radar intercomparison.
University of Nevada-Reno/ DRI (NSF)	May	Summary to appear in BAMS.
Julien (20 hr)	May-July	Fred Ogden CSU Ph.D. Civil Engineering dissertation completed.
McKee (20 hr)	June-August	Dave Speltz CSU Atmospheric Science M.S. thesis completed.
Hartley (20 hr)	May-August	Summary in Ag. Res. Svc. article.
(Rutledge; Class-room cases)	January-August	Data base for CSU Atmospheric Science radar class, summary to appear in BAMS. Antenna patterns, sphere calibrations, etc., for Ashok CSU Electrical Engineering (M.S. thesis completed).
1992		
Turk (20 hr)	March	Support of NASA ER2 over flights.
Srivastava (20 hr)	April-May	Continuation of 91 program.
Dixon (20 hr)	May - June	Ph.D. dissertation in progress.
Chandra REU (NSF)	June-August	Several senior year electrical engineering projects in progress.
T-28 tests (NSF)	June	Support data during T-28 test flights.
Cotton 92 (20 hr)	July-August modeling study.	Observational data for NSF funded
Connell (20 hr)	July-August	Exploratory data.
Rauber	October Sabreliner.	Cloud water sampler test on
1993		

Kennedy	Feb - April	Aircraft ground icing study.
Chandra (WISPIT)	Feb - March	In-situ aircraft / multi-parm radar comparison.
Roberts (WISPIT)	Feb - March	Combined dual-Doppler and multi-parm radar analyses.
Carey	May - June	Multiparameter radar and storm electrification study.
Holtzer	May - June migration.	Radar observations of insect
Aydin	June	Multi-parameter radar hail detection.
Bringi	July	" "
McAnelly	July - August	Upscale evolution of mesoscale convective systems.

1994

WISP94	Jan - March	Winter storms and icing project (NSF supported NCAR project).
ACTS	Beaver et al propagation (Ph.D.)	Meteorological effects on microwave
ANVIL	Hallett	Evolution of anvil airflow fields
APHID94	Holtzer et al	Migration patterns of Russian Wheat Aphids
DEN94	Clement and McKee	Multiparameter obs of storms over Denver urban flood district (MS)
RAIN94	Bringi	Comparison of WSR-88D and multiparameter based rainfall estimates
REU94	Chandrasekar	Research experience for EE undergraduates
MCS94	McAnelly	Observations of MCS genesis

1995

Carey and Rutledge	May-July	Combined electric field / multi-E-FIELD parameter radar observations of thunderstorms.
Chandrasekar	June-August	Exposure of undergraduate REU95 students to weather radar research project field activities.

Straka, Zrnic et. al	June	Aircraft collection of in-situ T28 cloud observations to validate multiparameter radar data.
Bringi	June-August	Use of mobile hydrometeor PRECIP VAN95 measuring systems to verify multiparameter radar data.
Breed	June-August	Sailplane observations of the SAILPLANE 95 early electrification stages of cumulus clouds.
Metcalf	June	Radar detection of cloud ICE ORIENTATION electrification through ice particle orientation signatures.
Bedard et. al.	June-August	Correlations between low LF SOUND frequency sound waves and convective storm life cycle.
Browning	July-August	Relationship between boundary PBL95 layer echo evolution and later convective development.
Heymsfield	July-August	Multiparameter radar REPLICATOR observations of convective cloud systems penetrated by a balloon-borne particle replicator.

<u>1996</u>

Kennedy and Chandrasekar FNL	Feb-April	Combined multiparameter radar and surface observations of winter season precipitation.
Cifelli PLATTEVILLE	May-June	Joint CSU-CHILL / NOAA profiler study of precipitating cloud systems.
Chandrasekar and Bringi REU96	June-August	Exposure of undergraduate students to weather radar research project activities.
Rutledge, Dye, and Tuck STERAO-A	June-July	Coordinated multiparameter radar, aircraft, and lightning study of deep convective storms.
Bedard LF SOUND	July-August	Correlations between low frequency sound waves and convective storm life cycle.

1997

Rasmussen et. al. PROWS97	Jan - March	Combined multiparameter radar and surface observations of winter season precipitation.
Chandrasekar REU97	June-August	Exposure of undergraduate students to weather radar research project activities.
Duke RAIN MAP	June-August	Multiparameter rainfall estimation over dense rain gage networks
Carey POS CG	June-July	Evolution of + CG producing thunderstorms using radar and lightning detection data
Petersen FIRST LTG	July-August	High time resolution radar observations of initial stages of storm electrification

Appendix D

1997 CSU-CHILL Newsletter

CHILL RADAR NEWS

from

Colorado State University

Seventh Edition
October 1997

Overview
(Steven Rutledge, Scientific Director)

This is the seventh edition of the Colorado State University (CSU)-CHILL newsletter which we distribute on an annual basis, near the start of the academic year. The newsletter is intended to provide information to the community regarding research, education, and refurbishment activities of the CSU-CHILL facility. In April 1995 Colorado State University was awarded a second five-year Cooperative Agreement from the National Science Foundation for operation and maintenance of the CSU-CHILL, a 10 cm, dual polarized Doppler radar. The radar is presently operational near Greeley, CO (located approximately one mile north of the Greeley-Weld County Municipal Airport), situated on an eighty acre agricultural site owned by CSU.

The use of the CSU-CHILL radar is granted by the National Science Foundation after review by the NSF Facilities Advisory Council and Observing Facilities Advisory Panel. We supported two NSF-reviewed projects during 1997, a Research Experience for Undergraduates project directed by Prof. Chandrasekar in the Department of Electrical Engineering, and PROWS, Polarimetric Radar Observations of Winter Storms, directed by a number of PI's from CSU and NCAR. In the REU project, eleven undergraduate engineering students from a variety of universities participated in a two month long storm chase program, operating instrumented vans to collect hail and rain data to verify polarimetric radar signatures. PROWS consisted of multiparameter observations of winter storms with both the CSU-CHILL and NCAR S-pol radars, along with a variety of ground-based observations, including a 2-D video disdrometer providing hydrometeor images. PROWS addresses the need to improve radar remote sensing of winter precipitation by NEXRAD radars, a research goal of the U.S. Weather Research Program.

For projects requiring less than about 20 hours of radar operational time, the Scientific Director of the CSU-CHILL facility can award the use of the radar for such projects, without OFAP/FAC review. In these projects, radar operational costs are provided by the Cooperative Agreement. These projects encourage use of the radar for highly focused experiments. These projects continue to be very productive. We supported three 20 hour projects in the past year, as detailed in the following sections. The radar also continues to be an integral component of several courses in the Departments of Atmospheric Science and Electrical Engineering.

During the last two to three years, numerous improvements have been carried out at the Facility, including the acquisition of a new high performance antenna, installation of a second FPS-18 transmitter and a second receiver (thus eliminating the need for a polarization switch), temperature stabilization of the front end's of both receivers (to improve estimates of differential reflectivity), and development of automated calibration procedures. These improvements and advances, coupled with regularly scheduled maintenance, have brought the facility to a high level of readiness and reliability.

Another highlight of this past year's activities has been the acquisition of the HOT radar from the Illinois State Water Survey. HOT is a 10 cm, Doppler system. HOT is now being readied for permanent dual-Doppler operations with the CSU-CHILL system. This dual-Doppler system will be available as a community resource. HOT will be located near Nunn, CO, which will provide a 48 km baseline with CHILL. We expect HOT to be operational by the end of summer 98.

The CSU-CHILL facility has been requested to support RACES in the summer of 98, a large experiment that will focus on lightning and severe storms here in Colorado. We also anticipate supporting another REU project during that same summer.

CSU-CHILL was also scheduled to support the WISP 98 project this coming winter in Wisconsin. However, funding for this project was recently declined by the NSF. CHILL staff spent the last two months readying the system for deployment, including identifying an excellent radar site near Green Bay, WI.

Radar Operations Summary
(Pat Kennedy, Facility Manager)

The CSU-CHILL facility supported two NSF-sponsored research programs and three 20 hour projects during the year ending in October 1997. Data were also collected during the historic flash flood event that took place on evening of 28 July 1997 in Ft. Collins.

The first NSF funded project was PROWS97 (Polarimetric Radar Observations of Winter Storms 1997). Both the CSU-CHILL and the NCAR S-POL dual polarization S-band research radar systems participated in the project. The NCAR / S-POL component of the project was directed by NCAR scientist Roy Rassmussen and Jim Wilson. CSU-CHILL operations were supervised by CSU Profs. Steven Rutledge and V. Chandrasekar. The experiment was designed to collect polarimetric radar data sets that could be compared with ground based precipitation observations (i.e., hydrometeor types, sizes, accumulation rates, etc.). These surface observations offered a verification standard against which various radar-derived characterizations of winter precipitation could be tested. Dedicated surface weather observations were made at the state climate network station on the CSU campus, and at NCAR's Marshall field installation near Boulder. The S-POL radar was operated from the Eastlake site (approximately 55 km southwest of CSU-CHILL). Coordinated dual Doppler scans were conducted by the two radars at 30 minute intervals. The overall data set collected in PROWS97 should usefully expand techniques for remotely sensing winter season precipitation with dual polarization radars.

Prof. V. Chandrasekar also was the Principal Investigator on the second NSF project of the year, REU97, which was conducted during the summer semester. This project involved a group of 11 undergraduate engineering students who came to CSU from universities located in four different states. Overview lectures and demonstrations were presented by Gene Mueller (engineering principles of weather radars), and Pat Kennedy (introduction to radar meteorology). Several of the students then participated in convective storm intercept operations that were directed in real time from the user van at the CSU-CHILL radar. The intercept van was equipped to capture falling hailstones as well as to record basic surface weather data (rainfall, wind speed and direction, etc.) The most successful storm intercept took place on the afternoon of 24 June, when hail data were collected at two different locations. The REU students each presented final reports summarizing the results of their summer's research activities.

A smaller scale (20 hour) research project was conducted by Harold Duke, an agricultural engineer in the USDA Agricultural Research Service (ARS). During the 1997 growing season, an ARS project was planned in which crop growth in two irrigated fields near Wiggins, Colorado was to be closely monitored. Dr. Duke desired to use CSU-CHILL data to augment the ARS project by generating radar-based rainfall maps for the region encompassing the test crop fields. These rainfall maps will be used to characterize the spatial variability of the naturally occurring convective season rainfall during selected storm events. Notable storm passages over the test crop sites were monitored by CSU-CHILL on several occasions.

The two final 20 hour radar projects were directed by CSU Atmospheric Science Department personnel. Larry Carey, a Ph. D. candidate, was interested in multiparameter data collected in volume scans of severe thunderstorms. His goal was the continued exploration of correlations between positive polarity cloud to ground (+CG) lightning discharges and thunderstorm severity. Carey collected a useful data set on 2 June 1997, when volume scans were recorded during most of the lifetime of a +CG producing severe storm. The second CSU-based 20 hour project was under the direction of Dr. Walt Petersen, a Research Associate in ATS. Dr. Petersen desired to collect high temporal resolution (under 2 minute cycle time) RHI volume scans of developing convective clouds. These data would be used to characterize the microphysical evolution of convective echoes as they initially become electrified. Preliminary analyses indicate that useful data sets were collected on the 8th and the 24th of July.

Atmospheric Science: The Ft. Collins Flood of 28 July 1997: Polarimetric Radar Observations

(Walter Petersen, Lawrence Carey, and Steven Rutledge, Atmospheric Science)

On the night of 28 July 1997, the city of Fort Collins, Colorado experienced a devastating flash flood that caused five fatalities and extensive property damage across the western side of the city. The CSU-CHILL radar was operating on that particular evening, providing an unprecedented documentation of the convection and rainfall associated with a flash flood from the view of an S-band dual-polarized radar.

Hydrologically, saturation of the soil in the surrounding area occurred in association with heavy rain showers that developed on July 27 and lasted through the morning of July 28. These rains were later followed by a series of training convective systems that propagated through the region during the afternoon and evening of July 28. Between 1700 and 2000 MDT on the 28th, two convective systems moved over the city from the south producing brief heavy rain, moving rapidly toward the north. However, between 2000 and 2300 MDT, a third group of convective cells moved over the headwaters of Spring Creek, situated in southwestern Fort Collins, and remained nearly stationary from 2045 MDT to 2215 MDT. Though stationary, the convection pulsed several times during this hour, sending embedded cores of very heavy rain eastward along the creek drainage and over the western portions of the city. This resulted in total rainfall amounts (gauge measured) over a five hour period that exceeded 10 inches on the southwestern side of Fort Collins (Fig. 1).

In some respects, the convection associated with this event seemed to be tropical "monsoon-like," exhibiting heavy convective rainfall with relatively little lightning. Indeed, when reflectivity-based estimates of rainfall (Z-R) were compared to amounts estimated using polarimetric variables (e.g., Kdp, Zdr), some interesting differences were observed, and it seems likely that some of the contrast is due to cloud microphysical characteristics associated with the "atypical" convective rainfall regime.

During the flood, the CSU-CHILL radar, located about 42 km to the east-southeast of Fort Collins, obtained low-level surveillance scans every 6-15 minutes. We utilized three observed polarimetric variables to estimate rain rates: the horizontal reflectivity, Zh; the differential reflectivity, Zdr; and the differential phase. The data were carefully edited to remove ground clutter contamination and other spurious data. The specific differential phase, Kdp, which is nearly linearly proportional to the rain rate, was estimated using a finite impulse response (FIR) filtering technique on the differential phase data. The following equations were utilized to create grids of instantaneous rain rate:

$$Zh = 300\,R^{1.4} \qquad (1)$$

(WSR-88D algorithm with standard 53 dBZ truncation)

$$R(Kdp) = 39.72\,Kdp^{0.866} \qquad (2)$$

(Doviak and Zrnic, 1993)

$$R(Kdp, Zdr) = 52\,Kdp^{0.96}\,Zdr^{-0.447} \qquad (3)$$

(Ryzhkov and Zrnic, 1995)

The grids of instantaneous rain rate from 1700 to 2215 MDT were converted to cumulative rainfall maps by assuming a 1-minute, step-wise linear interpolation between radar scan times.

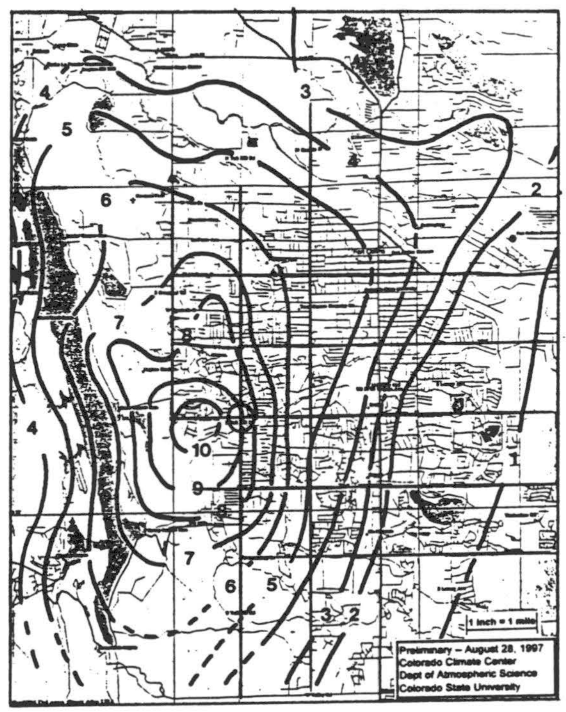


Figure 1. A cumulative rainfall map contoured in inches for the time period 17:30 to 2300 MDT on 28 July 1997. The "O" marks the origin of accompanying radar rainfall estimates shown in Figs. 2-3. East-west and north-south lines in figure denote major roads in the city. This road grid is identical to that shown in Figs. 2-3. Figure provided by Dr. Thomas McKee of the Colorado Climate Center and Department of Atmospheric Science.

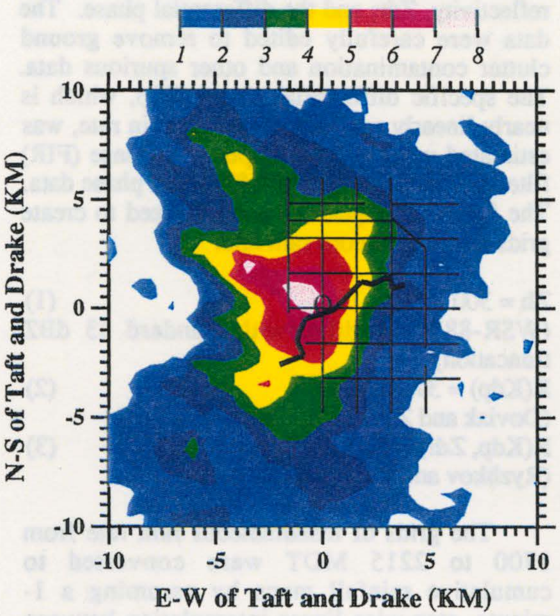


Figure 2. Cumulative rainfall totals (inches) computed from the R(Kdp,Zdr) technique, 28 July 1997, 1800-2215 MDT. An approximate city street map is overlayed with the origin at the intersection of Taft Hill and Drake streets in Fort Collins. A portion of Spring Creek is indicated by the bold, curved line.

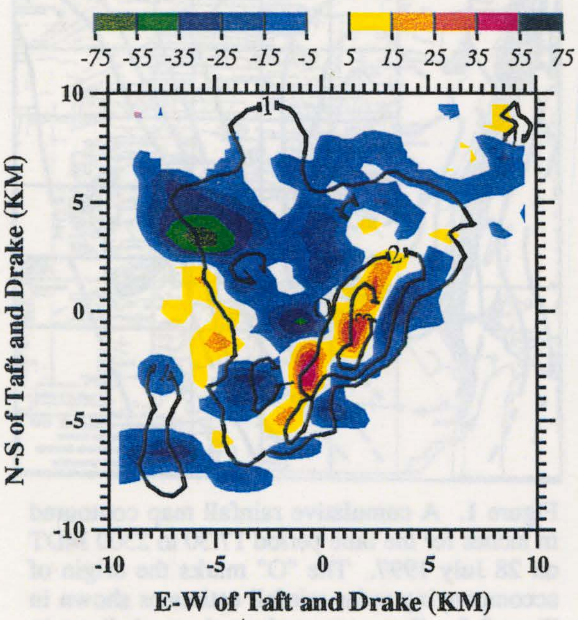


Figure 3. Instantaneous difference (mm/hour) in rainfall rate between the R(Kdp,Zdr) and Z-R methods [R(Zh) R(Kdp,Zdr)] at 2145 MDT. Overlayed are contours of Zdr at 1dB intervals beginning with a value of 1dB. Origin at the intersection of Taft Hill and Drake.

Figure 4: Photo of 2D-video distrometer installed in van.

For comparison with Fig. 1, the cumulative rainfall as estimated by CSU-CHILL measurements of Kdp and Zdr (Eqn. 3) is shown in Fig. 2. Note the similarity in the overall structure of the radar estimated and gauge measured rain maps. The north-south orientation of the flood event along the foothills of the Front Range (located at x = -4 km in Fig. 2) is well represented by the R(Kdp,Zdr) rain map. More importantly, both the gauge and radar rainfall totals are characterized by a strong east-to-west gradient located over central Ft. Collins (x = 2.5 km). As can be seen from both Figs. 1 and 2, rainfall accompanying the Ft. Collins flood was extremely localized, occurring primarily over western portions of the city. The cumulative rainfall as estimated by R(Kdp,Zdr) over Ft. Collins is within 70% to 75% of the gauge measured totals. The overall cumulative rainfall maximum estimated from Eqn. 3 is 7.4 inches (compared to 10.2 inches from the rain gauges). The location of the R(Kdp,Zdr) estimated maximum rain accumulation (x = -1 km, y = 0.5 km) compares very favorably to the corresponding gauge position. The southern portion of the extreme rainfall amounts (> 5 inches in Fig. 2) are located directly over the drainage basin for Spring Creek (dark line in Fig. 2), consistent with the property damage and fatalities which occurred in the vicinity of this creek.

Using rain gauge totals as ground truth, it is clear that the R(Kdp,Zdr) algorithm outperformed rainfall estimates from both R(Kdp) and R(Zh). Peak rainfall totals as estimated from R(Kdp) and R(Zh) were 6.15 and 5.75 inches respectively. This factor of two underestimation by the WSR-88D R(Zh) algorithm may be due in part to the unique, monsoon-like, microphysical nature (i.e., the drop size distribution) of the convection responsible for the flood.

To explore this hypothesis, we calculated R(Zh)-R(Kdp,Zdr) at 2145 MDT which was the approximate time of the most intense rainfall (Fig. 3). Throughout most of the echo, this difference is negative (cool colors) with some deficits in R(Zh) as high as 55 mm/h or more. In most of the regions in which R(Zh) < R(Kdp,Zdr), the differential reflectivity is characterized by small to moderate values (0.5 < Zdr < 1.5 dB). These values of Zdr correspond to reflectivity weighted drop diameters of 1.2 to 2.7 mm. Based on many eyewitness accounts, the presence of "sheets of small drops" was a common characteristic of the heavy rain in the Ft. Collins flood. This is consistent with the pattern of Zdr in Fig. 3 and suggests that the standard WSR-88D rain algorithm (Eqn. 1) may cause a significant underestimation of rain rates in monsoon-like convection characterized by small drops. On the other hand, R(Zh) > R(Kdp,Zdr) in a 2 km wide southwest-to-northeast oriented band at the leading edge of the storm (warm colors in Fig. 3) by 35 mm/h and more. This region is closely correlated with enhanced values of the differential reflectivity (2 < Zdr < 4 dB), and hence with the presence of large drops (3.3 < D < 5.7 mm). This potential over-estimation of the rain rate in regions characterized by a few large drops is consistent with the fact that reflectivity is proportional to the sixth moment of the drop diameter, and is therefore overly sensitive to the presence of large drops.

The above results suggest that dual-polarimetric radar data (along with rain gauge data) can be used to "tune" WSR-88D rainfall algorithms for particular storm types (tropical monsoon-like in this instance). Future work at Colorado State University will explore this potential. In addition, we plan to investigate the vertical kinematic and microphysical structure of the convection using CSU-CHILL and both Cheyenne and Denver WSR-88D radar data. A detailed cumulative rainfall comparison between rain gauges, CSU-CHILL polarimetric radar, and the two WSR-88D Doppler radars is currently underway. Lastly, we are investigating the utility of cloud-to-ground (CG) lightning data in the nowcasting of flash floods, particularly those of a tropical monsoon nature. Collision-coalesence (or warm rain) appears to be the dominant microphysical process responsible for heavy rains in these storms. Since the production of CG lightning is linked to the presence of a vigorous in-cloud mixed-phase process, preliminary results suggest that CG lightning may be of only limited use as a nowcasting tool for "monsoon-like" flash flood events.

Electrical Engineering
A. REU 96 Project
(V. N. Bringi, Co-Principal Investigator)

Classification of hydrometeor types in winter precipitation using polarimetric radar techniques is an area of effort within EE and ATS as part of PROWS97. To assist in this research, the 2D-video disdrometer was leased from Joanneum Research in Graz, Austria and installed in a van as shown in Fig. 4. The van was located (during the 1997 winter) for one period at the CSU campus weather station, and for another period at the NCAR Marshall field site near Boulder.

Fig. 5 presents a schematic of the measurement principle. The two line scan cameras are directed towards the openings of the illumination devices. The optical system is designed in such a way that (as seen through the camera lens) the slit of the illumination device appears as an evenly illuminated background of extreme brightness. To the cameras, any particle passing through the beam of light will appear as a dark silhouette against this bright background. A small height separation (» 6 mm) between the two optical planes allows the fallspeed to be estimated. Once the fallspeed is known, the height/width ratio of the particle can be calculated from the cameras' data as well as the volume-equivalent spherical diameter, D_{eq}. The size of the virtual measuring area is around 10 cm x 10 cm and only fully visible particles are counted. Horizontal particle velocity introduces image distortion; however, a correction can be applied by estimating the horizontal velocity. This is accurate when the particle has a symmetry axis, e.g., raindrops. Determination of D_{eq}, fallspeed and height/width ratio is independent of horizontal velocity. The horizontal resolution is better than 0.22 mm, while the vertical resolution is better than 0.3 mm (for fallspeed < 10 ms-1). The fallspeed accuracy is better than 5%. Fig. 6a shows the front and side views of a raindrop with D_{eq} = 7.4 mm from the 22 June, 1995 event. Fig 6b shows similar views of a large snowflake during a winter event on 6 February, 1997.

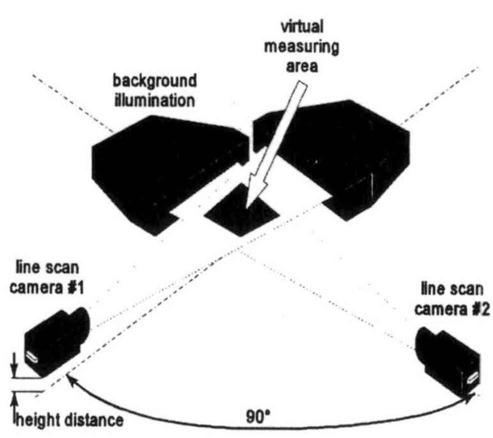


Figure 5: Schematic of measurement principle for the 2D-video distrometer.

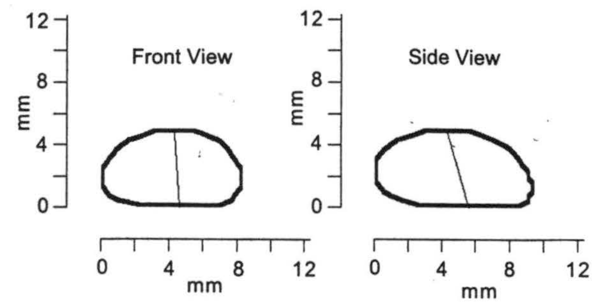


Figure 6a: Sample of front/side views of large raindrop.

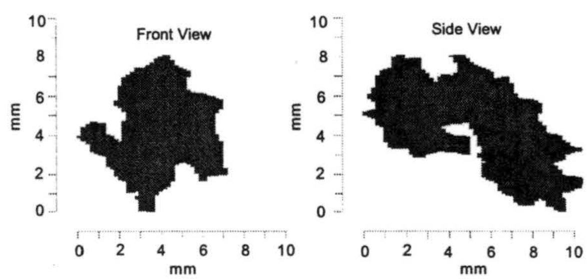
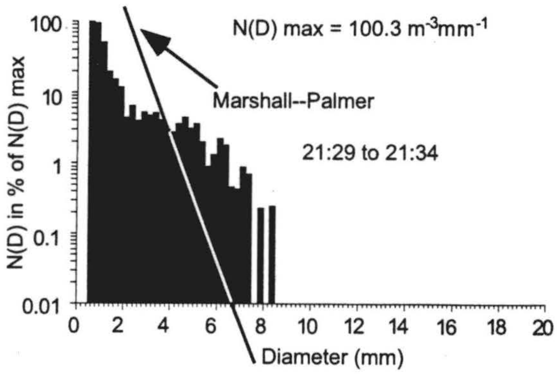


Figure 6b: Sample of front/side views of a large aggregate.

Fig. 7 shows drop size distributions during two periods of the 22 June, 1995 event analyzed by Hubbert et al. (Preprints 28th AMS Conf. Radar Meteor.). Fig. 8 shows an example of snow size distribution averaged over a 15 min. period from the 6 February, 1997 event. Aggregates up to 10 mm in size can be noted. One of our goals is to classify precipitation types using the polarimetric parameters such as Zdr, LDR and ρhv by directly comparing the signatures with hydrometeor image data.



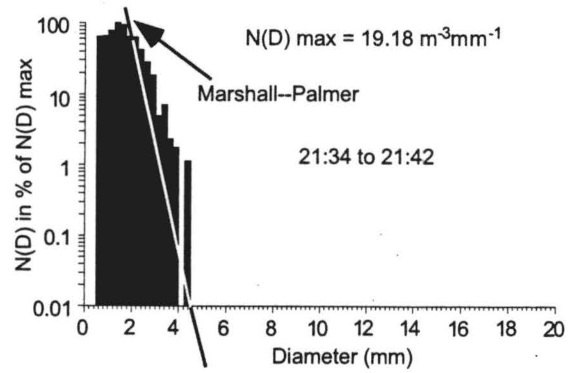


Figure 7: Drop size distributions in a convective rainshaft from the 2D-video distrometer on 22 June, 1995: a) (left) the high rainrate period and b) (right) the low rainrate period.

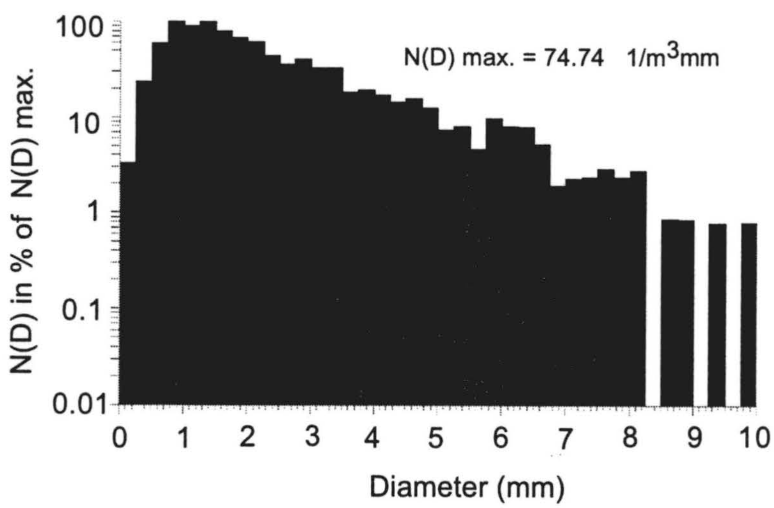


Figure 8: Snow size distribution from the 2D-vidio distrometer on 6 February, 1997 at the CSU campus site. The averaging period is 15 minutes.

A related effort within EE is the use of the Graves power matrix (or, polarization power matrix) to calculate the so-called asymmetry ratio (A) which is the ratio of equivalues of the power matrix (Kwiatkowski et al. J. Atmos. Ocean. Tech., 1995). The asymmetry ratio is similar to conventional Zdr except that it is independent of the canting angle. Fig. 9a shows A-Zdr versus conventional LDR for convective rain. For LDR < -26 dB, the data points fall within the scattering model curves (solid and dashed lines)
which are based on a Gaussian canting angle distribution (`q = 0, s = 5, 10, 12.5°) with equilibrium shapes and Marshall-Palmer distribution. Data points with LDR > -26 dB are likely rain mixed with hail. Previous observations of positive Zdr (typically a few dB) in winter storms have been ascribed to oriented planar crystals. Fig. 9b shows a scatter plot of A-Zdr versus conventional LDR from a winter storm where data points correspond to resolution volumes characterized by planar crystals (most likely dendrites). Also shown are scattering model results (solid and dashed lines) for oblate spheroids of ice with axis ratio varying between 0.1 to 0.5. For a fixed axis ratio, the mean canting angle in the model is increased from 0 to 45°. Note that the data points fall within the modeled curves quite well. Thus, it appears that the axis ratio (or, mean shape for oblates) and mean canting angle effects may be separable by using the asymmetry ratio in combination with conventional Zdr and LDR measurements. We believe that the asymmetry ratio may be a useful "proxy" for circular depolarization ratio (or, CDR) which is sensitive to particle oblateness but is independent of canting angle.

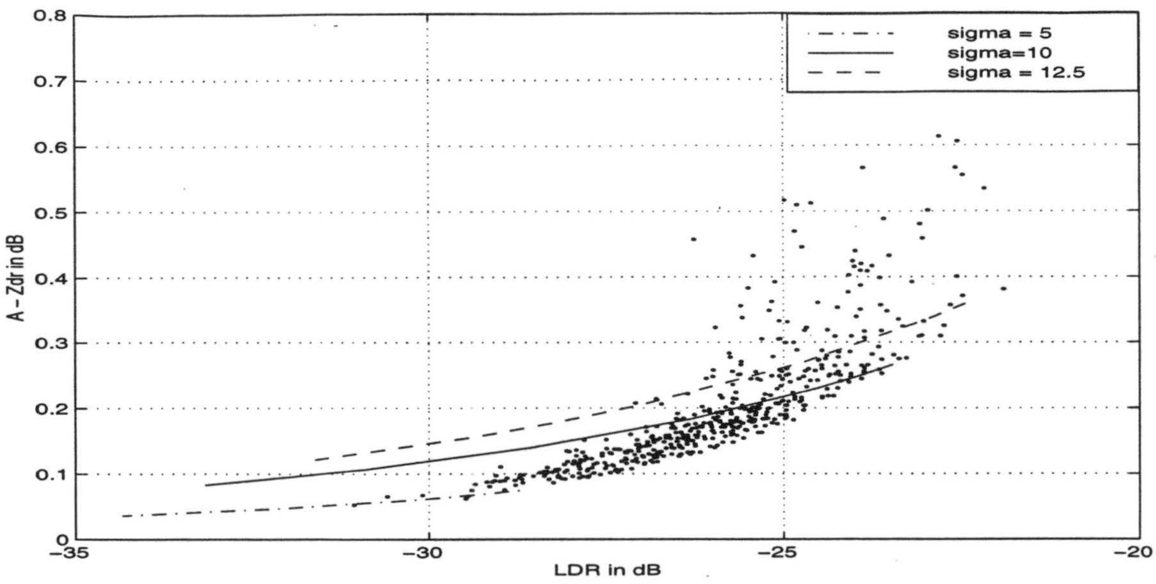


Figure 9: (a) The $A - Z_{dr}$ vs LDR Scatter Plot for Rain.

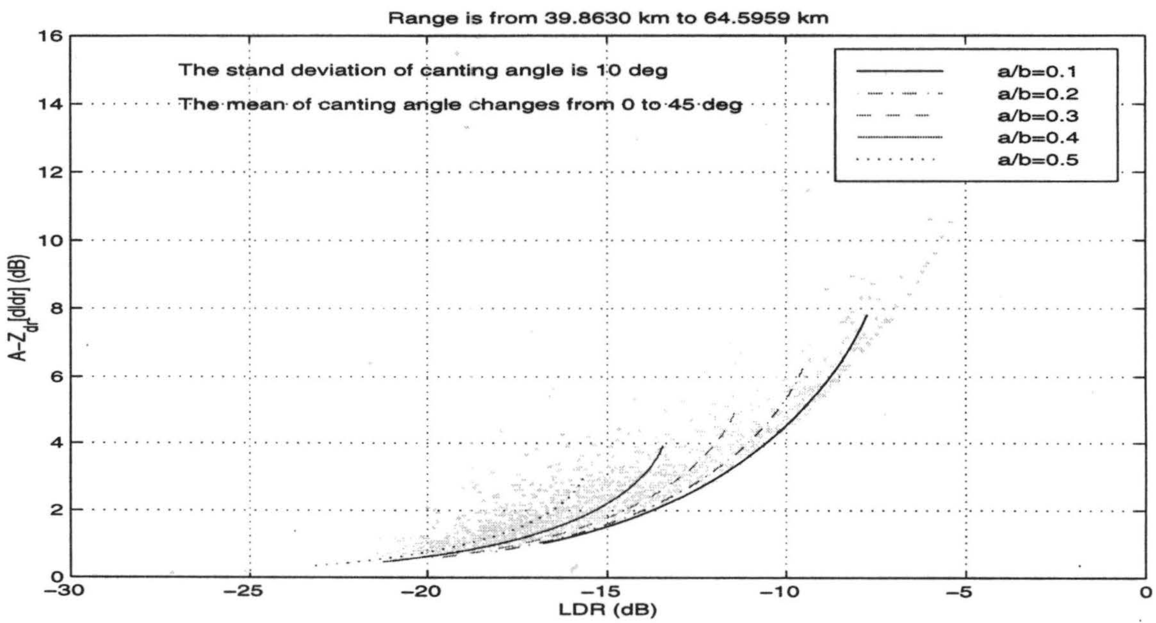


Figure 9: (b) The $A - Z_{dr}$ vs LDR Scatter Plot for winter event.

Another effort within EE is the evaluation of measuring conventional Zdr, ϕdp, and ρhv using slant 45° transmission with simultaneous reception of the horizontal and vertical polarized signals in a dual-channel receiver. Such a scheme is under consideration for the prototype WSR-88D radar system as a potential polarization upgrade. As an initial step in this evaluation, we have analyzed data acquired in the so-called STAR mode (simultaneous transmit, alternate receive, see Brunkow et al., Preprints 28th Radar Meteor. Conf.), i.e., simultaneous transmit means that both transmitters are "fired" simultaneously resulting in approximate slant 45° polarization, while the horizontal and vertical polarized received signals are alternately received via a single receiver (to avoid gain/phase mismatch when two receivers are used). The 4-panel Fig. 10 shows range profiles of reflectivity, Zdr, ϕdp and ρhv in a

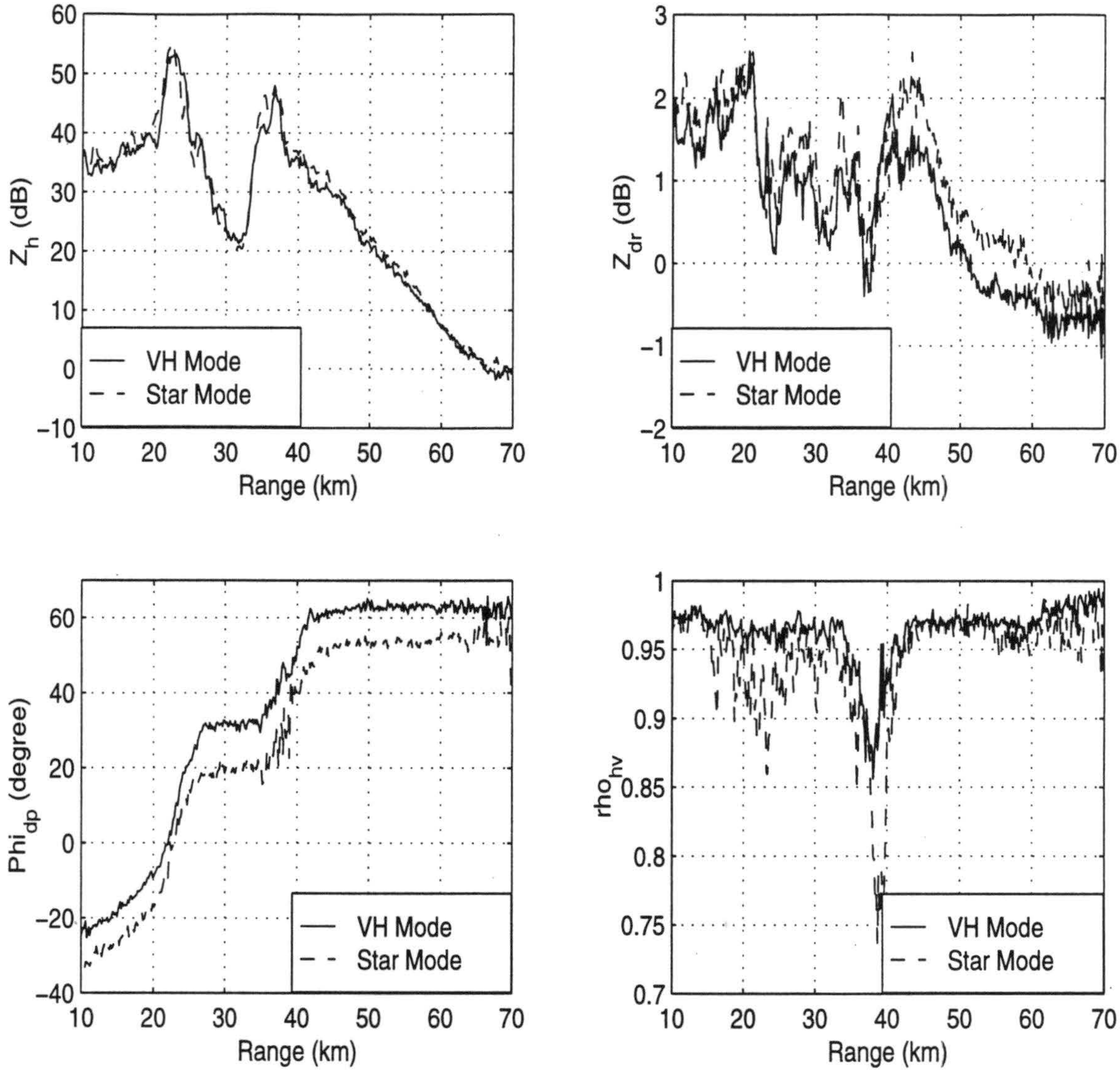


Figure 10: Four-panels comparing VH with Star-mode.

convective storm comparing STAR and conventional VH modes. These two modes were separated in time by a few minutes. While the reflectivity, Zdr and ϕdp agreement is good, there is a tendency for the STAR-mode ρhv to be biased low which we believe may be due to cross-pol coupling. We are using our generalized Stokes vector based propagation-cum-scattering model to study biases in radar measurands under the STAR-mode.

A related effort in EE together with the CSU-CHILL staff is the use of the two transmitter/two receiver system to measure the covariance matrix in the slant 45° /135° and circular RHC/LHC bases, in addition to our conventional linear H/V basis. Because we have two transmitters we can adjust the phase difference between channels to 0, 180° , or ± 90° quite easily while maintaining nearly equal power. We propose to receive the horizontal and vertical polarized signals simultaneously in our two receivers and essentially "re-construct" via software the copolar and cross-polar received components (i.e. the received components that are copolar and cross-polar to the transmit polarization state). This scheme avoids any high power microwave network "switch" which tends to compromise system isolation between channels.

The EE group is continuing its range/velocity ambiguity resolution studies using phase/ polarization coding and waveform design (for example, see Zhao et al., 28th Conf. Radar Meteor.). The CSU-CHILL radar is capable of transmitting random or systematically phase coded pulses with flexible PRTs. Further time series data will be collected and analyzed to evaluate the suppression of multiple trip overlaid echoes and unfolding of both first and multiple trip velocity signatures. A phase coding technique studied by Sachidananda and Zrnic (28th Conf. Radar Meteor.) will be evaluated. Simulations of this technique show that it is superior to random phase coding. Plans are underway to upgrade the CSU-CHILL radar with new dual-channel digital receivers and signal processor. The new receivers will sample the transmit pulse phase, and will provide phase corrections on a pulse-by-pulse basis to provide 0.1 deg rms error (with a target of 0.05 deg rms) over an integration interval of 50 ms. Such high accuracy is needed to fully realize the potential of the systematic phase coding technique proposed and simulated by Sachidananda and Zrnic (28th Conf. Radar Meteor.)

Mr. Scott Bolen of the Rome Laboratory has developed, as part of his Ph.D. thesis, several optimal area methods for comparing polarimetric radar rain rate estimates made aloft to surface rain gauge measurements (Bolen et al. 28th Conf. Radar Meteor.). Radar PPI scan data of Kdp at two elevation angles are used to map an arbitrary point on the surface to a corresponding optimal area on the PPI scan plane, including an estimate of the optimal delay. A schematic is shown in Fig. 11 which shows the two PPI scan planes (test plane and reference plane), as well as the target and displacement vectors. The displacement vector, in essence, maps the gauge location to the center of an optimal ellipse on the reference plane. Rain rate from Kdp is averaged spatially over this optimal ellipse. An optimal delay is also calculated which is used when comparing R(Kdp) with rain rate from the gauge. Fig. 12 shows an example comparison of using this method from the 6 July, 1996 event. Data from a mobile storm intercept van equipped with a Young capacitance rain gauge was used for comparison against CSU-CHILL radar rain rate estimates using a Kdp-based algorithm.

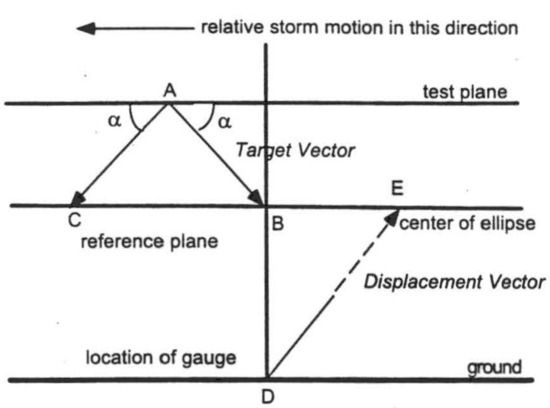


Figure 11: Schematic of the optimal area method.

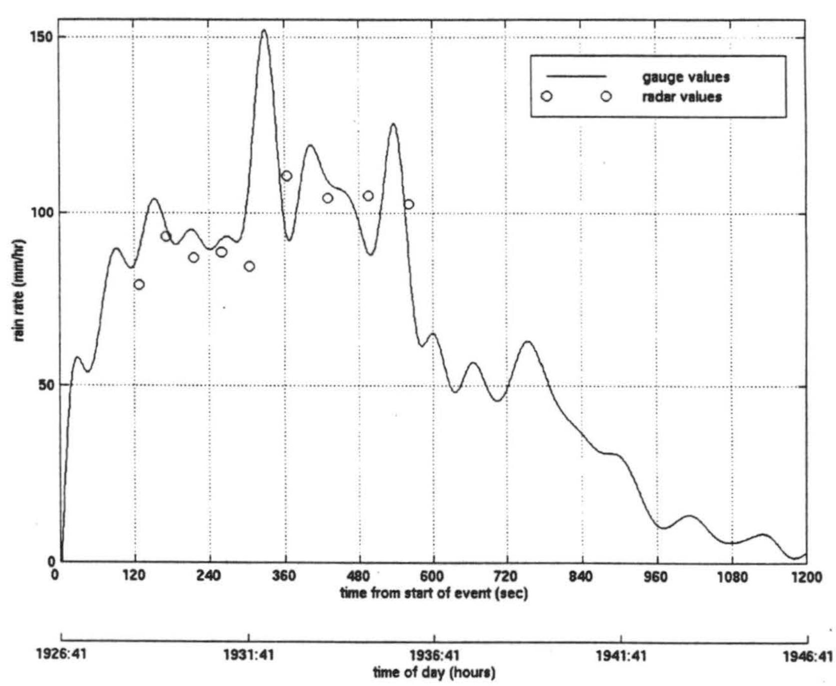


Figure 12: Rainrate from K_{dp} (open circles) versus gauge (solid line) for 6 July event.

Radar Engineering
(Dave Brunkow, Senior Engineer)
Technical Improvements

Real-Time Web Page

An automated system was developed which can grab images from the Adage display system, convert them to GIF format, and a create world wide web index to provide access to the images. The transfer of images from the VAX Adage host to a Sun workstation takes several minutes, but is fast enough to transfer 4 images every 15 minutes. Access to the images is via a standard web browser program. This has proved to be a very handy way of for researchers to keep track of the data acquisition phase of their projects without actually traveling to the radar. To see these images, look for the "Near-Real-Time Image" option on the CSU-CHILL Web page (http://olympic.atmos.colostate.edu/CHILL).

Simultaneous Transmit Tests

First tests of the simultaneous transmit operating mode were conducted. During these tests, only a single receiver was used. The receiver was alternately switch between the horizontal and vertical channels. This produced the same sequence of data at the copolar receiver that is produced in the alternating VH transmit mode, which simplified the signal processing requirements. This Simultaneous Transmit with Alternating Receivers (STAR mode) does have some practical application in the upgrading of existing radars to multi-polarization operation. Also of interest is the mode where both receivers are processed simultaneously. This requires somewhat greater signal processing capability, but has the advantage of isolating the differential phase (ϕdp) measurements from the velocity measurements. It also doubles the unambiguous range of the ϕdp measurements. This mode will be implemented on CSU-CHILL within the next year. Some images from alternating and simultaneous transmit modes are available on the web pages under "Misc. Research in Progress". The results looks promising, although there are some artifacts apparently due to crosstalk from depolarization on cases where there is significant hail present.

Remote Deployment Issues

The CSU-CHILL system was requested for participation in a winter project in the Great Lakes region. Although the project was canceled for reasons not related to the radar, progress was made on a variety of issues which will facilitate future deployments of the system. The first of these was the re-design of the concrete pad which supports the antenna pedestal. The size of the octagon was reduced from 28 to 18 feet, and the thickness was reduced to 42 inches. Design features were incorporated to facilitate the removal of the pad after a project is complete. This reduced the cost of site restoration to about $6000 in the Green Bay area. This issue proved to be of critical interest since all of the sites considered for this project would have required the removal of the pad. The new design still will support the antenna with a failed radome draped over it in a 100 mile per hour wind.

The second issue relates to the viability of the transmitters in new locations. It was found that available frequencies in the 2700-2900 MHZ band were very difficult to obtain in much of the proposed project area (Michigan). A frequency was available in Green Bay, but it was above 2800 MHZ, so it required a change of Klystrons in the transmitters. There are not as many tubes available in the higher frequency range, so there was some uncertainty there, but we found that we did have Klystrons which operated well in this part of the band. We now know that an operation above 2800 MHZ would be feasible.

Another issue related to the transmitters was the requirement to meet the NTIA RSEC criteria. These are a set of standards which have been established to allow as many radars as possible to operate in a region without interfering with one another. We found that the CSU-CHILL transmitters were very close to meeting these criteria without modification. Further, it was found that by reducing the rise time of the pulse we could easily meet the required bandwidth limitation and emission vs. frequency envelope required. These findings have reduced the uncertainty over licensing the radar in other locations, however, the crowded nature of this frequency band has made deployment to certain regions very difficult. This issue should be considered early-on in any future remote deployments.

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