Research and Graduate Education

Atmospheric Science

Colorado State University

RESEARCH AND GRADUATE EDUCATION

IN THE DEPARTMENT OF

ATMOSPHERIC SCIENCE

AT

COLORADO STATE UNIVERSITY

Materials presented in this report cover the academic year 1987-1988. The report is provided for prospective graduate students, representatives of industry, and federal agency sponsors.

Additional information about any of the projects described in this report can be obtained by contacting the department head, Stephen Cox, or Fred Smith, Associate Dean for Research and Graduate Studies.

Colorado State University is an affirmative action, equal opportunity institution.

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DEPARTMENTAL PERSPECTIVE

The Department of Atmospheric Science has had an outstanding year in 1987/88. Our fourteen academic faculty members have guided their own research and that of their students and staff with unerring skill. The department is pleased to welcome two new faculty members: Dr. David Randall, formerly of the NASA Goddard Space Flight Center and an internationally known expert in general circulation modeling, and Dr. Steven Rutledge, an expert in radar meteorology who comes to us from Oregon State University.

Supporting the academic and research activities of our faculty are 81 graduate students, 29 research faculty and 20 state classified employees. The department remains committed to the principle that the education of our graduate students is inextricably linked to the scholarly research conducted by the faculty.

More effort has been devoted during the past few years to attracting the most qualified graduate students available to the department. The quality of our graduate students has a positive impact on the quality of our entire program and on the ultimate success of the department. During this academic year, the department granted seven Doctor of Philosophy degrees and ten Master of Science degrees. In 1987 a total of 27 new students entered our graduate degree program. Twenty percent of our graduate students are foreign and eighteen percent are women. A recent review of our students indicates that sixty percent came from meteorology or atmospheric science backgrounds. The remainder obtained their undergraduate degrees in physics, mathematics or engineering. The diversity of our student body in terms of experience and background contributes to a healthy graduate program.

The research activities of the faculty were again very productive. While educating students continues to be our principal focus, research productivity can be measured in a number of ways. A strong indication of the vitality of the Atmospheric Science research program lies in the publication records of our faculty and students. A total of fifty-nine articles in the reviewed literature have been published or accepted for publication during the past year. Fifteen research reports have been added to the department's research report series. The Colorado State Climatology Office completed its eleventh year of continuous monthly reports featuring Colorado climatological data and analyses. The department research volume has again surpassed the three-million dollar level.

This past year several Atmospheric Science faculty banded together to successfully compete for instrumentation funds with other universities through the Defense University Research Instrumentation Program. As a result, in 1989 the Department will add to its already impressive field-observing capability a five beam VHF doppler wind profiler system. This acquisition will make Colorado State the only U. S. university with a five beam wind profiling capability. Both the

research and educational programs in the Department of Atmospheric Science will benefit from access to this state-of-the-art instrumentation.

Professors Tom McKee and William Cotton were elected as Fellows to the American Meteorological Society this past year. This brings the number of AMS Fellows among our Atmospheric Science faculty to eight.

Finally, all of our faculty and graduate students have access to virtually unlimited computer facilities directly from their offices. These resources range from desktop computers to large supercomputers via high speed data transmission links. The department is committed to providing our faculty, students and researchers with an environment which will ensure continued pre-eminence in our field, and to providing quality graduates to fill academic and research positions of the future.

Stephen K. Cox
Acting Department Head

FACULTY AND STAFF

Professors

Stephen K. Cox, Department Head, Ph.D., University of Wisconsin
Atmospheric Radiation

William R. Cotton, Ph.D., Pennsylvania State University
Dynamics of Clouds

Lewis O. Grant, M.S., California Institute of Technology
Cloud Physics

William M. Gray, Ph.D., University of Chicago
Tropical Meteorology

Richard H. Johnson, Ph.D., University of Washington
Mesoscale Meteorology

Thomas B. McKee, Ph.D., Colorado State University
Climatology

Roger A. Pielke, Ph.D., Pennsylvania State University
Mesoscale Modeling

Elmar R. Reiter, Ph.D. Dozent, University of Innsbruck, Austria
General Circulation, High-altitude Winds, Aerospace Science, Turbulence

Wayne H. Schubert, Ph.D., University of California
Atmospheric Dynamics

Duane E. Stevens, Ph.D., Harvard University
Dynamic Meteorology

Thomas H. Vonder Haar, Ph.D., University of Wisconsin
Satellite Applications

Associate Professors

David A. Randall, Ph.D., University of California
General Circulation

Peter C. Sinclair, Ph.D., University of Arizona
Meteorological Instruments

Graeme L. Stephens, Ph.D., University of Melbourne, Australia
Radiation Theory

Assistant Professors

Steven A. Rutledge, Ph.D., University of Washington
Radar Meteorology

Research Staff

Ron Avissar, Research Associate
Jan Behunek, Research Associate
James Bresch, Research Associate
Glen Brier, Research Scientist
Doug Castle, Research Associate
Paul Ciesielski, Research Associate
Paul DeMott, Research Associate
Nolan Doesken, Research Associate
Bei-Fen Fan, Visiting Research Associate
Rudy Garcia, Research Coordinator
Marion Haurwitz, Research Associate
Paul Hein, Research Associate
Ed Hindman, Research Associate
Chris Johnson-Pasqua, Research Associate
John Kleist, Research Coordinator
Marjorie Klitch, Research Associate
Bruce Macdonald, Research Associate
Jennifer Martin, Research Coordinator
Ray McAnelly, Research Associate
Richard Pearson, Research Scientist
Jennifer Martin, Research Coordinator
Ray McAnnelly, Research Associate
Richard Pearson, Research Scientist
Dave Rogers, Research Associate
Mordecay Segal, Research Scientist
John Sheaffer, Research Associate
Jenn-Luen Song, Research Associate
William Thorson, Research Coordinator
Craig Tremback, Research Associate
Si Chee Tsay, Research Associate
Robert Walko, Research Associate
Yungyu Xi, Visiting Scientist
Jiadong Ye, Visiting Research Associate
Zhoujia Ye, Visiting Research Associate

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Sally McLeland, Staff Assistant I
Walt Naylor, Department Manager
Jennifer Pollard, Word Processor Operator A
Brenda Thompson, Senior Secretary
Melissa Tucker, Senior Secretary
Juanita Veen, Staff Assistant I
Charles Wilkins, Instrument/Maker Fabricator II

RESEARCH

WILLIAM R. COTTON

NUMERICAL SIMULATION AND OBSERVATIONAL ANALYSIS OF MID-LATITUDE CONTINENTAL CUMULONIMBI AND MESOSCALE CONVECTIVE SYSTEMS

(1) Both individual case studies and composite analysis of the precipitation life cycle of MCC's reveal a well-behaved rainfall pattern that is normally distributed in time with its peak coincident with the maximum areal extent and intensity of the system. A parallel composite analysis of the MCC lifecycle of dynamic and thermodynamic properties has also been completed which reveals that MCC's evolve into inertially stable convective systems exhibiting a cyclone in the middle troposphere and anticyclone in the upper troposphere. It has been also found that approximately 30% of all MCC's produce severe linear winds sometime during their life cycle.

(2) Analysis of squall lines observed during the 1981 CCOPE revealed its low-level inflow of high theta_e air advected some distance over the downdraft outflow from an earlier supercell storm. Detailed multiple Doppler analysis revealed a complex flow structure and organization to the storm system including a mid-level jet that responded to the development of severe surface outflow. Also, the leading edge of convective elements was found to be very transient with older cells falling behind the squall front and periodically being replaced by new convective cells.

(3) A two-dimensional model extending from the Utah border to central Kansas has been designed to study the interaction among mountain slope flows, mountain waves, and deep convective systems on the propagation of mesoscale convective systems eastward from the Rocky Mountains onto the High Plains. A system with MCC-like features was simulated which exhibits a cyclone at low levels and anticyclone aloft, and maximum heating and vertical motion in the upper troposphere. The two-dimensionality of the Rocky Mountain barrier appears to be instrumental in establishing a regional-scale circulation that is favorable for the genesis of MCC's.

(4) The predictability of MCC's is being addressed with a nested grid version of the CSU Regional Atmospheric Modelling System (RAMS). It is found that it is possible to crudely simulate the genesis and lifecycle of individual MCC events. The model, however, is extremely sensitive to details in the initial, objectively analyzed, large-scale fields, soil moisture mappings, explicitly-resolved ice-phase physics, and the details of convective parameterization schemes. The extreme sensitivity of the model to these factors severely limits the overall predictability of MCC's in a general sense.

W.R. Cotton National Science Foundation

CENTER FOR GEOSCIENCES

Subtask - LES AND MESOSCALE MODEL SIMULATION

The fundamental approach in this research involves the development and application of a two-way nested grid version of RAMS to the simulation of plume transport and dispersion in a variety of terrain configurations, and to quantitative precipitation forecasting (QPF) in a variety of weather systems and terrain configurations. Specific tasks for each of these major research objectives are as follows:

Large Eddy Simulations

Specific research tasks consist of:

1. Continued merger of the modules in Pielke's groups hydrostatic mesoscale model with the modules in Cotton's groups non-hydrostatic cloud model into the RAMS modeling system.

2. Implementation of the two-way nested grid system including a moveable fine-mesh option into the RAMS system.

3. Development of a four-tiered interactive model grid with the finest mesh being a LES grid. The following is one possible configuration of the grids: Grid 1, horizontal domain = 135 km, Dx = 2.7 km; Grid 2, domain 45 km, Dx = 0.9 km; Grid 3, domain = 15 km, Dx = 0.3 km, Grid 4 (the LES grid), domain = 5km, Dx = a 0.1km.

4. Application of the above described nested model to a set of cases with inhomogeneous land use patterns and to hilly and complex terrain.

Quantitative Precipitation Forecasting

This component of the research involves the following activities:

1. Building on 1) and 2) above, a nested grid version of the moist, precipitating model is being implemented. Grid 1 will be hydrostatic with an approximate domain of 3000-3500 km with Dx = 80 km. It will be one-way nested with Grid 2, an approximately 1000 km domain model with Dx = 25 km, also hydrostatic. Grid 2 will one-way nest with Grid 3-a nonhydrostatic model-with a 405 km domain and Dx = 9 km.

   Grid 3 will interactively nest, in turn, with Grid 4 a 150 km domain, nonhydrostatic model with Dx = 3 km; which will interact

with Grid 5 a 50 km domain model with Dx = 1 km. The exact scales of each sub-model is not precise; the values given here are for illustrative purposes only.

Also, one-way nesting is currently planned between the hydrostatatic and non-hydrostatic models, although attempts to implement two-way nesting between these two physically different systems will be investigated.

2. Application of the nested grid model to convectively unstable situations will require the development of new formulations of convective parameterizations and sub-grid-scale closures. Some of this work will be supported by other funding, but the range of scale considered here will likely require additional development.

3. The nested grid model will then be preliminarily exercised in a variety of weather conditions including convectively unstable systems, coastal cyclonic storms, cyclonic storms over complex terrain, and stable orographic precipitation. These experiments will be of the nature of sensitivity studies to determine the importance of various physical models and parameterizations to quantitative precipitation forecasting.

4. Based on the results obtained in 3) it is anticipated that new developments in physical modules and parameterizations will be required, thus work in the most critical areas will be commenced.

5. Interface with the Information Extraction subproject in inserting model outputs into the project database.

CENTER FOR GEOSCIENCES

Subtask - LES, MESOSCALE MODEL SIMULATIONS-OBSERVATIONAL COMPARISONS

The major thrust of this sub-task is to quantitatively evaluate the LES and QPF mesoscale models by comparing model predictions with observations. The approach will be to select cases which can provide a definitive data base for evaluating the model's performance as well as provide sufficient data for unambiquous model initializations. The selected cases will include a variety of weather phenomena as well as terrain configurations. In some cases only raw data will be available, thus some amount of data analysis will be needed. The research tasks are as follows:

1. Obtain and analyze data for the testing of the LES model. The first step will be to evaluate cases appropriate for model evaluation obtained in the ASL WINDS experiment as well as the Colorado PHOENIX Experiment.

2. Select, obtain, and analyze data needed to evaluate RAMS during convectively unstable situations. Over flat terrain data will be sought from the 1985 Pre-STORM data set, the 1986 COMEX, the 1981 CCOPE, and the 1987 CINDE planned east of Boulder, Co. Additional cases of severe flash flooding will be sought for the Alleghenies and the Texas Embankment region along with events over southwestern China.

3. Select, obtain and analyze cases of non-convective precipitation events such as the CSU COSE, the Bureau of Reclamations SCPP (Sierra Cooperative Pilot Project) over the Sierra Nevada and upslope events along the Colorado Front Range.

4. Perform simulations of the selected cases and compare model predictions with observed data.

W.R. Cotton DOD Army Research Office

NUMERICAL MODELING OF MIDDLE AND HIGH LEVEL CLOUDS WITH THE COLORADO STATE UNIVERSITY REGIONAL ATMOSPHERIC MODELING SYSTEM - RAMS

This contract emphasizes the development and application of the CSU Regional Atmospheric Modeling System (RAMS) mesoscale model to the following:

a. Study the microphysical parameters governing visible and sub-visible ice clouds (cirrus) in various meteorological conditions. Different ice cloud systems to be considered are convectively-generated anvil parts of Mesoscale Convective Systems (MCSs), jet-stream type cirrus clouds, and pre-frontal and band-type ice clouds.

   We propose to use data from the Pre-STORM experiment for MCS studies and FIRE data for sub-visible and visible frontal-type clouds.

   This task will emphasize the development of a cirrus cloud microphysical parameterization for use in 2D and 3D mesoscale cloud models.

b. Study of the radiative properties of ice crystals. Anomalous Diffraction Theory (ADT) is applied to the study of the single-scattering properties of complex-shape ice crystals. The sum of log-normal or gamma distributions is used to obtain and investigate bulk extinction, absorption, and scattering coefficients for ice clouds. Sensitivity of these bulk properties to small ice crystal concentrations is being studied. Comparison of equal sphere volume and equal sphere surface, to ADT approximations will be performed.

   This task should result in the development of a bulk parameterization scheme for the RAMS radiative code.

c. Extend the RAMS multiple scattering code to the ice phase by defining a new set of parameterization equations for reflectance and absorptance. We also propose to investigate the suitability of matrix-exponential techniques for use as a fast Radiative Transfer Equation (RTE) solver in mesoscale models.

d. Study the physical mechanisms leading to the formation, structure, persistence and dissipation of high-level clouds. The physics will include microphysics, radiation and turbulence. The sensitivity studies involving different environmental conditions will be performed within 1D and 2D frameworks of the RAMS modelling system. This should also result in defining environmental conditions suitable for the development and dissipation of high-level clouds.

e. Simulate case studies of upper level clouds using the 3D RAMS model. Analysis of model output will include microphysics-

radiation interaction, its impact on large scale environmental structure, cloud cover and other meteorological characteristics, and statistics for small ice crystals and their occurrence within the cloud system. A large-eddy simulation (LES) will be used in which the LES model is nested in a mesoscale model domain.

W.R. Cotton

Air Force Office of
Scientific Research

ANALYSIS OF MESOSCALE CONVECTIVE SYSTEMS OBSERVED DURING PRE-STORM

This project supports two Ph.D. students to be involved in the analysis of two case study days observed during PRE-STORM: 3-4 June 1985 and 16-17 June 1985.

W.R. Cotton

National Oceanic and
Atmospheric Administration

STEPHEN K. COX

OBSERVATIONS OF UPPER AND MIDDLE TROPOSPHERIC CLOUDS

Instrumentation for measurements of cirrus (ice) clouds found between 30,000 and 45,000 feet altitude are being developed. These ice clouds play a very important role through their radiative properties in determining the climate at the earth's surface. Depending upon the ice clouds' radiative properties, they can either warm or cool the earth's surface. Recognition of the importance of these clouds has led to the design of a field experiment during the fall of 1986. This experiment will consist of satellite, aircraft, lidar, and remote sensing measurements of cirrus clouds by government laboratory and university scientists. The experiment will be located in central Wisconsin and last from approximately 10 October to 2 November 1986.

S.K. Cox

National Science Foundation
National Aeronautics and Space Administration

CIRRUS CLOUD MODEL

In addition to understanding the radiative properties of ice clouds, we must gain an understanding of why and when these clouds appear in the upper atmosphere. We have developed a two-dimensional numerical model which simulates the most important processes involved in the formation, maintenance and dissipation of cirrus clouds. This model is the most complete cirrus cloud model reported in the scientific literature to date. Using this model we have been able to ascertain the conditions under which cirrus clouds will form and persist. This model will serve as the framework around which the cirrus observational programs planned for the 1990's will be conducted.

S. K. Cox

National Science Foundation

THEORETICAL AND OBSERVATIONAL MARINE BOUNDARY LAYER STUDIES

A tethered balloon instrument package will be designed, fabricated and deployed in a marine boundary layer environment for marine boundary layer studies.

The instrument package will be designed for the NASA Wallops Flight facility tethered balloon or (in a reduced configuration) on the NRL balloon. The instrumentation may include measurements of meteorological dynamic and thermodynamic variables, radiation, cloud microphysics and photography. Data acquisition will be accomplished byan onboard microprocessor based computer system. This system will be very similar to an aircraft package previously designed by the principal investigators. The instrument package will be deployed at San Nicolas Island from 29 June to 20 July 1987 in support of the FIRE Marine Boundary Layer Experiment. Data from the FIRE Experiment will be analyzed to determine the thermodynamic and the moisture structures of the Marine Boundary Layer.

S. K. Cox — Office of Naval Research

VISIBLE AND INFRARED SPECTRAL RADIANCES/SURFACE ENERGY BUDGET

The surface energy budget drives the boundary layer during the diurnal cycle. This research is to investigate the sensible heat and radiation components of the surface energy budget locally and areally integrated over mesoscale regions. The research is a combination of analysis and observation. An important aspect is the development of new methods to estimate areal values for energy budget components.

T. B. McKee
S. K. Cox

U.S. Army Center for Geosciences

LABORATORY AND NUMERICAL MODEL STUDIES OF ICE FORMATION IN CLOUDS

This research is studying the formation of ice crystals by silver-iodide aerosols in supercooled clouds. The approach includes laboratory experiments, performed primarily in the CSU dynamic cloud chamber, and simulations with a detailed cloud microphysics computer model. The laboratory experiments measure the contributions to ice nucleating activity from four separate mechanisms and provides a description of expected activity as a function of the variables: temperature, water vapor concentration, aerosol and cloud droplet size and concentration, aerosol chemistry, time and environmental path preceding nucleation. The cloud model follows the same thermodynamic path as the cloud chamber experiments, and the model predictions of ice formation are compared for both the current descriptions of nucleation and for the new ones from this research. These results can be incorporated into cloud models,they will provide guidance for weather modification programs, and they will be useful in planning future field studies to assess the transferability of simulation results to real atmospheric situations.

D. C. Rogers
P. J. DeMott
L. O. Grant

EXPERIMENTS FOR BIO-PRODUCTS DIVISION OF EASTMAN KODAK COMPANY

Exploratory quantitative experiments on the ice nucleating function and activity of aerosols of the bacterial agent SNOMAX were conducted. The experiments utilized the CSU isothermal and dynamic cloud chambers. This permitted an analysis of nucleation by SNOMAX aerosols in both static supercooled cloud conditions and in cloud parcel conditions with active cloud growth and supersaturations present. Unique new results on bacterial ice nucleation were obtained that will allow Kodak to evaluate the utility of SNOMAX for various applications. Results are proprietary at this time.

L. O. Grant
P. J. DeMott

Eastman Kodak Company

WILLIAM M. GRAY

CLIMATOLOGICAL FACTORS INFLUENCING SEASONAL AND MULTI-WEEK VARIATIONS IN TROPICAL FREQUENCY

1) Analysis of 24-30 year period of alternating high and low Atlantic Hurricane Destruction Potential (HDP) for the period of 1886 to the present.

2) Analysis of physical reasons for the strong association of the phases of the east vs. west QBO stratospheric winds and Atlantic seasonal hurricane activity.

3) Statistical analysis of global and regional parameters associated with seasonal and monthly hurricane variability. An extensive statistical analysis of the author's Atlantic seasonal hurricane prediction scheme has been accomplished.

W. M. Gray
C. Collimore

National Science Foundation

ANALYSIS AND CLASSIFICATION OF DIFFERENT TYPES OF TROPICAL CYCLONE INNER REGIONAL CIRCULATIONS FOR BOGUSING

Recent tropical cyclone research results are being obtained which may be useful as background information to forecasters. Findings and speculations are: (1) various climatological characteristics of tropical cyclones; (2) tropical cyclone formation processes, (3) tropical cyclone structure and structure change, (4) tropical cyclone intensity change, and (5) tropical cyclone outer radius wind strength variations.

W. M. Gray
R. Zehr
J. Martin
C. Collimore

Naval Environmental Prediction Research Facility

OBSERVATIONAL ANALYSIS OF PROCESSES INFLUENCING TROPICAL CYCLONE MOTION IN THE NORTHWEST PACIFIC

We will examine the following tropical cyclone (TC) motion questions:

1) TC recurvature as measured by composite rawinsonde data;

2) TC recurvature as measured by the Guam AF reconnaissance data;

3) Systematic cyclone motion deviations from steering flow as may be due to:

   a) Beta-influence,
   b) differences in cyclone strength (or 1-2 degree radius mean tangential wind),
   c) difference in cyclone intensity,
   d) differences in eye wall convection as measured by radar from aircraft penetration, and
   e) differences in cyclone speed and direction of motion;

4) Right versus left quadrant wind asymmetry beyond that specified by tropical cyclone motion;

5) How tropical cyclones are steered in an environment current with vertical and horizontal wind shear; and

6) Factors responsible for tropical cyclone oscillating and looping motion.

W. M. Gray
C. Weatherford
S. Hodanish
D. Shoemaker
J. Kossin

Office of Naval Research

OBSERVATIONAL STUDIES IN SUPPORT OF TROPICAL CYCLONE AND FGGE RESEARCH ACTIVITIES

This program is studying tropical cyclones in all its phases of climatological setting, genesis, structure, intensity change, motion, and influence on the general circulation. To properly understand these storm topic areas, we need to employ a large number of the meteorological observations collected through the recent special tropical experiments of GATE, FGGE, and MONEX, together with many years of conventional rawinsonde data sources.

This past year, activity has included utilization of FGGE data as supplied on magnetic tape and in map form from the ECMWF Center in Reading, England. Rawinsonde composite analysis was also utilized in the three ocean basins of the Northwest Atlantic, Northwest Pacific, and the South Pacific - Australian region.

Research has been conducted on the association of Atlantic seasonal hurricane frequently as related to the El Nino, Stratospheric QBO, and springtime Carribbean Basin sea-level pressure. Surprisingly good associations have been found. A scheme to forecast seasonal hurricane activity at the beginnings of the hurricane season has been devised.

Development of a 20-25 year Australian/South Pacific region rawinsonde data set has continued for tropical cyclone and other tropical meteorology studies. Also, development continues of our western North Pacific rawinsonde data set from 10 (1961-1970) to 21 (1957-1977) years with the inclusion of Mainland China data and also 3 Taiwan upper-air stations for 15-20 years.

The European Center (ECMWF) FGGE year data set available on magnetic tape at NCAR was obtained and reduced. We are now beginning to make individual case analyses of all 60-70 tropical cyclones occurring during the FGGE year.

W. M. Gray
R. Zehr
J. Martin
D. Shoemaker
J. Kossin

National Science Foundation

DEVELOPMENT AND SCIENTIFIC ANALYSIS OF TROPICAL CYCLONE AIRCRAFT RECONNAISSANCE DATA SETS

All military reconnaissance aircraft flights into and out of typhoons during the last seven years are being processed and analyzed for new research insights into the behavior of these storm systems. Data sets on tropical cyclones are being developed and used for this purpose.

These new tropical cyclone data sets are allowing us much more extensive insights into the behavior characteristics of tropical cyclones than has previously been possible. We are documenting the large structural differences in tropical cyclones and how minimum central pressure and maximum sustained wind speeds are often quite misleading parameters in specifying a cyclone's net angular momentum, kinetic energy, moisture budget, and general damage potential.

W. M. Gray
J. Martin
S. Hodanish
D. Shoemaker
J. Kossin

National Science Foundation

OBSERVATIONAL STUDIES OF TROPICAL CYCLONES

Studies will be performed upon the following six research topics.

1) TC Formation vs. Non-Formation - Continued examination of the differences in conditions associated with tropical disturbances which develop into name TC's vs. those prominent tropical disturbances which do not develop.

2) TC Structure - Further research to try to explain the large variability in tropical cyclone structure which occur. This includes structure differences in tropical cyclones resulting from differences in cyclone latitude, season, life cycle, motion, eye characteristics, deep convection, net cloudiness, etc. We will also analyze the role of the lower-stratosphere on the structure of tropical cyclones.

3) TC Intensity Change - The different physical processes which cause changes in inner-core maximum wind and minimum sea-level pressure change are extremely complex and need as much observational documentation and physical synthesis.

4) TC Motion - Inner-core and outer radius factors related to TC motion and its changes. How closely do steering flow and its changes relate to cyclone center motion and its change? Are there systematic differences with intensity, outer-region wind strength, etc? Are there any reliable relationships between TC motion and deep convection.

5) Influences of Aircraft Reconnaissance on TC observations and Forecasting. A general investigation of this very important and current topic (resulting from 1987 decisions of the AWS) will be made.

W. M. Gray
J. Kossin
J. Martin
S. Hodanish
R. Zehr
D. Shoemaker
C. Collimore

National Science Foundation

RICHARD H. JOHNSON

MESOSCALE CONVECTION AND THE ATMOSPHERIC BOUNDARY LAYER

This research is directed toward an improved understanding of mesoscale convection, that is moist convective weather phenomena having horizontal dimensions on the order of 100 km. that is observed in both the tropical atmosphere and at midlatitudes. Processes which initiate, maintain and modulate mesoscale convection, as well as effects of convection on the boundary layer of the atmosphere and treatment of their effects in large-scale numerical weather prediction models, will be investigated. Both analysis of observations and mathematical/physical models will be employed in this research effort. Additionally, characteristics of the atmospheric boundary layer in the region of the summer monsoon of Southeast Asia will be studied.

The primary observational sources for this research project are: (1) the Taiwan Area Mesoscale Experiment (TAMEX; May-June 1985) and (2) PRE-STORM (Oklahoma-Kansas Preliminary Regional Experiment for STORM-Central).

R. H. Johnson National Science Foundation

THOMAS B. MCKEE

DIURNAL EVOLUTION OF WIND AND THERMAL STRUCTURE IN COMPLEX TERRAIN

The observed diurnal variation of winds from up-slope and up-valley in the day to down-slope and down-valley in the night in complex terrain have been of great interest for a long time. An understanding of the details of mountain winds and thermal structure and their interaction with the larger scale atmosphere has not been easy to achieve. Currently available observing systems and numerical model capability have allowed significant advances in complex terrain problems. The proposed project will use analysis of existing data, additional observations and models to increase our understanding of wind and thermal structure in mountain valleys which will be tested with existing data and new observations. A new approach to estimate the soundings, and satellite observations. The interaction of the valley atmosphere with regional and synoptic scales through an intermediate layer will be pursued to understand the means by which the atmosphere couples and decouples in the vertical.

Thomas B. McKee — National Science Foundation

CLIMATE DATA INFORMATION SERVICE FOR COLORADO

This is a diverse project involved in all aspects of Colorado climate. This broad research activity uses extensive available current and historic climatic data resources to study the complex local and regional climate system and its effects on agriculture, water resources, energy, and the natural and human-effected environment. Central to the project is a consistent, on-going program of acquisition, archival, utilization, and dissemination of climate information collected in Colorado. Current climatic conditions are monitored each month and compiled in detailed, widely-disseminated summary reports used to keep officials, researchers and educators throughout the state informed. Climatic data, data summaries, research results, and basic climate expertise are made widely available through publications, direct computer access, news media and personal contact.

T. B. McKee
N. J. Doesken
CSU Agricultural Experiment Station

METEOROLOGICAL OBSERVATIONS

The main campus weather station has been operated continuously since 1887. Measurements of temperature, precipitation, snowfall, humidity, pressure, wind, cloud cover, solar radiation, visibility, soil temperature and evaporation are taken daily in an effort to thoroughly monitor and document the climate of this area. Data is archived, summarized and disseminated to widely diverse users both on and off campus and are used by literally dozens of separate research projects. Observations are also taken every two hours around the clock in support of aviation operations and National Weather Service forecasting and warning activities. Data collected at the weather station are publicly accessible through a phone answering system, computer data files and climate publications.

T. B. McKee
N. J. Doesken

CSU Agricultural Experiment Station

BOUNDARY LAYER, SURFACE RADIATION AND ENERGY BUDGETS

The surface energy budget drives the boundary layer during the diurnal cycle. This research is to investigate the sensible heat and radiation components of the surface energy budget locally and areally integrated over mesoscale regions. The research is a combination of analysis and observation. An important aspect is the development of new methods to estimate areal values for energy budget components.

T. B. McKee
S. K. Cox

U.S. Army Center for Geosciences

CLIMATE AND STREAMFLOW VARIABILITY IN THE WESTERN UNITED STATES

Surface water supplies in the Rocky Mountain west are a precious commodity continuously affecting and limiting economic growth and development in the region. Management of this natural resource is made difficult by its large and unpredictable year-to-year variability which has been particularly extreme during the past ten years. This research is intended to increase our understanding of regional variations and their relationship to larger scale atmospheric phenomena. Available precipitation, temperature, snowpack, and streamflow data in selected river basins from Montana to New Mexico will be used in this study. The relative variability to each component will be analyzed and correlated and related to aspects of the large scale atmospheric circulation.

T. B. McKee
N. J. Doesken

U.S. Geological Survey

ROGER A. PIELKE

INFLUENCE OF TERRAIN FORCED-MESOSCALE SYSTEMS IN LONG-RANGE TRANSPORT OF AIRBORNE GASES

There are two major facets of our investigation of the role of terrain-forced mesoscale circulations on long-range transport in the northeast United States. These are:

(a) to estimate the frequency of occurrence of the different types of terrain-forced mesoscale systems within subregions of the northeast quarter of the United States, and

(b) to perform finer resolution mesoscale numerical model calculations for specific subregions using selected simulation results from the NCAR/Penn State model.

The synoptic classification of daily surface weather patterns has been completed on a 5 x 7 grid of eastern North America for the five-year period 1975-79. We are now using this data set to prepare a mesoscale climatology for this region.

We have used a coupled mesoscale meteorological model and a Lagrangian particle model to study several aspects of mesoscale pollutant dispersion, including the interaction of mountain-valley winds with pollutant being transported across a mountain range, the interaction of lake and land breezes with pollutant being transported across a large lake, and the influence of diurnal and inertial atmospheric cycles on mesoscale plume dispersion. We are presently implementing time-dependent lateral boundary conditions in the mesoscale meteorological model to permit one-way nesting of this model with the NCAR/Penn State model.

R. A. Pielke
M. Segal

Electric Power Research
Institute, Inc.

MESOSCALE MODELING

Studies of mesoscale meteorology and its relation to air quality are being applied to National Park Service managed lands. A combined mesoscale meteorological model and Lagrangian pollutant dispersion model are used to evaluate case study days from the WHITEX 1987 and the 1985 Grand Canyon Field Experiment. This will aid in the evaluation of model performance and will also enable the assessment of the contribution of local sources relative to long-range transport for the winter stagnation episodes during WHITEX. The models are also being used (along with climatological data) to help determine the level of model complexity needed for source attributions in the western United States. Model enhancements are also under development. Those include the coupling of the Lagrangian particle model with a chemical kinetics mechanism, and development of more efficient methods of assessing pollutant concentrations.

R. A. Pielke
M. Segal
R. W. Arritt

National Oceanic and
Atmospheric Administration
National Park Service

A QUANTITATIVE STUDY OF FLORIDA DEEP CONVECTION IN SEA BREEZE ENERGETICS

Mesoscale modeling studies of the sea breeze-deep convection interactions over the Florida Peninsula. The last report (August, 1986) described the derivation of a cumulus parameterization and its application to the study of the Florida mesoscale-convection interactions (see detailed discussions in Song and Pielke, 1987a and b). To evaluate cumulus parameterization, we have developed a systematic methodology utilizing a state-of-the-art numerical tool (as described in Song, Cotton, and Pielke, 1987) for the summertime Florida environment. Two-dimensional preliminary results of the Mesoscale Cumulus Eddy Simulation (MCES) are briefly described.

R. A. Pielke
M. Segal
J.-L. Song

National Aeronautics and Space
Administration
No. NAG5-359

EVALUATION OF SURFACE THERMAL AND MOISTURE CHARACTERISTICS, AND TERRAIN CONFIGURATION ON THE INITIATION AND DEVELOPMENT OF CONVECTIVE CLOUDS

We propose a continuation and extension of our previous numerical modeling research on terrain-forced mesoscale circulations in which the interaction of these circulations with moist processes will be considered. Particular emphasis will be placed on the role of these circulations on the initiation and growth of convective storms. The completion of the ongoing merger of our numerical model with that developed by W. R. Cotton and colleagues into a new modeling system referred to as the Regional Atmospheric Modeling System (RAMS) provides a refined tool for achieving the objectives of this project. The RAMS system will include the boundary layer and surface parameterizations developed by our group (e.g., parameterizations of soil physics and vegetative cover) with the representations of moist processes developed by the Cotton group. The fully integrated system will be available by the beginning of the proposed research.

Case studies will focus on the Colorado Front Range area and the Great Plains, due both to the high density of observational data in this region and the extensive past research studies in this area. We plan to utilize, among other sources, data from the Convective Initiation and Downdraft Experiment (CINDE) to be conducted in northeast Colorado in 1987, along with additional data available for this area. These data will be used for model verification and to describe and interpret the observed atmospheric behavior using numerical simulations.

R. A. Pielke
M. Segal
R. W. Arritt
R. Avissar

National Science Foundation

LES AND MESOSCALE MODEL SIMULATIONS

LES AND MESOSCALE OBSERVATIONAL COMPARISONS

The fundamental approach in this research involves the development and application of a two-way nested grid version of RAMS to the simulation of plume transport and dispersion in a variety of terrain configurations, and to quantitative precipitation forecasting (QPF) in a variety of weather systems and terrain configurations. Specific tasks for each of these major research objectives are as follows:

(a) Large Eddy Simulations

1. Merger of Pielke's hydrostatic mesoscale model with Cotton's non-hydrostatic cloud model.

2. Implement a two-way nested grid system into the RAMS System.

3. Develop a four-tiered interactive model grid with the finest mesh being a LES grid.

4. Apply the above described model to a set of cases with inhomogeneous land use patterns and to hilly and complex terrain.

(b) Quantitative Precipitation Forecasting

1. Implement a nested grid version of the moist precipitating model.

2. Develop new formulations of convective parameterizations and sub-grid-scale closures.

3. Test the nested grid model under a variety of weather conditions.

R. A. Pielke
W. R. Cotton

Army Research Office

WIND TUNNEL AND NUMERICAL MODELING OF COASTAL MARINE FLOWS

Objectives of the research are specifically:

1. Improve mesoscale numerical models to routinely incorporate medium range weather forecast results.

2. Improve numerical prediction of coastal zone winds by:

   (a) Parameterizing subgrid-scale forcing of heterogeneous surfaces, and

   (b) Nonlinear normal mode initialization procedures.

3. Verify numerical code against detailed wind-tunnel data taken over models of idealized coastal shorelines, shore line topography, and land aspects.

Office of Naval Research

R. A. Pielke
R. N. Meroney

STEVEN A. RUTLEDGE

STUDIES OF MIDDLE LATITUDE MESOSCALE CONVECTIVE SYSTEMS

This research is focussed on the analysis of the PRE-STORM data set, and is directed towards acquiring a better understanding of Mesoscale Convective Systems (MCSs), including their behavior with time, kinematic properties, structure, and precipitation mechanisms. Emphasis is placed on the stratiform regions associated with these storms. Analysis of both single- and dual-Doppler radar data, conventional radar and satellite data, and airborne mecrophysical data are currently being carried out. Additionally, two- and three-dimensional kinematic modeling studies serve as a vehicle for furthering our understanding of physical processes within MCSs.

The specific objectives include:

a. 10-11 June case study completion

Analysis of single and dual-Doppler data, along with airborne microphysical data are being conducted in this well-documented squall line case. Deposition and aggregation are the dominant precipitation mechanisms in the extensive anvil cloud.

b. Vortex storms case studies

Examples of well-defined mesoscale vortices within the stratiform region of several MCSs were particularly well-captured by the dual-Doppler network in PRE-STORM. Vortices in the 28 May and 4 June MCSs extended from mid-tropospheric levels to very near the surface. Both of these storms formed in weak synoptic situations which likely played a key role in allowing for the establishment of such vortices.

c. Mesoscale updraft-downdraft synthesis

The single-Doppler data collected in PRE-STORM provide a unique opportunity to document the depth, magnitude, and behavior of the mesoscale vertical motions using the VAD (Velocity-Azimuth-Display) technique. Approximately 14 volumes of single-Doppler data have been analyzed using the VAD technique, yielding vertical profiles of mesoscale motion in the 10-11 June, 28 May, and 4 June storms. Considerable variability in the mesoscale vertical motion exists between these cases, and even among profiles within a given storm acquired in different portions of the stratiform region relative to the convective region. Furthermore, relationships between mesoscale downdraft intensities and depth appear to be closely linked to the depth, location, and intensity of the rear inflow jet.

d. Thermodynamic retrievals

Retrieval of thermodynamic fields based on Doppler-derived air motion patterns has received considerable attention in the past several

years. A weakness of this method has been the lack of knowledge of diabatic processes associated with cloud microphysical processes. Often these contributions are only crudely parameterized. It is established that heating through deposition above the 0°C level, and cooling via melting and evaporation below this level, are important mechanisms for driving the mesoscale circulation in the stratiform region of MCSs. Furthermore, knowledge of the pressure fields over time will likely lead to insights into the dynamical processes important in generating the observed mesoscale air motion pattern, such as the rear inflow jet. Work is in progress to merge our microphysical retrieval model with a thermodynamic retrieval model at NOAA.

S.A. Rutledge National Science Foundation

A STUDY OF CLOUD-TO-GROUND LIGHTNING ACTIVITY IN MESOSCALE CONVECTIVE SYSTEMS

The objectives of this research are:

Objective A: Determine relationships between the frequency and polarity of cloud-to-ground lightning and cloud parameters as inferred from GOES satellite data collected in PRE-STORM (Preliminary Regional Experiment for Stormscale Operational and Research Meteorology).

Objective B: Determine relationships between positive and negative cloud-to-ground lightning and the structure and evolution of Mesoscale Convective Systems.

Objective C: Determine the mechanisms responsible for the production of positive cloud-to-ground lightning in stratiform precipitation associated with Mesoscale Convective Systems.

Objective D: Develop and apply diagnostic models to study the electrification of stratiform anvil clouds associated with Mesoscale Convective Systems.

The analysis of seven PRE-STORM cases has been completed. Approximately 90% of all positive flashes in these storms were situated in the stratiform precipitation regions. Furthermore, their frequency of occurrence was highest in the mature stages of all storms studied, despite broad variances in observed storm radar echo structure.

Recently, we have developed a 1-D charging model to study the electrification of stratiform anvils. We consider the charging process to occur when small ice crystals, which are observed in large concentrations in the anvil clouds, undergo collisions with larger ice particles (snow and graupel). Necessary to the charging process is the presence of liquid water in the anvil, which has yet to be directly measured by very limited in-situ airborne observations. Only small amounts of cloud water are required, typically 0.1 g m^{-3}. Studies

with the 1-D model indicate that large charge densities (1-3 C km^{-3}) are possible in the anvil the in-situ charging. Interestingly, the model predicts the presence of an inverted electrical dipole in the anvil cloud, with positive charge (centered near -5 °C) underlying negative charge (centered near -15 °C). The existence of an inverted electrical dipole is likely central to the positive cloud-to-ground lightning flash in this type of storm, and may very well explain the occurrence of positive flashes in winter cyclonic storms. However, we have yet to establish the presence of an inverted dipole from field measurements.

Field work is planned to obtain measurements of the charge density in stratiform clouds associated with MCSs. These data will be used in conjunction with 2-D models currently under development to further study in-situ charging in the anvil. The model will also be used to address the advection of electrical charge into the anvil cloud from the convective region.

Steven A. Rutledge National Science Foundation

STUDIES OF DYNAMICS AND ELECTRIFICATION OF DEEP CONVECTION AND MESOSCALE CLOUD CLUSTERS NEAR DARWIN, AUSTRALIA

Field studies of tropical convection are being conducted in the near vicinity of Darwin to study the structure, dynamics, and electrical properties of tropical cloud clusters associated with continental and monsoon (oceanic) convection. Data are being acquired from a dual-Doppler network jointly operated by Colorado State University, the Massachusetts Institute of Technology, NASA, and various agencies within Australia. In addition to the radar observations, measurements of in-cloud and cloud-to-ground lightning are being obtained with a special surface network.

The scientific objectives of this research include investigations of the scaling behavior of lightning frequency and latent heat release in deep convection (for examlple, are deep tropical clouds more highly electrified than shallower mid-latitude storms), the anomalous ratio of in-cloud to cloud-to-ground lightning in tropical storms, and the differences in convective development, mesoscale structure and electrification between oceanic and continental convection, and comparison to similarly structured stoms in middle latitudes.

Preliminary results indicate that tropical storms are largely dominated by in-cloud lightning but they are hardly devoid of cloud-to-ground flashes. From the past field season it has become evident that tropical deep convective cells are quite capable of producing strong microbursts, which are often preceded by peak cell lightning activity. Lightning rates are normally higher in continental tropical convection compared to the convection that forms in monsoonal conditions. These differences appear to be related to small but systematic differences in the convective available potential energy.

Steven A. Rutledge National Science Foundation

NUMERICAL MODELING OF CLOUD AND PRECIPITATION CHEMISTRY IN FRONTAL RAINBANDS

This project addresses the topic of acid deposition associated with mesoscale rainbands in extratropical winter storms. The processes whereby pollutants such as sulfur dioxide, sulfate, and nitrate are removed from the atmosphere are studied using two- and three-dimensional cloud-chemistry models. Particular emphasis is placed on identifying the cloud physics mechanisms that are responsible for scavenging the gases and particles in various types of mesoscale rainbands. Studies of mesoscale rainbands containing little cloud water reveal that scavenging efficiencies are rather low, and occur by impaction scavenging above and below cloud base. Scavenging efficiencies are not correlated with precipitation efficiencies in these cases. Nucleation scavenging followed by in-solution oxidation operate in rainbands where riming is the main precipitation process. Scavenging efficiencies are roughly proportional to precipitation efficiencies in these situations. The model outputs are compared to field measurements of rainband chemistry obtained in the GALE (Genesis of Atlantic Lows Experiment) project.

Steven A. Rutledge Electric Power Research Institute

DAVID A. RANDALL

PARTLY CLOUDY BOUNDARY LAYERS

This project is intended to contribute to the planning for the Atlantic Stratocumulus Transition Experiment (ASTEX) that will be conducted in spring or summer of 1992, in the eastern North Atlantic Ocean. The purpose of ASTEX is to identify the mechanisms responsible for the observed rapid transitions from marine stratocumulus clouds to shallow cumulus clouds. These transitions lead to a large reduction in the fractional cloudiness. During ASTEX, measurements will be made to determine the reason for these dramatic transitions in the cloud regime. This project is designed to identify which observational strategies will be most useful. The approach is to conduct theoretical and numerical studies of the transition, in order to determine the key physical processes in advance. These model results can be partially validated against data collected during FIRE (the First ISCCP Regional Experiment; ISCCP is the International Satellite Cloud Climatology Experiment). Results to date indicate that conditional sampling methods and/or canonical component analyses should be used to measure the fluxes, variances, and skewnesses of the vertical velocity and thermodynamic fluctuations associated with organized vertical motions.

David A. Randall Office of Naval Research

CLOUD/HYDROLOGIC STUDIES

The CSU general circulation model (GCM) is being used to perform an extensive and detailed analysis of the seasonally and diurnally varying cloud radiative forcing and its effects on the hydrologic cycle. The effects of land-surface vegetation on the hydrologic cycle are also being assessed. A three-year annual cycle simulation has been completed, and is being continued for at least two more years. A number of shorter experiments have also been conducted. Model results are being compared with observations, including data from ISCCP, ERBE, and Nimbus 7. Through the analysis of these results, we have discovered a truly dramatic and previously unknown impact of the cloud radiative forcing on the atmospheric general circulation land the hydrologic cycle. The effects of land-surface vegetation on the hydrologic cycle are also being simulated and analyzed. The diurnal variability of the hydrologic cycle is being analyzed in detail and a journal article will be prepared describing the results. In addition, we have participated in a GCM Intercomparison Project designed to reveal the key differences among 14 GCMs used for climate research at various institutions around the world.

David A. Randall National Aeronautics and Space Administration

FIRST ISCCP REGIONAL EXPERIMENT

This project is in support of the First ISCCP Regional Experiment (FIRE; ISCCP is the International Satellite Cloud Climatology Project). The emphasis of this project has been on modeling studies, particularly of boundary-layer clouds as simulated by a general circulation model (GCM). Simulations with the GCM have demonstrated the model's ability to simulated qualitatively the observed distribution of marine subtropical boundary-layer cloudiness. One problem, however, is that the current model is incapable of dealing with partly cloudy layers. We have developed a simple, physically based model that can determine the fractional cloudiness and deal with incompletely mixed layers. The model is suitable for use as a partial cloudiness parameterization for GCMs. It is currently being tested using the FIRE data collected in June-July 1987. It will then be incorporated into the GCM.

David A. Randall National Aeronautics and Space Administration

WAYNE H. SCHUBERT

DYNAMICS OF TROPICAL WEATHER SYSTEMS

This is a three year project to investigate the dynamics of tropical weather systems using both numerical modeling and analytical methods. The models are used as tools for studying the banded structure of tropical cyclones and the relative roles of convective heat and vorticity sources in cloud clusters.

W. H. Schubert — National Science Foundation

DEVELOPMENT AND APPLICATION OF MULTIGRID AND SPECTRAL METHODS IN NUMERICAL WEATHER PREDICTION

Over the past eight years multigrid methods and spectral methods have proven very useful in solving a variety of problems in physics and fluid dynamics. This project's goal is the further development and application of these methods to theproblem of numerical weather prediction.

W. H. Schubert — Office of Naval Research
G. Taylor

THEORETICAL AND OBSERVATIONAL MARINE STRATOCUMULUS STUDIES IN SUPPORT OF FIRE

A four-year research project to investigate marine stratocumulus convection is underway. This work is in support of the first ISCCP Regional Experiment (FIRE) and involves both numerical modeling and observations. The expertise of theinvestigators lies in the areas of dynamics, cloud physics, and radiation. The modeling work involves explicit simulations of boundary layer convective elements using spectral techniques (both Fourier-Chebyshev and normal mode). The observational work involves thermodynamic and cloud microphysical measurements from a tethered balloon on San Nicolas Island in June 1987 and 1989.

S. K. Cox — Office of Naval Research
W. H. Schubert
G. Stephens

WESTERN PACIFIC TROPICAL CYCLONE MOTION STUDIES

The production of a dynamical forecast of tropical cyclone motion involves four parts: observation, analysis, initialization, forecast. Observation involves measurements of the wind and mass fields of both the cyclone and the large scale surroundings. Since these may be irregular in space and time, they must be analyzed onto some kind of uniform grid. If these analyzed fields are inserted into a primitive equation model, large gravity wave oscillations may occur because of initial dynamical imbalances. Thus, an initialization step is required to make small adjustments in the initial mass and wind fields, so that the primitive equation forecast proceeds in a smooth fashion. The actual computer model forecasts then proceed for typically 24 to 72 hours. This procedure can be repeated in such a way that previously forecast values are used as first guesses in the analysis procedure; this helps fill in data-void regions.

The present project is investigating data assimilation and initialization procedures whose goal is to reduce track forecast errors. Particular emphasis is being placed on the study of the adjoint method.

W. H. Schubert Office of Naval Research

PETER C. SINCLAIR

DEVELOPMENT AND APPLICATIONS OF ADVANCED TRACER TECHNIQUES TO VALIDATE MODEL FLOWS FOR COMPLEX TERRAIN AND LONG RANGE TRANSPORT

This research is designed to provide a basis from which transport and diffusion models can be validated by the development and application of advanced tracer techniques. In order to improve our understanding of circulation systems which provide the short- and long-range transport-diffusion pathways in the atmosphere, we are developing a new class of biological tracer materials and detectors that have absolute detection limits of 1--100 molecules. The new tracer system utilizes the detection of female insect pheromone compounds (mono- or dienic fatty alcohols, aldehydes, or acetates) with instrumented male (roach) antenna receptors. Each male antenna carries a dense array of approximately 17,000 sensory hair lumens, each of which lead to a receptor dendrite or cell, which can detect <u>one molecule</u> of a particular pheromone compound (i.e., a detection sensitivity of 1 ppv 10^{23}). The electrical impulse from the insect antenna can be recorded <u>continuously</u> in <u>real-time</u>. ''Biological amplification'' of the antenna signal can be achieved by using antenna arrays and binary pheromone mixtures. In addition, pheromone tracer concentrations can be measured directly from calibrated laboratory electroantennograms. Entomologists have had considerable success in the laboratory in developing these detection techniques. The tracer system is now under laboratory development and we feel that its detection sensitivity of approximately 1 ppv 10^{23} which is 10^{5}--10^{6} greater than any known atmospheric tracer, is so significant that its development and testing will be of great importance to the field of atmospheric transport and diffusion. The research plan involves a strong interdisciplinary collaboration between scientists in the CSU Atmospheric Science and Entomology Departments.

In order to test the usefulness of the pheromone tracer system, a simple flow situation for a plain intersecting a sloping barrier (i.e., a Colorado Front Range location) would be employed to compare measured tracer material trajectories and concentrations with the Pielke (1983) numerical mesoscale model simulations. A previously developed cesium tracer system (Sinclair and Finnegan, 1981) will be used as a bench mark check on the plume transport and dispersion boundaries. Both winter and summer flow situations would be investigated with instrumented aircraft measurements of tracer location and concentration, winds (u, v, w), temperature, pressure and dew point. Inner-mountain, complex terrain tests would follow these initial tracer-model validation experiments.

P.C. Sinclair
L. Bjostad
S. Drake
G. Edelen
R. Hill

Army Research Office

THUNDERSTORM OUTFLOW BOUNDARIES AND THE GENESIS OF DEEP CONVECTIVE ACTIVITY

This research is designed to provide indepth understanding of the natural mechanisms that lead to the development of deep convective storms through the integration of rapid scan satellite data with research aircraft measurements. Previous research using the rapid scan imaging mode of the GOES system has shown that convective scale interaction is of primary importance in determining the evolution of deep convection. This interaction anifests itself as the merger and intersection of thunderstorm outflow boundaries (arc clouds) with other convective lines, areas and boundaries. A vivid, although tragic, example of this storm interaction phenomenon involved the Pan Am Flight 759 that crashed shortly after taking off from Moisant Field, New Orleans, Louisiana on 9 July 1982.

In order to bring into sharper focus the dynamical and thyermodynamical features of these arc clouds and boundary intersections that lead to development of deep convection, it is proposed that in-situ research aircraft measurements be combined with near simultaneous, rapid scan GOES data. An integral part of the airborne field measurements is the development of a small, lightweight data acquisition and display system that will permit near real-time assessment of the measurement results in order to allow recise decision control of the field experiment phase. The aircraft measurements are designed to provide detailed air motion and thermodynamic data near and within arc line convection genesis areas. These data (aircraft and GOES) will be used to develop a quantitative model for new deep convective development and dissipation which occurs along the arc line frontal system. In addition, the field data analysis will provide the input for the development of near real-time NOWCASTING aids for determining arc line propagation speeds and hence, new storm genesis areas. The field measurement phases will have data support from the NCAR radar (CP-2), PROFS mesonet, and the Craig-Sterling vertical sounding system.

P.C. Sinclair
J.F.W. Purdom
R. Dattore

National Science Foundation

GRAEME L. STEPHENS

AN INVESTIGATION OF THE APPLICATION OF MONTE CARLO METHODS TO PROBLEMS IN VISIBILITY

The investigation conducted under this grant has focused on the physical aspect of visibility in the National Parks. A hierarchy of methods have and are being developed that are specific to the problem of light attenuation in an optically thin, polluted atmosphere. These methods range in sophistication from a Monte Carlo model to a very simple parametric description of the radiative processes that influence visibility. The work continues with investigation of the effects of: variable lighting conditions, spatially varying aerosol concentrations, non-uniform surface reflectances, and the optical properties of the particles on visibility.

G. L. Stephens
S. Tsay
T. Greenwald

National Park Service

STUDIES OF THE RADIATION BUDGETS OF FAIR WEATHER CUMULUS & STRATOCUMULUS CLOUDS

The overall objective of this investigation is to provide a better understanding of the spatial variability of the optical properties of clouds and the impact of this variability on the radiation budgets of individual clouds and cloud ensembles. There are two components to the investigation. The first involves analysis of aircraft radiation and cloud physics data to study:

(i) the spatial variability of reflectivity, microphysical, and optical properties of cloud ensembles

(ii) the spectral variability of cloud reflectivity

(iii) the correlation of cloud reflectivity and cloud emissivity

(iv) statistics relevant to the definition of the radiation budgets of cloud ensembles

(v) validation (or lack of) theoretical calculations

(vi) measurements of the average broadband radiative heating fields of cloud fields.

The second, and complementary, component of the research involves development of appropriate multidimensional radiative transfer theories which have been used to provide a basis for the analysis of the data as well as an overall framework for the development of the parameterization of radiative transfer in spatially non-homogeneous optical media.

G. L. Stephens National Science Foundation

THE EFFECT OF CIRRUS CLOUDS ON SATELLITE OBSERVED RADIANCES

We plan to investigate the interaction of radiation with cirrus clouds with some emphasis on the retrieval of cloud properties from satellite radiance data. In order to achieve the stated objectives of this research and for the purposes of future developments of cirrus cloud parameterization, we plan to develop a microphysical model of cirrus and to couple this model to a radiative transfer scheme that will allow a convenient way of treating the radiative heating term to the microphysical growth equation while at the same time provide simulated "satellite" radiance data. We also plan to be involved in the future FIRE cirrus cloud experiment and propose to develop an ice water content probe for use in these field experiments. Measurement of this parameter will be important in testing the cloud model simulations, radiation parameterizations and cloud retrieval schemes to be developed under this proposal.

G. L. Stephens
S. K. Cox

National Science Foundation

THE EQUATORIAL MESOSCALE EXPERIMENT: EMEX

The research here represents a component of a highly focused field experiment (The Equatorial Mesoscale Experiment: EMEX) and research plan aimed at investigating the heating mechanisms within tropical cloud clusters to define the effect of these cloud systems on the vertical profile of large-scale heating through the troposphere. The primary observing platforms for this experiment will be the NOAA WP-3D research aircraft, the CSIRO Fokker F-27 aircraft and the NCAR L-188 Electra which is under request. In addition, it is expected that a dedicated EMEX ship from the People's Republic of China will take part in the experiment.

The EMEX will be conducted from 1 January - 15 February 1987 out of Darwin, Australia, over Northern Australia and Southern Indonesia. It will coincide in space and time with two independent but complementary experiments: The Australian Monsoon Experiment (AMEX) aimed at defining the synoptic-scale structure of the northwest monsoon, and the NASA Stratospheric-Tropospheric Exchange Program (STEP) aimed at examining the mechanisms of stratospheric-tropospheric interchange and interaction.

The particular objective of the research to be conducted under this proposal concerns the analysis of aircraft radiation and cloud microphysical data in order to provide estimates of vertical radiative heating through the cloud system.

G. L. Stephens

National Science Foundation

THEORETICAL AND OBSERVATIONAL MARINE BOUNDARY LAYER STUDIES

This project will investigate marine stratocumulus convection. This work is in conjunction with the First ISCCP Regional Experiment (FIRE) and involves both numerical modeling and observations. The expertise of the investigators (S. Cox, W. Schubert, G. Stephens) lies in the areas of thermodynamics, dynamics, radiation and cloud hysics. The modeling work involves explicit simulations of boundary layer convective elements using spectral techniques (both Fourier-Chebyshev and normal mode). The observational work involves thermodynamic, dynamic, radiation and cloud microphysical measurements from a tethered balloon on San Nicolas Island in July 1987 and 1989.

S. K. Cox
W. Schubert
G. L. Stephens

Office of Naval Research (ONR)

MICROWAVE RADIATION TRANSFER STUDIES IN CONVECTIVE STORMS DURING SPACE

This is a proposal to study microwave radiative transfer through convective storms during the Satellite Precipitation and Cloud Experiments (SPACE). The main components of this proposal are:

(i) study of the vertical structure of storm microphysics as related to radiative transfer,

(ii) use of (i) to compute extinction and phase matrices

(iii) develop a vector radiative transfer model employing (ii) as input,

(iv) compare the output from such a model to dual-polarized microwave radiance measurements.

Investigation (i) will involve coordinated CP-2 multiparameter radar and T-28 aircraft measurements in conjunction with a one dimensional hydrometeor melting model. Investigation (ii) will use the T-matrix scattering method averaged over hydrometeor size, shape, orientation and phase distributions. Investigation (iii) will employ existing radiative transfer techniques which will be modeled to include the full Stokes vector descriptions of radiance. Investigation (iv) will involve coordinated CP-2 radar, and ER-2 aircraft measurements of dual-polarized brightness temperatures, for comparison with radiative transfer model results.

G. L. Stephens
V. Bringi

NASA

DUANE E. STEVENS

DYNAMIC INSTABILITIES OF ATMOSPHERIC MEAN FLOWS

In the fourth year of the continuing study of Dynamic Instabilities of Atmospheric Mean Flows, we will complete two investigations of inertial instabilities and proceed with a study of dynamical mechanisms by which the synoptic environment affects hurricane intensification.

A linear spectral model has been developed to investigate the inertial instability of a mean zonal flow with vertical and meridional shear. We are now integrating this time-dependent model to obtain growth rates, phase speeds, and normal mode structures for instabilities as a function of zonal wavenumber. We propose to complete this study.

Wave-like disturbances have been identified from satellite pictures in the region of a very strong jet. We propose to complete analysis of this case to determine whether these waves may be related to the inertial instability being investigated with the numerical model.

Intensification of hurricanes appears to be related to the environmental flow patterns, particularly in the upper troposphere. The upper tropospheric environment of the hurricane satisfies the necessary condition for barotropic instability, and occasionally for inertial instability as well. We propose to investigate how the weather patterns surrounding the hurricane can affect intensification, perhaps through excitation of fluid instabilities in the outflow layer.

D. Stevens
M. Flatau
M. Ringerud
P. Ciesielski

National Science Foundation

DYNAMICS OF LARGE-SCALE ATMOSPHERIC CIRCULATIONS

Several specific lines of research are proposed in this three-year research program.

Preliminary calculations have shown that vertical shear of the basic state wind field plays a crucial role in the thermodynamic balance of tropical easterly waves, as well as in the qualitative structure of the atmosphere's response to convective heating. We use observed wind fields along with a consistent Hadley cell to study the response to convective heat and momentum sources in a linear framework, and then compare the model results with recent observations.

The zonal wind structure, Hadley cell advection, and cumulus momentum mixing also influence circulations over South America. The linear wave model will be used to study the response to both stationary and diurnal forcing located over Brazil.

The zonally symmetric linear response to the zonal average component of diabatic heating has proved difficult to obtain when using primitive equation models that do not reduce to shallow water systems. We suspect that the magnitude and parameterization scheme of dissipation strongly influence the response, and therefore propose to study the zonally symmetric problem. A time integration model may be required.

Further advances un understanding, simulation, and eventual prediction of middle latitude blocks require additional analysis of observations. We will complete a study, already begun, which focuses on the interaction of blocks with cyclones by analyzing isentropic potential vorticity fields and isentropic trajectories.

Barotropic instability is important as a dynamic mechanism in large-scale flows. The spatial and temporal structures of barotropically unstable modes will be investigated by analytic study of a function of the wind field, complemented by a numerical eigensolution technique.

D. Stevens
M. Flatau
F. Crum
S. Lee
Q. Hu
P. Ciesielski

National Science Foundation

THOMAS H. VONDER HAAR

SCIENTIFIC INVESTIGATION FOR THE EARTH RADIATION BUDGET EXPERIMENT

Nasa has launched instrumental earth-orbiting satellites to monitor the earth's radiation budget by simultaneously measuring both the outgoing reflection of the sun's energy and the long-wave radiation emitted from the earth's surface and atmosphere. The purpose of this effort is to provide scientific support during instrument development and perform data use investigations with observations of the earth's radiation budget parameters as determined from the satellite measurements.

T. H. Vonder Haar
G. G. Campbell
D. Randel
L. Smith

National Aeronautics and Space Administration

RAIN VOLUME ESTIMATION OVER AREAS USING SATELLITE AND RADAR DATA

The principal goal of the project is to investigate the feasibility of rain volume estimation over fixed and floating areas using rapid scan satellite data following a technique recently developed with radar data called the Area-Time-Integral (ATI) technique. To accomplish this task, continuous case studies were selected on the basis of existing radar and satellite data sets which match in space and time.

T. H. Vonder Haar
D. Reinke

National Aeronautics and Space Administration

ANALYSIS OF NIMBUS-7 SOLAR AND EARTH RADIATION BUDGET

This research focuses upon intensive analysis of the long-term (approx. 10 years) time series of Earth Radiation Budget (ERB) measurements obtained from NASA satellites NIMBUS-6 and NIMBUS-7. The satellite measurements are studied using correlative data describing atmospheric and oceanic circulation and cloudiness. The research strongly supports development and improvement of atmsopheric-ocean coupled climate models.

T.H. Vonder Haar
G.G. Campbell
D. Randel
L. Smith

National Aeronautics and Space Administration

SATELLITE REMOTE SENSING AND OBSERVATIONS OF AREAL PRECIPITATION

The primary objectives of this project are to explore new physical and statistical methods and approaches to the remote sensing of lower tropospheric moisture; to study the physical basis of detection of area precipitation; and to explore new (e.g., lidar) satellite remote sensing methods for aerosols, clouds, and related parameters. These new studies will take advantage of the rapidly expanding opportunities for remote sensing from civilian and DoD spacecraft.

T. H. Vonder Haar — Army Research Office
T. B. McKee

DEVELOPING AND UNDERSTANDING A SENSOR-TOPOGRAPHIC-MODELING DATABASE

The database required in the Geoscience research consists of topographic data, sensor data from radar, lidar, satellites, etc., model output, as well as data from physical observations. Because a wide variety of data will be generated in the Geoscience research, the objective of this research is to investigate methods of generating a topographic sub-database using data from topographic mapping satellites.

T. H. Vonder Haar — Army Research Office
T. A. Brubaker
G. K. Lee

INFORMATION EXTRACTION ALGORITHMS THAT OPERATE ON A TIME-VARYING DATABASE

The research on information extraction will focus on physical algorithms that generate timely and physically accurate information. The algorithms must generate information rapidly as conditions change and, at the same time, be capable of implementation on computer systems used in field operations. Algorithms will be developed and tested using sensors and models utilized within the Center for Geosciences project.

T. H. Vonder Haar — Army Research Office
T. A. Brubaker
R. Loomis

DISPLAY OF THE BEST POSSIBLE CURRENT AND FORECAST HYDROMETEOROLOGICAL CONDITIONS WHEN SENSOR DATA VARIES

This research is concerned with the information display which is effectively the user interface. The research will focus on imaging because color and visual images have the potential of rapidly conveying hydrometeorological information in a form that is quickly assimilated by personnel at all levels. Imagery methods will be tested on existing data and on data collected within the project. The human factor or MANPRINT aspects of the research will be related to the basic display research.

T.H. Vonder Haar
T.A. Brubaker

Army Research Office

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RICHARD H.JOHNSON

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ROGER A. PIELKE

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DAVID A. RANDALL

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STEVEN A. RUTLEDGE

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WAYNE H. SCHUBERT

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GRAEME L. STEPHENS

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Campbell, G.G., and T.H. Vonder Haar, 1987: Spatial scale of radiation to space: A spectral and structure function analysis of satellite imagery. Preprints, Third Conference on Satellite Meteorology and Oceanography, January 31 - February 5, 1988, Anaheim, California. Amer. Meteor. Soc.

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Shih, C.-F., M. Wetzel, and T.H. Vonder Haar, 1987: Effects of data resolution on marine stratiform cloud detection using AVHRR and VISSR satellite data. Preprints, Third Conference on Satellite Meteorology and Oceanography, January 31 - February 5, 1988, Anaheim, California. Amer. Meteor. Soc., 401-403.

Smith. L.D., and T.H. Vonder Haar, 1987: Temporal variability of the outgoing infrared flux from NFOV daily data: Comparison between NOAA and NIMBUS-7 polar orbiting satellites. Preprints, Third Conference on Satellite Meteorology and Oceanography, January 31 - February 5, 1988. Anaheim, California. Amer. Meteor. Soc.

Behunek, J.L., C.-F. Shih, and T.H. Vonder Haar, 1987: Estimation of meteorological parameters over mesoscale regions from satellite and in situ data. Preprints, Third Conference on Satellite Meteorology and Oceanography, January 31 - February 5, 1988, Anaheim, California. Amer. Meteor. Soc.

Kelly, F.P., T.H. Vonder Haar, and P.W. Mielke, Jr., 1987: The use of multi-response blocking procedures in classification and verification of satellite data. Pattern Recognition, (Submitted).

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Kelly, F.P., T.H. Vonder Haar, and P.W. Mielke, Jr., 1988: Imagery Randomized Block Analysis (IRBA) applied to the verification of cloud edge detectors. J. Atmos. Ocean Tech., (Submitted).

GRADUATE DEGREES

Summer 1987

Hamilton, Paul, M.S.
"Observations of a Mid-Latitude Squall Line Boundary Layer Wake," (Richard H. Johnson)

Howard, George, M.S.
"Modeling Cloudy and Clear Interval Length Probabilities Using Space Shuttle Imagery," (T. H. Vonder Haar)

Lunney, Patrick, M.S.
"Environmental and Convective Influence on Tropical Cyclone Development vs. Non-Development," (W. M. Gray)

O'Neal, Robert, M.S.
"Intra-Valley Topographical Control of Nocturnal Valley Winds," (T. B. McKee)

Sorlin-Davis, Janet, M.S.
"Determination of Cloud Base Height and Emissivity from Downwelling Angular Radiances," (S. K. Cox)

Ackerman, Steven, Ph.D.
"Radiative Characteristics of Soil Derived Aerosols," (S. K. Cox)

Kuo, Hung-Chi, Ph.D.
"Dynamical Modeling of Marine Boundary Layer Convection," (T. H. Vonder Haar)

Weatherford, Candice, Ph.D.
"Typhoon Structure as Revealed by Aircraft Reconnaissance," (W. M. Gray)

Fall 1987

Alberta, Timothy L., M.S.
"Anisotropy in Reflected Solar Radiation from Fields of Finite Clouds," (S. K. Cox)

Middlebrook, Michael G., M.S.
"Investigation of Tropical Cyclone Genesis and Development Using Low-Level Aircraft Flight Data," (W. M. Gray)

Wong, Takmeng, M.S.
"Sensitivity Study from One Dimensional Ocean-Atmosphere Climate Model," (G. L. Stephens)

Stone, Robert, M.S.
"Optical Properties of Cirrus Clouds from Satellite Imagry and Radiative Transfer Calculations," (G. L. Stephens)

Nicholls, Melville, Ph.D.
"A Numerical Investigation of Tropical Squall Lines," (R. H. Johnson and W. R. Cotton)

Toth, James J., Ph.D.
"Interaction of Shallow Cold Surges with Topography on Scales of 100-1000 Kilometers," (R. H. Johnson)

Tucker, Donna, Ph.D.
"The Anatomy of Heavy Rainfall Episodes over Complex Terrain: A Modeling Approach," (E. R. Reiter)

Weaver, Clark, Ph.D.
"Observational Analysis of Cumulus and Stratocumulus Entrainment Using Ozone," (R. Pearson)

Spring 1988

Combs, Cynthia, M.S.
"Transmittance of Solar Radiation Determined by the Multiple Field of View Radiometer Under Various Cloud Covers for Mauna Loa, Hawaii," (S. K. Cox)