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Department of Atmospheric Science

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1985/86

ATSL

Annual Report 1985-1986

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DEPARTMENTAL PERSPECTIVE

The past year has been a good year for Atmospheric Science. The Department has continued with a full staff of fourteen academic faculty including one member on a transitional appointment, forty-five general faculty, twenty-five state classified employees, and sixty-one graduate students. Research expenditures remained above \$3 million for the year, and the faculty participated in many local, national and international conferences. A major thrust was initiated this year to develop a state-of-the-art weather laboratory. Two years will be required to bring the new system to completion with all real time weather data arriving via satellite communications and data processing and analysis accomplished on newly acquired computer equipment. Equipment acquisition this year for the weather laboratory and for research in satellite meteorology is valued at slightly more than \$1 million. This new equipment to be used in the academic and research programs is a symbol of the enthusiasm and outlook of the Department for the next several years.

Professional activity of the faculty continues to grow. A few examples include Professor Stephen Cox serving as the Chairman of the FIRE Science Experiment Team. FIRE is the first ISCCP Regional Experiment for which ISCCP is the International Satellite Cloud Climatology Project. Professor Thomas VonderHaar is serving as an elected member of the University Corporation for Atmospheric Research's Board of Trustees. Professor Richard Johnson and Wayne Schubert have become the Co-Chief Editors of the Journal of Atmospheric Science. Other faculty are serving in a variety of local, state, and international panels and committees.

A total of sixty-one graduate students were enrolled in our program in Fall 1985. Graduates included five Ph.D. and eighteen M.S. students. The Ph.D. graduates have accepted jobs with the federal government (2), private companies, (2), and as a Colorado State University research staff member (1). Our students continued to be in demand.

Thomas B. McKee
Department Head

FACULTY & STAFF

Faculty

- William R. Cotton, Professor
Numerical modeling, cloud physics and dynamics, mesoscale meteorology
- Stephen K. Cox, Professor
Radiation physics, general circulation
- Lewis O. Grant, Professor
Precipitation physics, weather modification, mountain weather, hydrometeorology
- William M. Gray, Professor
Tropical meteorology, atmospheric vortices, cumulus convection
- Bernhard Haurwitz, Professor Emeritus
Theoretical meteorology, atmospheric waves, upper atmosphere
- Richard H. Johnson, Professor
Atmospheric convection, boundary-layer meteorology, synoptic and mesoscale meteorology
- Roger A. Pielke, Professor
Mesoscale modeling, weather forecasting, air-quality modeling
- Elmar R. Reiter, Professor
General circulation, high-altitude winds, aerospace science, turbulence
- Wayne H. Schubert, Professor
Dynamic and theoretical meteorology, parameterization of cumulus convection, planetary circulations
- T. H. VonderHaar, Professor
Satellite meteorology, radiation physics, global climate
- Richard Pearson Jr., Associate Professor
Atmospheric chemistry, atmospheric measurements, air pollution
- Peter Sinclair, Associate Professor
Severe storms, cumulus dynamics, thunderstorm modification, meteorological instrumentation
- Graeme L. Stephens, Associate Professor
Radiation theory, radiative parameterization, Cloud/climate studies
- Duane E. Stevens, Associate Professor
Earth and planetary physics; applied mathematics, numerical modeling, geophysical fluid dynamics, applied physics

Research Staff

Jan Behunek, Research Associate
Randolph Borys, Research Associate
James Bresch, Research Associate
Glen Brier, Research Scientist
Cheryl Burton, Research Coordinator
Grant Burton, Research Coordinator
Lie Ting Chen, Visiting Research Associate
LongXun Chen, Visiting Research Associate
Paul Ciesielski, Research Associate
Don Cobb, Research Coordinator
John Davis, Research Associate
Paul DeMoot, Research Associate
Nolan Doesken, Research Associate
Zhiqiang Feng, Visiting Research Associate
William Finnegan, Research Associate
Scott Fulton, Research Associate
Rudy Garcia, Research Coordinator
Marion Haurwitz, Research Associate
Tenmi Henmi, Research Associate
Ed Hindman, Research Associate
Chris Johnson-Pasqua, Research Associate
Robert Kessler, Research Associate
John Kleist, Research Coordinator
Marjorie Klitch, Research Associate
Kevin Knupp, Research Associate
Patrick Laybe, Research Coordinator
Minzhi Li, Visiting Research Associate
Bruce MacDonald, Research Associate
Ray McAnelly, Research Associate
Walter Naylor, Department Manager
Richard Peek, Research Coordinator
William Physick, Visiting Research Associate
Brian Plomondon, Research Associate
William Randel, Research Associate
Robert Rauber, Research Associate
Dave Rogers, Research Associate
Mordecai Segal, Research Associate
John Sheaffer, Research Associate
Ru-Jin Shen, Visiting Research Associate
Zhengshan Song, Visiting Research Associate
Luiz Teixeira, Visiting Research Associate
William Thorson, Research Coordinator
Greg Tripoli, Research Associate
Ding Wen Wei, Visiting Research Associate
Jiadong Ye, Visiting Research Associate

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Elmer Sterkel, Electronic Specialist C
Cleon Swain, Instrumentation/Maker, Fabricator II
Brenda Thompson, Senior Administrative Clerk
Melissa Tucker, Secretary
Juanita Veen, Staff Assistant II
Gail Watson, Administrative Clerk
Charles Wilkins, Instrumentation/Maker Fabricator II
Delbert Wilkins, Utility Worker II
Rosemary Wright, Secretary

RESEARCH

W. R. COTTON

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

Major findings of this research include:

(1) Low-level convective downdrafts are composed of four distinct branches with the intensity of the downdraft controlled by static stability of the environmental air, melting and evaporation of precipitation, and the size distribution of the precipitation elements.

(2) The three-dimensional cloud model was applied to the simulation of an extensively analyzed case described by Knupp and Cotton (1982a,b), and predictions were found to agree with many of the observed storms' features. Major findings were: (1) the observed storms' structure was not sensitive to the details of the observed initialization scenario, but only the local wind hodograph and stability, (2) the left-moving storm was driven by pressure forcing as in severe right-moving storms, and (3) pressure forcing seems to be more important in driving the updown downdraft branch than inferred by Knupp.

(3) The circulations and intensity of the stratiform region of mesoscale convective systems is strongly modulated by the intensity of the low-level jet, longwave radiative cooling (heating), liberation of the latent heats of freezing and sublimation in the upper troposphere, and melting of precipitation.

(4) MCC's typically form from a cluster of thunderstorm elements organized on the meso- β scale which merge to form the large meso- α system; the meso- β elements often have a well-defined mountain origin in the case of MCC's forming in the western high plains.

(5) Both individual case studies and composite analysis of the precipitation life cycle of MCC's reveals 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 is currently underway.

(6) Analysis of squall line observed during the 1981 CCOPE revealed its low-level inflow of high θ_e 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.

(7) 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 a warm core aloft and a cool core near the surface. The system propagates eastward destroying the inversion over the plains at a speed comparable to the observed translation of these convective systems.

(8) Model development in the Regional Atmospheric Modeling System (RAMS) has included the development of major pre-processor and post-processor algorithms, as well as development of hydrostatic regional versions along with retaining the nonhydrostatic cloud-scale versions of one system. Developments have been made in cloud microphysics to include aggregation, the addition of shortwave and longwave radiation schemes, an explicit surface energy budget, and turbulence routines. The system is now more "user friendly" and is being increasingly exercised as a "community" modeling system.

W. R. Cotton

National Science
Foundation

AN ANALYSIS OF RADAR ECHO MORPHOLOGY AND MESOSCALE PROCESSES ASSOCIATED WITH MESOSCALE CONVECTIVE SYSTEMS IN THE UNITED STATES NORTHERN PLAINS

We are examining the three-dimensional radar-echo morphology associated with the evolution of Mesoscale Convective Systems (MCSs) in the Montana/Dakotas region, based on field data collected during the summer of 1981. The primary feature of interest is the Meso- α scale (200-2000 km) Convective Complex (MCC), a particularly large, well-organized and long-lasting type of MCS that accounts for much of the convective-season rainfall over the Great Plains and Midwest. Our preliminary findings, based primarily on one well-observed case of MCC development in the experimental region, are:

(1) The dominant convection the MCC's formative stages was organized into three meso- β (20-200 km) convective components. Though the specific convective structures and configuration of the meso- β components varied from those seen in other cases, such multiplicity of meso- β components is characteristic of most MCCs.

(2) The development of the mature MCC occurred as the three meso- β convective components came closer together in a convergent tracking motion. Such convergent motion between meso- β elements, which sometimes results in their complete merger, typifies MCC upscale development.

(3) The merging tendency of the two major meso- β elements was likely due, in part, to significant boundary layer modification by the first component, a supercell. This cooling resulted in the second component, a squall line, being decoupled from the surface layer, allowing it to propagate faster and "catch up" with the first storm. This represents only one of many merging mechanisms that occur in MCCs. A more common mechanism, also seen in this case, is a confluent steering flow at 700 mb.

(4) The initial merging of the supercell and squall line radar echoes was at their anvil levels, about 2 h prior to the "start" of the MCC. The anvil echo was relatively thin and very high at this time, so that the merger occurred at the 8-9 km AGL level. After the initial merger, the opposing divergent outflows between the closing storms resulted in a thickening anvil.

(5) The mature MCC anvil echo retained a thin merger at 8-9 km AGL between the two meso- β convective components. It thickened to a 4-12 km AGL layer towards the north, with the maximum reflectivity at about 6 km. Further to the north, it thickened even more so that precipitation reached the ground, with the maximum reflectivity at the freezing level near 4 km AGL. Convective debris from the northern part of the squall line apparently contributed to the most intense region of the stratiform echo.

We are continuing to quantify the transition rate from convective to stratiform echo regimes in relation to the satellite-observed growth rate of this and comparative cases, seeking to find an "onset" to the meso- α circulation.

W. R. Cotton

National Science
Foundation

NUMERICAL MODELING OF MARINE FOGS, STRATOCUMULUS CLOUDS AND TRADEWIND CUMULI

In this research a one-dimensional, time-dependent, higher-ordered turbulence model was applied to the simulation of marine stratocumulus and boundary layer cumulus clouds. The model is able to respond to both solar and terrestrial radiative heating and cooling. Model simulations revealed that the cloud properties are strongly controlled by both wind shear and buoyancy generation of turbulence. Wind shear buoyancy production and cloud-top radiative cooling can interact to create sporadic episodes of cloud top entrainment of a 15 to 20 min periodicity.

The response of a marine cloud layer to solar heating is dependent upon the magnitude of large-scale subsidence in the overlying airmass and to the moisture content of the airmass above the capping inversion. The presence of middle and high level clouds also affects the magnitude of liquid water in the boundary layer clouds as well as the fluxes in the cloud layer.

The model was also applied to trade-wind cumulus fields and demonstrated it was robust enough to go from a 100% cloud cover stratus layer to a 15-20% cloud cover cumulus-capped boundary layer.

W. R. Cotton

Electric Power Research
Institute

CLOUD/MESOSCALE MODEL DEVELOPMENT AND APPLICATION STUDIES

The Colorado State University Regional Atmospheric Modeling System (RAMS) is being applied to the simulation and prediction of: (1) extreme wind shear and turbulence generated by severe thunderstorms; (2) the liquid water, areal coverage, and radiative properties of middle and high clouds; and (3) potential aircraft icing conditions. Research involves testing the model predictions of liquid water, the development of new parameterizations for calculating solar and terrestrial radiation through middle and high-level clouds, and the development of improved yet simplified turbulence models for calculating the properties of middle and high clouds on the mesoscale.

W. R. Cotton

Air Force Biophysical
Laboratory

LARGE-EDDY SIMULATIONS OF PLUME TRANSPORT AND DISPERSION OVER FLAT AND HILLY TERRAIN

Research involves the adaptation of Colorado State University RAMS to the simulation of boundary layer eddies and the associated transports and dispersion of plumes from power plants. The approach is referred to as large eddy simulations (LES). The model is being tested against observed properties of the boundary layer variances. Particularly unique is the LES of boundary layer eddies and transports over hilly terrain. New model developments involve the implementation of two-way nested grid meshes and the use of multigrid techniques for inverting the elliptic equation of pressure. A Monte Carlo dispersion model has also been developed as a diagnostic routine for dispersion calculations.

W. R. Cotton

Electric Power Research
Institute

S. K. COX

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

Studies of visibility in the Grand Canyon setting in the presence of varying concentrations of atmospheric aerosols have been conducted. A unique part of this investigation is the inclusion of both horizontal and vertical gradients in aerosol concentrations. These studies have defined optimum viewing conditions for discerning geometric details of the scene and have shown how visibility is modified as the concentration of atmospheric aerosols changes.

S. K. Cox

National Park Service

ANALYSIS OF MONEX RADIATION BUDGET FIELDS

Satellite, aircraft and surface data obtained from the MONEX (Monsoon Experiment) project conducted in and around the Indian subcontinent in 1979 have been analyzed. The Indian summer monsoon is a fundamental atmospheric response to the changing seasonal solar and infrared radiation patterns over the subcontinent and adjacent oceanic regions. The MONEX data have been used to construct these seasonal radiation patterns from January 1979 to August 1979. These radiation patterns are used in large scale atmospheric models to simulate and study the summer monsoon and its relationship to the surface and atmospheric radiation energy budgets.

S. K. Cox

National Science
Foundation

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

A 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 has served as the framework around which the cirrus observational program planned for fall 1986 will be conducted.

S. K. Cox

National Science
Foundation

A LABORATORY INVESTIGATION OF THE VARIABILITY OF CLOUD REFLECTED RADIANCE FIELDS

Using the similarity of optically dense, nonabsorbing scattering media, we have used styrofoam and surgical cotton to simulate the reflective properties of nonhomogeneous cloud fields. The laboratory measurements have shown that these analog techniques are capable of reproducing reflected energy observations obtained by satellite observations and detailed computer calculations. The advantage of the analog techniques developed are their economy and the fact that the simulated "clouds" do not change during the course of a set of observations. These techniques have been used to explore and explain a number of problems in the interpretation of cloud field images taken from satellites.

S. K. Cox

National Aeronautics
and Space Administration

L. O. GRANT

ANALYSIS OF STATE OF UTAH/NOAA CLOUD OBSERVATIONS OVER THE TUSHAR MOUNTAINS OF SOUTHWEST UTAH

This study involves the analysis of cloud measurements made by the state of Utah and its contractors over the mountains of southwest Utah. These analyses focus on specific studies of the spatial and temporal distribution of supercooled water, hydrometer trajectories, and precipitation processes. These analyses are carried out in a manner to provide information on the weather modifications potential of different weather systems and portions of weather systems passing through the area.

R. M. Rauber
L. O. Grant
D. C. Rogers

Utah Department
of Water Resources

THE CHEMICAL COMPOSITION OF SNOWFALLS AND SNOWPACKS: THE CONTRIBUTION OF RIME AND HOAR

The growth of ice by vapor diffusion in mixed phase clouds is effectively a distillation process. Most of the scavenging of aerosols and gases, however, is the result of liquid droplet aerosol collection, nucleation and growth. Two mechanisms in cold clouds can directly remove pollutants containing cloud droplets from the mountain clouds: snow crystal and mountain surface riming. These two cloud water removal mechanisms are being studied to determine their contributions to the total chemical composition of snowfall and the resulting snowpack.

R. D. Borys
E. E. Hindman
L. O. Grant

National Science
Foundation

WEATHER MODIFICATION RELATED PHYSICAL STUDIES OF ROCKY MOUNTAIN CLOUD SYSTEMS

This research involves the collection and interpretation of focused, direct, and remotely sensed measurements of a wide variety of Rocky Mountain cloud systems. These measurements are now possible because of new instrument systems that have removed many earlier observational limitations. Measurements can be made with instruments such as radiometers to remotely and continuously detect cloud liquid and ice water, and airborne laser probes to measure cloud particles. Analyses of recent field observations will make significant advances possible in understanding the characteristics of cloud liquid and ice water regions and the precipitation efficiencies for different types of cloud systems. Analyses utilize case studies and data compositing approaches for different storms. The studies include conceptual and numerical model development and testing to describe cloud and cloud modification processes.

L. O. Grant
E. E. Hindman
W. R. Cotton
R. M. Rauber
R. D. Borys
P. J. DeMott
L. A. Mulvihill
T. Uttal
R. M. Blumenstein

National Science
Foundation

CHARACTERIZATION OF ICE NUCLEUS AEROSOLS

This research was carried out to determine the functioning characteristics of ice nucleus aerosols which are introduced into simulated warm cumulus cloud bases and transported by simulated updrafts into the supercooled portions. The questions addressed were: do nuclei introduced into cumulus cloud bases in this manner survive warm cloud passages and those portions of the cloud between 0°C and -5°C; do these nuclei then function at the initial temperatures of activity determined in isothermal cloud chamber tests, or at some lower temperature; and, assuming activity is demonstrated beginning at some temperature, what fractions of the initial nucleus concentrations used function to produce ice crystals?

W. G. Finnegan
L. O. Grant
P. J. DeMoot

Alberta Research
Council

THE CHEMICAL CHARACTERISTICS OF CLOUD WATER, SNOW AND INTERSTITIAL AIR
IN THE WESTERN ROCKIES

This program involves studies of the chemical composition of clouds, precipitation and interstitial aerosol at a mountaintop location in the Rocky Mountains of northwestern Colorado. The measurements are analyzed in relation to meteorology and microstructure of clouds during different storm episodes.

L. O. Grant
R. D. Borys
E. E. Hindman

National Oceanic and
Atmospheric
Administration/Earth
Research Laboratory

HYDROMETEOROLOGY

This research emphasizes the hydrometeorological aspects of water supplies and water quality of Colorado mountain snowfall. The water supply studies are presently concentrating on the water balance (vapor, liquid, ice) in different portions of orographic clouds developing in different types of weather systems. Cloud water quality studies are concentrating on pollutant contamination collected and transported in differing forms of cloud water and precipitation.

L. O. Grant
R. M. Rauber
R. D. Borys

Agricultural Experiment
Station

ICE NUCLEUS AEROSOLS FROM COMBUSTION OF SHUTTLE PROPELANT IN SMALL
ROCKET MOTORS

This program was conducted to explore the possibility that aluminum oxide aerosols produced by shuttle rocket motor burns might differ in ice nucleation effectivity from the aerosol previously tested by unpressurized propellant burns. Field observations by other researchers have suggested that there might be a difference. Additional aspects of the research included investigations of nucleation poisoning effects by other materials in the rocket cloud, and, in parallel with the testing in the Colorado State University cloud chambers, the calibration of a small ice nuclei counter used for field measurements of shuttle aerosols.

W. G. Finnegan
P. J. DeMott
L. O. Grant

Universities Space
Research Association

EVALUATION DESIGN FOR THE MOROCCOAN WEATHER MODIFICATION PROGRAM

This program involves the development of the design procedures for the evaluation and testing of cloud seeding effects on the streamflow and precipitation in Morocco. The research involves the utilization of evaluation procedures developed for Colorado. The refined statistical procedures will be based on nonparametric techniques such as multi-response permutation procedures and least absolute deviation regression. Specific control variables being tested include streamflow, precipitation, and numerical model estimated precipitation. In an effort to facilitate the research and its utilization in the field, attempts are being made to adapt the application procedures to a mini-computer.

P. W. Mielke, Jr.
L. O. Grant

Bureau of Reclamation
National Science
Foundation

LONG DISTANCE DISPERSAL AND WATER CONTAMINATION BY ERWINIA CARTOVARA

The project addresses the potential long distance dispersal of phytopathogenic bacteria and their role in disease epidemiology using *Erwinia Cartovara* as a model system. All phyotologic and ecologic aspects of the research are being carried out by the Plant Pathology Department. Our group is providing support in the snowfall collection and analysis, consideration of atmospheric transport processes, and laboratory tests of the nucleation characteristics of *Erwinia Cartovara*.

R. D. Borys
P. J. DeMott
L. O. Grant

U.S. Department
of Agriculture

TESTING AND DESCRIPTION OF THE ICE NUCLEATING CHARACTERISTICS OF AgI AEROSOLS GENERATED USING NEWLY DEVELOPED GROUND-BASED SOLUTION COMBUSTION GENERATORS

This testing program provided a laboratory characterization of the ice nucleating ability of aerosols produced from the burning of silver iodide in two prototype ground-based generators. The characterization included descriptions of the effectivity, rates, and mechanisms of the nucleants produced.

W. G. Finnegan
P. J. DeMott
L. O. Grant

Colorado International
Corporation

NUCLEANT SAMPLE PREPARATION AND TESTING FOR USE IN CALIBRATING THE NEWLY DEVELOPED CLOUD CHAMBER IN YUGOSLAVIA

One sample of paired samples of nucleants was tested and described using the Colorado State University cloud chambers. The other sample of the pair is being used in the newly developed cloud chamber in Yugoslavia for the calibration and comparison of the results from that chamber.

P. J. DeMott
L. O. Grant

Boris Kidric Institute
of Nuclear Sciences

CHARACTERISTICS OF AEROSOLS FROM THE LOHSE AERIAL ICE NUCLEI GENERATOR

This study is carried out to describe the functioning characteristics of the AgI-AgCl-4NaCl and AgI-AgCl aerosols as generated by Lohse aerial ice nuclei generator. The nucleants tested have been recently developed at the Colorado State University cloud simulation laboratory. The Lohse aerial ice nuclei generator is the generating dispersal device for the state of North Dakota weather modification programs.

W. G. Finnegan
L. O. Grant

North Dakota Weather
Modification Board

TESTING OF THE ICE NUCLEATING ABILITY OF AEROSOLS FROM THE NEI TB-1 FORMULATION PYROTECHNIC WITH CESIUM IODATE ADDED

This testing program involved studies of the nucleating characteristics of the Aerosystems Pyrotechnics with cesium iodate added. This commercially produced pyrotechnic is used for the Bureau of Reclamation weather modification research program in the Sierra Nevada mountains of California. The program included physical and chemical descriptions of the nucleating aerosols.

P. J. DeMott
L. O. Grant

Aerosystems, Inc.

W. M. GRAY

FEASIBILITY OF USING VAS DATA FOR IMPROVING TROPICAL CYCLONE FORECASTING

Determination of how well the new NASA Vertical Atmospheric Sounder (VAS) on-board geostationary satellites might be used to determine current and short-term future of tropical cyclone behavioral characteristics through measurements of horizontal temperature gradients across such storms.

The VAS can successfully measure deep-layer (850-300 mb, or 850-200 mb) horizontal temperature gradients across tropical cyclones at radii beyond the cloudiness of these storms. Deep layer temperature gradients can be measured to an accuracy of $\pm 1^{\circ}\text{C}$ or less if this information is averaged from a number of repeated sounding samples at each of two widely spaced ($\sim 10\text{-}15^{\circ}$) cloud free areas. The VAS system appears to be particularly applicable to the measurement of parameters around oceanic tropical weather systems where conventional meteorological data sources are not available are too few to allow a meaningful multi-level analysis.

Investigation using the VAS system for improving operational forecasting of tropical cyclone motion and cyclone intensity change was pursued.

W. M. Gray
Lianshou Chen
C. L. Chan
C. S. Lee
C. Matsumoto
R. T. Merrill

NASA-Goddard Space
Flight Center

SYNOPTIC TROPICAL CYCLONE INTENSITY FORECAST SCHEME

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
Lianshou Chen
C. L. Chan
C. S. Lee
C. Matsumoto
R. T. Merrill

Office of Naval Research

DEVELOPMENT OF GLOBAL RAWINSONDE DATA DECKS FOR TROPICAL CYCLONE ANALYSIS

Complete acquisition, arrangement of nearly 21 years of rawinsonde data in the western Pacific is underway for the purpose of tropical cyclone analysis. Ten years of Japanese rawinsonde data have been entered onto tape, Chinese coastal rawinsonde data have been reduced, and use has been made of Taiwan upper air rawinsonde data. These, plus US data, have been augmented onto tapes and used for computer runs.

W. M. Gray
R. Edson
R. T. Merrill
C. S. Lee
C. Matsumoto
D. W. Wei
C. Weatherford

National Science
Foundation

OBSERVATIONAL STUDIES IN SUPPORT OF TROPICAL CYCLONES 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 frequency as related to the El Nino, stratospheric QBO, and springtime Caribbean 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 analysis of all 60-70 tropical cyclones occurring during the FGGE year.

W. M. Gray
R. T. Merrill
C. Askue
C. S. Lee
C. Matsumoto
E. Rodgers
C. Weatherford
L. Chen

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
R. Edson
C. S. Lee
C. Weatherford
M. Middlebrooke
P. Lunney

National Science
Foundation

R. H. JOHNSON

**A PROGRAM OF ENHANCEMENT OF THE COLORADO STATE UNIVERSITY DEPARTMENT OF
ATMOSPHERIC SCIENCE SYNOPTIC/MESOSCALE METEOROLOGY LABORATORY**

A modern, computerized classroom weather laboratory has been established in the Department of Atmospheric Science at Colorado State University. Students can access realtime weather data via satellite communications, a department computer, and two portable microcomputer workstations (MICROVAX workstations). Meteorological software from NASA has been incorporated into the computer system for processing, analyzing and displaying weather information.

R. H. Johnson
R. Pielke

National Science
Foundation

**COLORADO STATE UNIVERSITY PARTICIPATION IN PRE-STORM (PRELIMINARY
REGIONAL EXPERIMENT FOR STORM-CENTRAL)**

A major meteorological field experiment, PRE-STORM (Preliminary Regional Experiment for STORM-Central), was conducted during May - June 1985 in the central United States. The objective was to investigate the very large, mostly nocturnal, severe storms that occur over Kansas, Oklahoma and the surrounding states during the summer months. Our research project established a network of surface stations over Kansas and Oklahoma for the duration of the experiment and participated extensively in the field effort. PRE-STORM was an immense operational success and with preparation of data sets now nearly complete, we are beginning the analysis phase of this research activity. Already, new and exciting results concerning mesoscale convective systems have emerged from the results of this project.

R. H. Johnson
W. R. Cotton
R. McAnnelly
K. Knupp

National Science
Foundation

MESOSCALE CONVECTION AND THE ATMOSPHERIC BOUNDARY LAYER

Studies are being conducted on atmospheric convection and the planetary boundary layer. The response of the boundary layer to cold surges over the South China Sea have been studied using data from the International Winter Monsoon Experiment. Analysis of the statistical properties of thermals over the Colorado Front Range using aircraft data from PHOENIX is underway and a new interpretation of the heating of the planetary boundary layer is emerging. Numerical simulations of squall lines over the eastern Atlantic has provided new insight into the development and maintenance of these convective storms.

R. H. Johnson
M. Nicholls
G. Young
J. Zimmerman

National Science
Foundation

T. B. MCKEE

EVOLUTION OF TEMPERATURE INVERSIONS IN REGIONS OF COMPLEX TERRAIN

Temperature inversions in complex terrain vary considerably from those over flat terrain. Temperature inversions are a key ingredient in air pollution problems. This investigation includes observational and numerical model studies of inversion evolution in several valleys in western Colorado. Studies have included valleys which drain and those which do not drain at night. Research interest has also expanded to include regional as well as valley problems.

T. B. McKee
W. R. Cotton

National Science
Foundation

CLIMATE DATA INFORMATION SERVICE FOR COLORADO

This is a diverse project involved in all aspects of Colorado climate. The basic thrust of the project is acquisition, archival, utilization, and dissemination of climate information collected in Colorado. This includes the monitoring of current conditions across the state on a monthly basis and the preparation of a detailed summary report describing these conditions. Close coordination is maintained between all Federal and State agencies involved in monitoring different aspects of the State's weather and climate. The project also has a large research component utilizing current and historic climate data to study the complexities of the local climate system and its impact on various fields such as agriculture, energy, and water resource management. The project also has a large service component. Information archived and summarized by the Colorado Climate Center is made available to outside users both within and outside of Colorado through publications, computer access, news media, and direct 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

R. PEARSON

THE CHEMISTRY AND TRANSPORT OF OZONE IN A MARINE STRATOCUMULUS-CAPPED MIXED LAYER

Ozone occupies a central role in the photochemistry of the troposphere. It is a direct precursor of the hydroxyl radical. Significantly, it is one of a very few molecules whose turbulent fluxes can be measured by direct eddy correlation methods. Turbulent or eddy-fluxes of ozone, sensible heat (and related thermodynamic quantities), water vapor and momentum were measured on the NCAR Electra during the Dynamics and Chemistry of Marine Stratocumulus experiment (DYCOMS) during July and August 1984. The equipment for ozone measurements was developed at Colorado State University.

The data obtained have been used to determine the surface deposition rate for ozone in a well characterized marine boundary layer at a remote, "clean air" site. They will also be used to estimate the net chemical or photochemical production or destruction of ozone in this marine boundary layer from a mean concentration budget for ozone. Published data suggest that this marine boundary layer (MBL) may be a significant sink for tropospheric ozone. If confirmed, this behavior would be the opposite of the existing observations over continental North America and over the Gulf of Mexico -- areas with at least some anthropogenic emissions of photochemically reactive gases. Lastly, measurements of the vertical eddy flux and mean profile of ozone will be used to measure the rate at which air is entrained into the marine boundary layer. These data will be used both to increase our understanding of the evolution of the stratocumulus, and to estimate fluxes of species such as NO_x , SO_2 , and HNO_3 which cannot be measured directly with present instrumentation. They will also improve our ability to forecast the behavior of these clouds which may have a significant application to operational aviation meteorology.

R. Pearson
S. R. Kawa
C. J. Weaver
B. Jesse

National Science
Foundation

R. 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.

Questions to be addressed will be linked directly to the NCAR study and are intended to yield an additional understanding of the physical processes involved with subregional air-pollution meteorology. They include the general questions:

- (i) To what extent do these local circulations result in differences in trajectory path as compared to the NCAR/Penn State model calculations without this effect?
- (ii) Since several of these mesoscale systems vary significantly during the diurnal heating cycle, how do trajectory paths differ when the air passes over the subregion on a clear night as opposed to a sunny day?
- (iii) How significant is local recirculation of air within the subregion as compared with transport across the area?
- (iv) What type of trajectory differences result between low level areal emissions as opposed to elevated emissions by utility and other industrial sources? What is the difference in their transport patterns out to distances of up to several hundred kilometers from their emission sources?
- (v) To what extent do snow cover, soil wetness and vegetation cover influence the intensity and structure of the subregional mesoscale perturbations to the synoptic flow, and the resultant local trajectories?

R. A. Pielke
M. Segal

Electric Power
Research Institute

MESOSCALE MODELING

Studies of mesoscale meteorology and its relation to air quality are being conducted in Shenandoah National Park and the Lake Powell area. For these studies, we will describe the general applicability of the mesoscale model to assess air quality impacts in National Park areas. Special tasks for Shenandoah National Park include: (1) calculate pollutant concentrations in the park area due to several types of hypothetical local sources. Meteorological input will be from 3D simulations for climatologically representative summer and winter cases; (2) utilize parameterizations for dry depositions to estimate preferred areas for deposition of SO_2 and SO_4 onto the surface (or canopy) in the park area; and (3) study the transport of pollutants into the Shenandoah Valley region from industrialized areas to the west, with particular emphasis on the interaction of the local mountain-valley circulations with the synoptic flow. The ability of the Shenandoah Valley to trap and to accumulate this pollution over time will be explored. Differences in trapping as a function of time of day will be described. Long-range transport estimates from SAI/NPS studies will be used as the upwind boundary condition.

R. A. Pielke
M. Segal

National Oceanic and
Atmospheric
Administration
National Park Service

E. REITER

ENERGY BUDGET IN COMPLEX TERRAIN

We have measured the complete surface radiation, sensible, and latent heat budgets at a measurement site in the Gobi Desert of western Gansu Province, Peoples Republic of China, and at several sites in the Rocky Mountains of Colorado. Data from these field experiments are presently being analyzed. A similar, but larger field experiment is planned for June/July 1986 in Tibet. Two fully equipped radiation and energy budget stations will be installed near Lhasa (ca. 3500 m a.m.s.l.), and near Nagqu (ca. 4500 m), and will collect data for at least 6 weeks.

Our analyses of these data have indicated that the drag coefficient usually assigned to these mountainous regions has been overestimated in the past. The new estimates have significant impact on numerical modeling and forecasting of weather events in mountainous terrain. Also, the detailed assessment of surface energy budgets and their relationships to surface radiation characteristics is of importance to the calibration of satellite data.

E. Reiter

National Science
Foundation
National Aeronautics
and Space Administration
U. S. Air Force Office
of Sponsored Research

MESOSCALE FLOW PATTERNS OVER MOUNTAINS

During July/August 1985 detailed measurements of wind and temperature conditions were carried out on nineteen mountain peaks between southern Wyoming and northern New Mexico. In addition, energy budgets were measured at four of these stations. The project was carried out in cooperation with the Los Alamos National Laboratory, the U. S. Forest Service, and with the management of local ski areas. Data from this experiment (ROMPEX-85) are presently being analyzed. They reveal the effects of the generation and dissipation of large convective systems over some of the main mountain ranges of Colorado. We also gained detailed insight into the formation of monsoonal and non-monsoonal weather systems over Colorado. Some of the details in flow patterns revealed by our study lend themselves to practical application for air safety in mountainous terrain.

E. Reiter

U.S. Department of Energy

MESOSCALE FORECASTING OVER COMPLEX TERRAIN

We have developed a numerical prediction model for weather development over complex terrain. The model is run on an HP 9000 desktop computer. This model has been tested successfully over Tibet and over the western United States for severe weather events during summer. A nested-grid version of this model has been highly successful in simulating the time sequence of events surrounding the Big Thompson flood of 1976 and the Cheyenne flood of 1985. This model version has performed significantly better than the NMC LFM predictions issued for these events. Also, the non-nested model version has performed better than the LFM in predicting "explosive" cyclogenesis in the lee of the Rocky Mountains. A modified version of this model is currently being developed for application over Brazil.

E. Reiter

National Science
Foundation
U. S. Air Force Office
of Sponsored Research

WEATHER AT SEA

We are investigating by means of diagnostic and modeling studies the meteorological and oceanographic factors which are most likely responsible for rapid and severe cyclogenesis over the oceans. Such cases of cyclogenetic "bomb" development pose a severe threat to naval operations. In the initial phase of this study, we have investigated a number of "bomb" developments over the contiguous United States where data are more abundant than over the ocean. So far, we have been successful in isolating the implications of a traveling short wave at tropopause level and its superposition over a low-tropospheric wind streak in the development of such cyclones. Both conditions appear to be necessary to provide tightly focused divergence almost throughout the entire vertical air column in the pressure fall center at the surface, whereas in "normal" cyclogenetic cases there appears to exist a better defined level of non-divergence in the lower troposphere. We are presently exploring the applicability of satellite data to detect the signatures of these upper and lower tropospheric wind maxima over ocean areas. Our next step will be to design artificial intelligence-based procedures for the analysis and incorporation of appropriate satellite data into the prediction process for severe cyclogenesis at sea.

E. Reiter

Office of Naval
Research

LONG RANGE POLLUTION TRANSPORT

Under sponsorship by the U. S. National Park Service we have developed trajectory analysis techniques which allow an assessment of source-receptor relationships in pollution transport to pristine National Park areas. This technique has been highly successful in identifying the impact of ore smelters in the southwestern United States and Mexico, and of pollution sources in California on visibility degradation in several Park areas of the western United States.

E. Reiter

National Park Service

W. H. SCHUBERT

DYNAMICS OF TROPICAL WEATHER SYSTEMS

There 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

MULTIGRID AND SPECTRAL/MULTIGRID METHODS IN NUMERICAL WEATHER PREDICTION

Over the past eight years multigrid methods and spectral methods have proved 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 the problem of numerical weather prediction.

W. H. Schubert
G. Taylor

Office of Naval
Research

P. C. SINCLAIR

THE ATMOSPHERIC ENVIRONMENT OF THE GRAND CANYON

The air quality of the area surrounding and within the Grand Canyon is of interest to the National Park Service (NPS) and to the tourists who visit this area year around. Because of the burning operations the NPS conducts near the Canyon during the Spring and early Fall, there is concern as to the possible visibility degradation in the Grand Canyon on both a short and a long term basis. In order to avoid unnecessary pollution of the Grand Canyon, detailed aircraft measurements of the atmospheric motions near and within the Grand Canyon have been carried out to provide the data base from which a forecast procedure can be formulated to guide the burning operations. This investigation has obtained the first detailed measurements and analyses of the coupling (or non-coupling) of the synoptic-mesoscale motions surrounding the Canyon with the smaller scale motions within the Canyon itself. Our previous atmospheric research programs which have extensively used research aircraft for defining and modeling such micro-mesoscale motions has provided a well-trained and suitably equipped research group to accomplish the desired measurements and analyses.

P. C. Sinclair
P. Scott
G. Edelen
R. Hill
L. Sterns

National Oceanic and
Atmospheric
Administration

ROPE CLOUD EXPERIMENT - TEXAS EXPERIMENT (TEXEX)

Gust fronts developed from dry lines and weak frontal systems can produce rope shaped clouds along their boundaries. This research program was developed in cooperation with NOAA to obtain detailed air motion and thermodynamic data near and within rope cloud regions. We plan to use aircraft, infrared Doppler Lidar, microwave radiometer, and GMD rawinsonde data to develop new quantitative models of the gust front and rope cloud system.

P. C. Sinclair
J. F. W. Purdom
B. F. Weber
G. Edelen
R. Hill

National Oceanic and
Atmospheric
Administration

THUNDERSTORM OUTFLOW BOUNDARIES AND THE DEVELOPMENT OF DEEP CONVECTIVE ACTIVITY

This research is designed to provide in-depth understanding of the thunderstorm outflow mechanisms that lead to the development of deep convective storms through the integration of rapid scan satellite data with research aircraft measurements. To bring into sharper focus the dynamical and thermodynamical features of these outflow boundaries and the arc clouds that develop along these boundaries, we have obtained in situ research aircraft measurements with near simultaneous, rapid scan GOES satellite data. The aircraft measurements have provided detailed air motion and thermodynamic data near and within arc line convection genesis areas. These data (aircraft and GOES) are being 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. An integral part of the airborne field measurements has been the development of a small, lightweight, computer controlled, data acquisition and display system (CCDAS-1A) that will permit near real-time assessment of the measurement results in order to allow precise decision control of the field experiment phase.

P. C. Sinclair
J. F. W. Purdom
R. Zehr
J. Weaver
G. Edelen
R. Hill

National Science
Foundation

ALKALINE AEROSOL PRODUCTION BY DUST DEVILS

Acid rain can be partially neutralized by injection of alkaline particles into the precipitation, and by the solution of the particulate alkaline substances. It appears probable that the pH of rain can be significantly altered by alkaline particles. Southwestern soils are pedocals and often contain large amounts of the alkaline elements Ca, Mg, K, and Na. Sinclair (1975) has shown that dust devils are significant sources of airborne soil particles in the southwestern U.S. Preliminary estimates of dust devil emissions are as large as road dust emissions, with the height of aerosol dispersion extending up to 500 mb. These facts point to the possibility that dust devils are the strongest source of long-lived airborne soil particles in the southwestern U.S. This research is designed to improve our knowledge of dust production in the Southwestern U.S., elucidate the dust devil production mechanism, and produce data on the transport of dust into convective clouds. Airborne samples of dust taken during the summer (1985) field experiment are being analyzed for size distributions and solubility, elemental abundance, and chemical fractionation.

P. C. Sinclair
D. Gillette
M. C. Sinclair
G. Edelen
R. Hill

National Oceanic and
Atmospheric
Administration

G. 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. K. Cox
T. B. McKee
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

D. E. STEVENS

DYNAMIC INSTABILITIES OF ATMOSPHERIC MEAN FLOWS

The study of inertial/barotropic instability of a geophysical fluid is being expanded as we are investigating the more realistic case of a zonal jet with shear in the vertical direction as well as the latitudinal direction. We are developing a spectral, prognostic numerical model in order to accomplish this study. Most unstable modes are being calculated in regions of negative potential vorticity with our time integration model. This method will enable us to generalize more directly to non-linear dynamical flows.

D. E. Stevens
M. Ringerud

National Science
Foundation

DYNAMICS AND MODELING OF PLANETARY TO SYNOPTIC SCALE ATMOSPHERIC CIRCULATIONS

A global semi-spectral model for linearized perturbations has been developed. The model was used to investigate the Walker Circulation. Results indicate that when cumulus friction is included in the linear model calculations, a mean vertical velocity field should also be included. When the effects of the zonal mean winds and the Hadley Cell/cumulus friction terms are included, the model response resembles the observed tropical and subtropical responses to the El Nino ocean temperature anomaly. The linear model was also used to investigate the inertial instability of the sheared flow. Results suggest that deep atmospheric circulations in spatially confined regions of negative potential vorticity may develop as asymmetric rather than symmetric instabilities.

The influence of pressure gradients on the parameterization of cloud momentum transports was also investigated. Results suggest that horizontal pressure gradients should be taken into account in modeling of convective lines.

Planetary wave propagation in the southern winter hemisphere was studied. An average or composite over several propagating cases reveals the wave structure and evolution, and suggests a source of planetary wave activity in the upper troposphere.

The energetics of the atmospheric primitive equations was also investigated.

D. E. Stevens
M. Flatau
P. Ciesielski

National Science
Foundation

MODELING INVESTIGATIONS OF TWO SHORT TERM CLIMATE PHENOMENA

The first of two short term climate phenomena investigated in this study is the 40-50 day oscillation in the tropical troposphere. A linear model with a basic state consisting of a Hadley cell is found to give rise to a class of slow, wavelike motions which are in agreement with observations of the 40-50 day oscillation. These perturbations on a zonally symmetric Hadley cell basic state form a dynamical explanation for the time scale of the oscillation. Modeling efforts with zonally asymmetric basic states are also considered.

The second area of investigation is the blocking phenomena of mid-latitudes. Analysis of Ertel potential vorticity on isentropic surfaces is a fundamental diagnostic tool for large-scale dynamical processes. Therefore, a case study of a particular blocking event is considered with emphasis placed on an isentropic evaluation of its evolution and structure. Interactions with the higher frequency synoptic storms are considered by means of trajectory analysis and Eliassen-Palm fluxes.

D. E. Stevens
F. Crum

National Science
Foundation

T. H. VONDERHAAR

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. VonderHaar
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. VonderHaar
P. Laybe
R. Craig

National Aeronautics
and Space Administration

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D. E. STEVENS

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T. H. VONDERHAAR

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G. LOVE

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N. J. DOESKEN

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GRADUATE DEGREES

(January - December 1985)

Doctor of Philosophy

Ray Arritt

Numerical Studies of Thermally and Mechanically Forced Circulations
Over Complex Terrain (Roger A. Pielke)

David Bader

Mesoscale Boundary Layer Development over Mountainous Terrain
(Thomas B. McKee)

Kevin Knupp

Precipitating Convective Cloud Downdraft Structure: A Synthesis of
Observations and Modeling (William Cotton)

Robert Merrill

Environmental Influences on Hurricane Intensification (William Gray)

Robert Rauber

Physical Structure of Northern Colorado River Basin Cloud Systems
(L. O. Grant)

Master of Science

Brian Alworth

Evolution of Potential Vorticity in a Tropical Cyclone Model (Wayne
Schubert)

Rochelle Blumenstein

Characterization of Silver Iodide-Sodium Iodide Ice Nuclei Using
Chemical Kinetic Methodology (L. O. Grant)

James Bossert

Associations between Summer Circulation Anomalies and Sea Surface
Temperature Forcing (Elmar Reiter)

Cheng-Li Chen

Plan B - no thesis (William Gray)

Mike Flannigan

Forest Fire Monitoring Using the NOAA Satellite Series (Thomas H.
VonderHaar)

Maria Flatau

The Effect of Horizontal Pressure Gradients on the Momentum
Transport in Tropical Convective Lines (Duane E. Stevens)

Piotr Flatau

Study of Second-Order Turbulence Closure Technique and its
Application to Atmospheric Flows (William Cotton)

Jingwen Li

Plan B - no thesis (Duane E. Stevens)

- Art Meade
Applications for Three-Dimensional Computer Graphic Cloud
Representations Produced from Satellite Imagery (T. H. VonderHaar)
- Jeffery McQueen
A Numerical and Climatological Investigation of Deep Convective
Cloud Patterns in South Florida (Roger A. Pielke)
- Ray Roetman
Plan B - no thesis (Richard Pearson, Jr.)
- Jerome Schmidt
Structure and Evolution of a Squall Line with an Embedded Super Cell
(William Cotton)
- Taneil Uttal
Distribution of Liquid, Vapor and Ice in a Phase Budget in a
Colorado Orographic Cloud System (L. O. Grant)
- Candis Weatherford
Typhoon Structural Variability (William Gray)
- Michael Weissbluth
A Modeling Study of Visibility in the Grand Canyon (Stephen K. Cox)
- Craig Wilkes
Plan B - no thesis (T. B. McKee)
- Daniel Wolfe
Early Morning Evolution of the Convective Boundary Layer at the
Boulder Atmospheric Observatory (R. H. Johnson)
- Chang-Han Yu
Mesoscale Air Quality Under Stagnant Synoptic Cold Season Conditions
in the Lake Powell Area (Roger A. Pielke)