NASA Technical Memorandum 86238

Severe Storms Branch Research Report (April 1984 — April 1985)

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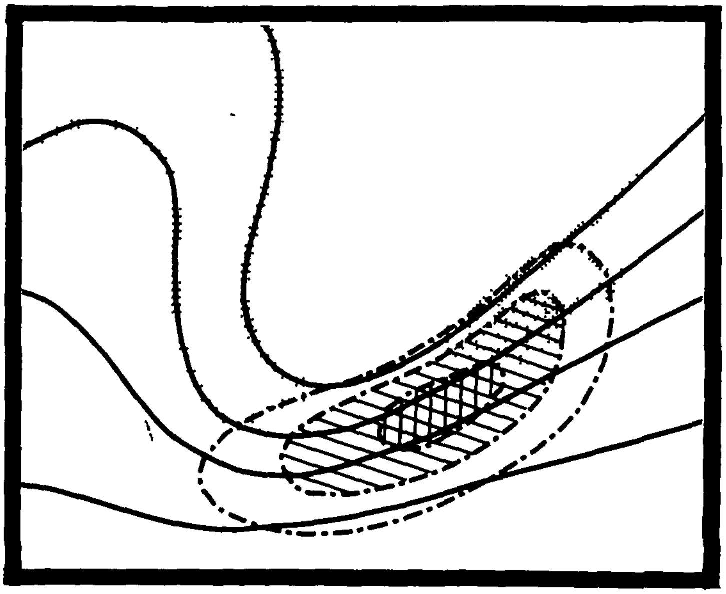

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Jet Core Ozone Model: This schematic jet streak/ozone concentration model shows typical 300 mb contours (thick solid), isotachs (thin solid and hatched), and areas of enhanced total ozone concentrations (black areas). The ozone enhancements to the left rear of the jet core are due primarily to large-scale horizontal advections, while those in the left front are due to stratospheric subsidence associated with the mesoscale vertical circulations ahead of the propagating jet streak.

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Severe Storms Branch Research Report (April 1984 — April 1985)

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NASA/GSFC Laboratory for Atmospheres

Severe Storms Branch

Research Report for April 1, 1984, to April 1, 1985

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1. INTRODUCTION

Progress reports are prepared by various Branches of the GSFC Laboratory for Atmospheres (GLA) in order to assist the internal GSFC executives and administrative offices at various levels within NASA in monitoring, coordinating, evaluating, administering, and planning their activities. These reviews play an important part in making the most efficient and effective use of our resources and provide a convenient medium for the various Branches of GLA to keep abreast of the breadth of activities taking place within the Laboratory. Usually, there is an oral version of these reviews prepared primarily for the benefit of the NASA Headquarters level personnel. This year, this presentation was given on May 14 through 16, 1985, at GSFC.

This report is comprised primarily of material prepared for this oral presentation. The material was edited, reorganized, and supplemented where such modifications were appropriate. Most of this report is in a standard outline format which highlights goals, accomplishments, current work, future plans, and resulting publications. All publications included with each task summary (excluding those in preparation) have been consolidated and placed at the end of the report for convenient reference.

Following this brief introduction, there are overviews which summarize this period of activity and provide some perspective relative to the larger laboratory and national severe storms research activities. More detailed descriptions of our work follow and are grouped into sections consistent with the two administrative groupings within the Severe Storms Branch. The final section consists of a comprehensive listing of publications and presentations resulting from this work, a listing of the Severe Storms Branch staff, and a short index to acronyms and abbreviations.

2. OVERVIEW

2.1 NASA'S Mesoscale Atmospheric Processes Research Program (J. Dodge - NASA HQ)

NASA's Mesoscale Atmospheric Processes Research Program is a nationwide program of integrated studies with the goal of achieving improved understanding of the basic behavior of the atmosphere through the use of remotely sensed data and space technology. The four main elements of the program consist of special observations and analysis of mesoscale systems, the development of quantitative algorithms to use remotely sensed observations, the development of new observing systems, and numerical modeling.

The Severe Storms Branch of the Goddard Laboratory for Atmospheres at NASA's Goddard Space Flight Center (GSFC) is an extremely important component of the Mesoscale Atmospheric Processes Research Program. It is at the GSFC where special talent and emphasis are placed upon storm-scale cloud top studies, satellite data precipitation estimation techniques, soil moisture estimation, three-dimensional modeling ranging from mesoscale to storm scale, advanced IR and microwave storm observations from high-flying aircraft, the interpretation and validation of new types of space data, such as VAS and TOMS, tropical cyclone studies, sophisticated meteorological analyses of detailed atmospheric evolution, such as ageostrophic circulations involving jet streaks, stratospheric-tropospheric exchanges, atmosphere-ocean interactions, and land surface-atmosphere interactions.

Special facilities at GSFC include the highly capable Atmospheric and Oceanographic Information Processing system (AOIPS), the NASA High-Speed Computing Facility (NHSCF), which uses a CDC CYBER 205 parallel processing computer, and laboratories for the development and calibration of aircraft remote sensors.

The GSFC mesoscale researchers and their associated university researcher colleagues form a highly motivated, highly productive team that has received national and international acclaim for their accomplishments.

2.2 Summary of GLA Severe Storms Program: April 1984 to April 1985
(J. Simpson - Branch Head)

The primary program objectives continue to be improvement of our understanding, diagnosis, and prediction of a wide range of atmospheric storms, which includes severe thunderstorms, tornadoes, flash floods, tropical cyclones, and winter snowstorms (with the combined use of space observations, radar, conventional data, models, and other tools). By-products of the research often shed light upon various aspects of local weather, such as fog, sea breezes, air pollution, showers, and other products of non-severe cumulus cloud clusters. Conversely, the small part of the program devoted to boundary layer processes, gust front interactions, and soil moisture detection from satellites has contributed insights into storm growth and behavior.

Clearly, a spectrum of motion scales, from planetary waves down to turbulent eddies, interact to produce severe storms and to determine their products, such as high winds, hail, or tornadoes. The GLAS program focuses upon and is primarily organized around two scales, namely the mesoscale (100-1000 km) and the storm scale itself (5-100 km). The Branch is comprised of two closely interacting groups, named according to these scales as described in Table 2.2A (names of personnel are listed in paragraph 5.2). The hurricane subprogram is presently a part of the Storm Scale Group mainly because of that group's interests in tropical meteorology and tropical convection.

The main accomplishments during the past 12 months are summarized briefly in Table 2.2B and in somewhat more detail in the group overviews (paragraphs 2.3 and 2.4). More explicit summaries are provided by the text following. A major emphasis, which will continue to be encouraged, is cooperation with the several branches of GLA; with other divisions at Goddard, particularly in regard to computation, land and ocean processes, with operational groups in NOAA, and with a number of university colleagues. The complex severe storm area requires a strong interweaving of many skills, tools, and fields of knowledge to advance the frontier so that space observations will bring their optimum pay-offs when combined with models, radar, dynamical considerations, and observations from other sources.

Major thrusts for the next few years, particularly new developments and/or emphases, are highlighted in Table 2.2C. These various concentrations of our research efforts have one central focus which is to improve and/or maintain standards of living and capabilities of life support for inhabitants of our planet Earth. In addition to these major thrusts, there has been significant progress in adapting models and research activities to newly developed research resources. The new CYBER 205 installation is presently supporting an appreciable portion of our computer requirements and the AOIPS upgrade effort is progressing on schedule. Development of these support facilities is expected to continue as new equipment technology develops and as progress in research requires.

Table 2.2A Organization and Personnel of the Severe Storms Branch

J. Simpson, Branch Head
L. Dubach, RTOP Manager

o Two Interacting Groups

Storm Scale Group:	Dr. R. F. Adler, Leader
Mesoscale Group:	Dr. L. W. Uccellini, Leader

o Total Personnel consists of

- 15 Civil Service Scientists (11 Ph.D.)
- 1 Meteorological Technician, 1 Secretary
- 20 In-House Contractor Support Persons (excluding computer operators, etc.)
- 2 Resident Research Associates
- 3 Summer Faculty Visitors

Table 2.2B GSFC Severe Storms Program Objectives and Accomplishments

Objectives

o Understand, diagnose, and predict severe convective, winter cyclonic, and tropical storms using space observations in conjunction with other data, numerical models

o Assess impacts of existing data and new space observations on storm and mesoscale models, diagnoses, nowcasting

o Assess, develop methods to estimate precipitation from space observations

o Develop techniques to interpret, combine, and display space observations of storms and surroundings together with model output and other data, analyses

Table 2.2 (continued)

Accomplishments

- o Severe thunderstorms, tropical cyclones, other convective systems, and their surroundings (including PBL) analyzed by a combination of observations and numerical models
- o Scale-interactive processes leading to
  - frontogenesis
  - tropopause folds
  - winter and spring storms

  analyzed by rawinsondes, 6.7 µm moisture channel, TOMS, other data, numerical simulations
- o Impacts assessed of VAS imagery and soundings in analysis and numerical simulation of storm systems
- o Significant advances in development of data analysis/display systems (e.g., GEMPAK and AOIPS)
- o 35 in-house journal publications during the past year

Table 2.2C GSFC Severe Storms Program Future Plans (1986-1990)

- o Increased interdisciplinary emphasis
  - troposphere-stratosphere interaction in extratropical (GALE) and tropical cyclogenesis—assess TOMS, VAS impacts
  - air-earth boundary studies, soil moisture—ISLSCP
  - sea-air interaction in cyclogenesis (GALE), tropical cloud interactions
- o Increased model emphasis on cloud interactions, coupled dynamic/radiative models—developed with available data sets (e.g., cloud tops, 1984; pre-STORM, 1985; SPACE/MIST, 1986, EMEX/STEP, 1987)
- o Increased emphasis on precipitation from space, including tropical cloud systems, using models, ground truth, aircraft, space observations
- o Work toward VAS physical retrievals, applications to tropical, extratropical storm formation
- o Inter-agency field participation
  - GALE; SPACE/MIST (1986)
  - possible role in EMEX (1987) in collaboration with Microwave Group
  - preparation for STORM-Central (planned for 1990)
- o Help develop plans, foundation studies for new atmospheric space missions (e.g., Tropical Rainfall Measuring Mission, Earth Observing System, Lidar Atmospheric Sounding Experiment, Geosynchronous Microwave Sounder/Imager)

2.3 Storm Scale Group Overview (R. Adler - GSFC)

RESEARCH OBJECTIVES:

The objectives of the group are: 1) to determine the physical and dynamical characteristics and evolution of severe thunderstorms, tropical cyclones, and other precipitating cloud systems; 2) to develop the techniques to use satellite and other data in the analysis and forecasting of these storms and their environment; 3) to determine the potential of current satellite data in the analysis of storms; and 4) to determine the observational requirements for future low-orbiting and geosynchronous satellites.

The tools used by the group include: 1) satellite data (GOES short-interval, visible, IR and stereo observations, GOES/VAS temperature and moisture information, and low-orbiting microwave ozone and other data);
2) radar data (conventional and Doppler); 3) aircraft data (high-altitude overflight radiometer); and 4) numerical models of clouds (one-dimensional, two-dimensional, and three-dimensional) and numerical models of associated phenomena (e.g., boundary layer, surface processes, etc.).

SIGNIFICANT ACCOMPLISHMENTS:

a) Analysis of 92 and 183 GHz passive microwave observations from a high-altitude aircraft indicates that these frequencies can be used to detect rain areas over land and over water and that rain rate can be estimated.

b) Satellite, aircraft, and radar observations and cloud models have led to a more complete understanding of severe thunderstorm top dynamics, including the importance of stratospheric mixing in producing satellite-observed IR patterns.

c) Satellite observations, including VAS and Nimbus TOMS (ozone), have been combined to show the importance of storm-environment interaction in the rapid intensification of tropical cyclones.

d) Three-dimensional cloud model runs for a tropical, waterspout-producing cumulus indicate that vortex pairs reaching well below cloud base were produced by cumulus drafts tilting the vortex tubes in an environment with the observed shear and under other special shear conditions.

e) The importance of land-air interaction in the initiation of intense convection has been shown, especially in relation to soil moisture effects, and an ability to measure the properties of surface moisture from space has been developed.

f) A new display technique using perspective images of satellite or aircraft data allows height information to be combined with visible images to provide a dramatic view of cloud systems on many scales.

g) Analysis of satellite visible and IR data and ground-based radar data indicate the limitations, but also the potential payoff directions, of estimating convective precipitation from geosynchronous cloud observations.

FUTURE PLANS:

a) Develop and test techniques to estimate precipitation from space with microwave, IR, and combined techniques using a triad of cloud dynamic models, radiative transfer models, and aircraft and satellite observations.

b) Utilize three-dimensional (and other) cloud models for both individual convective elements and cloud systems to study cloud system dynamics for comparison with satellite, aircraft, and other observations.

c) Determine tropical cyclone/environment interaction in relation to intensification, movement, and genesis using satellite and other data.

d) Study the air-land interactions using a multi-disciplinary approach including models and in situ and remote observations.

2.4 Mesoscale Analysis and Modeling Group Overview (L. Uccellini - GSFC)

RESEARCH OBJECTIVES:

The general objective of the Mesoscale Analysis and Modeling Group is to study the synoptic to mesoscale processes which organize, initiate, and maintain severe convective storms and major winter storm systems. The research approach emphasizes an interdisciplinary diagnostic case study approach, utilizing special network data, VAS and TOMS satellite data, and numerical model experiments. Specific objectives include:

1) detailed studies of the SESAME-, VAS-, and CCOPE-related cases and other cases as well emphasizing the role of gravity waves, jet streaks, and frontogenesis in severe local and winter storms;

2) studies emphasizing the interactions between a) larger-scale dynamics-boundary layer, b) atmosphere-ocean and stratosphere-troposphere during severe weather events;

3) numerical simulations of specific cases to better understand a) the scale interaction associated with fronts and jets, b) the synergistic relationship between large-scale dynamics and physical processes in the pre-storm environment, and c) the sensitivity of the forecasts to initial state perturbations;

4) the assessment of total ozone analysis from TOMS and water vapor imagery for the study of jet streak circulations, tropopause folds, and associated severe weather events; and

5) an evaluation of mesoscale models over a large number of cases to determine the utility of the models for satellite impact studies. This research effort includes a major emphasis in developing model initialization schemes which are designed to incorporate satellite data and the application of the model to VAS impact studies.

The case study and model research have been conducted within the Severe Storms Branch, at the Pennsylvania State University (NCAR/Penn State model), at Systems and Applied Sciences Corporation (Mesoscale Atmospheric Simulation System, MASS), and at Colorado State University.

SIGNIFICANT ACCOMPLISHMENTS:

Recent significant results include:

1) Numerous numerical simulations of various severe weather events have been completed which appear to accurately simulate scale-interactive processes which lead to severe storms. The cases include the SESAME I Wichita Falls tornado case, the Grand Island tornado outbreak, the Presidents' Day snowstorm, and other cases of severe storms in the Midwest and East Coast snowstorms.

2) The VAS Assessment has been completed, which shows the utility of VAS moisture imagery and sounding profiles in the analysis of a pre-storm environment when optimal sounding conditions exist (no cloud contamination). Recent sounding advancements have been made which provide VAS sounding results in image-like format, yielding consistent, quantitative fields with mesoscale resolution.

3) A simple Lagrangian-based isentropic model has been completed and applied to several cases, including those for which VAS data was available. The results show that this model can be used on a mini-computer in a nowcasting mode to produce 0-12 h forecasts of moisture, temperature, and wind fields used to make convective stability forecasts.

4) An independent evaluation of near real-time numerical forecasts using the MASS model has been completed with results indicating that mesoscale models have great potential in the prediction of severe convective storms. The model was then applied to numerous studies concerning the means by which diabatic processes feed back to the larger scale, enhancing dynamically driven circulations which contribute to severe convective storms and major winter snowstorms.

5) SESAME and CCOPE case studies have further isolated the role of "lids," gravity waves, jet streaks, and frontogenetical circulations in the development of severe convective storms. The SESAME I analysis and modeling also reveal that a minimum of 3-h rawinsonde data was necessary to properly resolve the mass-momentum adjustments which are associated with the development of the low-level jet within the exit region of the upper-tropospheric jet streak.

6) Case studies and idealized model studies have been completed that show how deformation patterns along the axis of jet streaks lead to upper-level frontogenesis and tropopause folding. A case study has also been completed which relates surface frontogenesis to the development of line convection.

7) The analysis of the Presidents' Day snowstorm continues. Results indicate the importance of upper- and lower-level jets in the pre-cyclogenetic environment. The results also point to the mesoscale nature of the cyclogenetic environment, to the importance of unbalanced flow in producing a major winter storm, to the role of a stratospheric-tropospheric exchange in the rapid development of the cyclone, and to the feedback of diabatic processes on larger-scale circulations during the pre-cyclogenetic and rapid cyclogenesis phases.

8) The GEneral Meteorological PAcKage (GEMPAK) on the VAS Applications Processor (VAP) has been upgraded. The entire GEMPAK system (which includes a generalized mapping routine, GEMPLT) has been delivered to several universities (University of Illinois, Naval Postgraduate School, Yale, UCLA, Colorado State University) and was recently chosen by UNIDATA as the system that meets the requirements for the university community to process and analyze meteorological data.

FUTURE PLANS:

a) The documentation of the SESAME and CCOPE case studies and of the Presidents' Day storm case study will be continued. These studies will not only emphasize those processes which appear to be critical for the development of severe local storms (e.g., frontal circulations, gravity waves, jets), but will also focus on limitations of the current data base and the need to supplement observations for analysis and numerical modeling.

b) The analysis of the two VAS cases (July 20, 1981, and March 6, 1982) is being completed to assess the impact of ancillary conventional data and TOMS data in VAS temperature and moisture retrievals.

c) Modeling activity will be continued, with emphasis placed on detailed analysis of specific weather events and the design and implementation of initialization schemes capable of utilizing satellite-derived parameters. Controlled experiments will be conducted on more simplified two-dimensional models of frontal and jet streak circulations, the results of which could be used as a basis for future studies. Numerical impact studies using satellite data will remain an important part of the program over the next several years and involve determining basic adjustment concepts to serve as a basis for model initialization on the mesoscale. The numerical studies will also provide a means to study the complex relationship between dynamic and diabatic processes which appear to play an important role in the development of severe storms and explosive cyclogenesis.

d) Major new activity includes the participation of the Mesoscale Analysis and Modeling Group in the Genesis of Atlantic Lows Experiment (GALE), both for diagnostic analysis and numerical modeling studies. The research includes studying the role of jet streaks, fronts, and boundary layer processes in the rapid development of East Coast storms.

3. STORM SCALE RESEARCH (R. Adler and Staff)

3.1 Hurricane Structure and Dynamics from Stereoscopic and Infrared Satellite Observations and Radar Data (A. Hasler - GSFC and R. Morris - GSC)

RESEARCH OBJECTIVES:

The objective of this research is to determine the relation of tropical cyclone cloud characteristics and structure to storm rainfall and dynamics. The emphasis is on special data sets where geosynchronous satellite observations (visible, infrared, and stereo) of clouds are available along with cloud track winds (with stereo height assignment) and ground-based or aircraft-based radar reflectivity data.

SIGNIFICANT ACCOMPLISHMENTS:

a) Infrared and stereoscopic visible satellite data from GOES-East and -West were combined with ground-based radar data from Hurricane Frederic (1979) and time-composited airborne radar from Hurricane Allen (1980) to investigate hurricane cloud and precipitation structure. Cloud winds with stereoscopic cloud top height assignments were measured within a ten degree latitude radius of Hurricane Frederic using 7.5 min interval GOES data and were combined with rawinsonde and low-level aircraft wind data.

b) It was observed that stereoscopically measured cloud top heights in these hurricanes are not nearly as closely correlated to radar reflectivity at lower levels as they are in intense thunderstorms over land. In the eye wall of Hurricane Frederic, some of the high-reflectivity regions appear as stereoscopically observed overshooting tops, but major radar-observed precipitation areas outside the eyewall were not evident in the overlying cloud top structure. The most extensive precipitation band was located beneath a warm trench in Frederic's central overcast. As indicated by radar, most of the cyclone's broad, cold central overcast produced no significant precipitation. These results imply that satellite precipitation estimation techniques for tropical cyclones will not be accurate for time and space scales less than several hours and a few hundred kilometers, respectively.

c) In the stronger Hurricane Allen, it was found that the highest radar reflectivity regions in the eyewall lie under a pronounced outward slope above 10 km of the eyewall cloud boundary which is indicated by the stereoscopic satellite observations.

d) Clouds used as tracers to estimate winds which had heights below 5 km were shown to move with the winds at cloud base. Inflow and outflow were found at the same height levels in separate regions of the cyclone at middle and upper levels of Frederic. Deeper convective clouds tended to be associated with the outflow at these upper levels. IR-derived cloud heights with emissivity corrections applied, showed errors in excess of 5 km

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when compared to the stereo heights for cirrus outside the central overcast and were as great as 10 km with no corrections applied.

FUTURE PLANS:

It is recommended that more planned examples of stereoscopic data be produced for tropical storms in various stages of development in conjunction with aircraft radar observations in order to further determine the impacts of stereo cloud top heights and cloud winds on monitoring and forecasting tropical cyclone intensity and development. Because of the relatively slow changes in tropical storms compared to severe thunderstorms, continuous rapid scanning in the stereo mode would not be necessary, minimizing the disruption of normal satellite operations. For cloud wind and stereo height determination, a short (1 hour) burst or rapid-scan imagery at 7.5 min intervals or less from a single geosynchronous satellite, synchronized with the scanning of either a second geosynchronous or a polar-orbiting satellite on normal operation schedules, would provide useful research data sets if done on a once or twice daily basis.

Algorithms for automatic height contouring of stereo image pairs will be investigated.

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3.2 Monitoring Tropical Cyclone Growth Using GOES VISSR/VAS and Nimbus-7 TOMS Data (E. Rodgers - GSFC, J. Steranka, and J. Stout - GSC)

RESEARCH OBJECTIVES:

The objective of this task is to monitor and possibly predict tropical cyclone intensity change (maximum winds or minimum pressure), strength change (average wind speed at radii between 100 and 300 km), and outer circulation change (average wind speed beyond 400 km) (Merrill, 1984; Holland and Merrill, 1984; Weatherford and Gray, 1984) using GOES VISSR/VAS and Nimbus-7 TOMS data. Tropical cyclone growth changes are dependent upon the inertial stability of the storm's circulation (Holland and Merrill, 1984). The more stable the flow, the greater the resistance will be to environmental forcing. Since the storm's lower and middle troposphere is highly stable while the upper troposphere is weakly stable, strength and outer circulation changes will be monitored by examining the lower- and middle-tropospheric forcing and intensity changes will be monitored by examining the upper-tropospheric forcing.

SIGNIFICANT ACCOMPLISHMENTS:

Multiple linear regression equations have been derived to retrieve geopotential height, layer thickness, and precipitable water content from GOES VAS every 3 h in clear regions surrounding Tropical Cyclones Beryl (August 1982) and Debbie (September 1982). The GOES VAS observations of the environmental mass and thermodynamic fields help to monitor upper-/middle-tropospheric troughs that these tropical cyclones encounter downstream. By monitoring these troughs, it was observed for the Beryl case that Beryl deintensified as the storm moved into the convergent part of the trough, while for the Debbie case, the upper-tropospheric coupling between the storm and the divergent part of the trough allowed for further intensification.

Advective and mass adjustment processes associated with changes in the upper-tropospheric circulation surrounding Tropical Cyclone Irene (September 1981) were examined using the GOES VISSR and Nimbus-7 TOMS data. Fig. 3.2(1) shows the evolution of Irene's upper-tropospheric environmental mass and circulation fields during a period of intensification (~1500 GMT 24-26 September 1981). The figure depicts the location of Irene at observation time (closed hurricane symbol) and 3 h before and after observation time (open hurricane symbol). The number next to the hurricane symbol is central pressure in mb. Also depicted on the figure are the upper-tropospheric wind field (mainly derived from cirrus tracers) in m s^{-1} and the Nimbus-7 TOMS-derived total ozone anomalies in Dobson Units. Since ozone may be considered as a passive tracer in the lower stratosphere and ozone gradients are strongest just above the tropopause, fluctuations of total ozone are primarily due to variation in tropopause height caused by vertical and horizontal advection. For example, subsidence lowers the tropopause and increases total ozone, while ascending motion raises the tropopause and decreases total ozone. Thus, high positive (negative)

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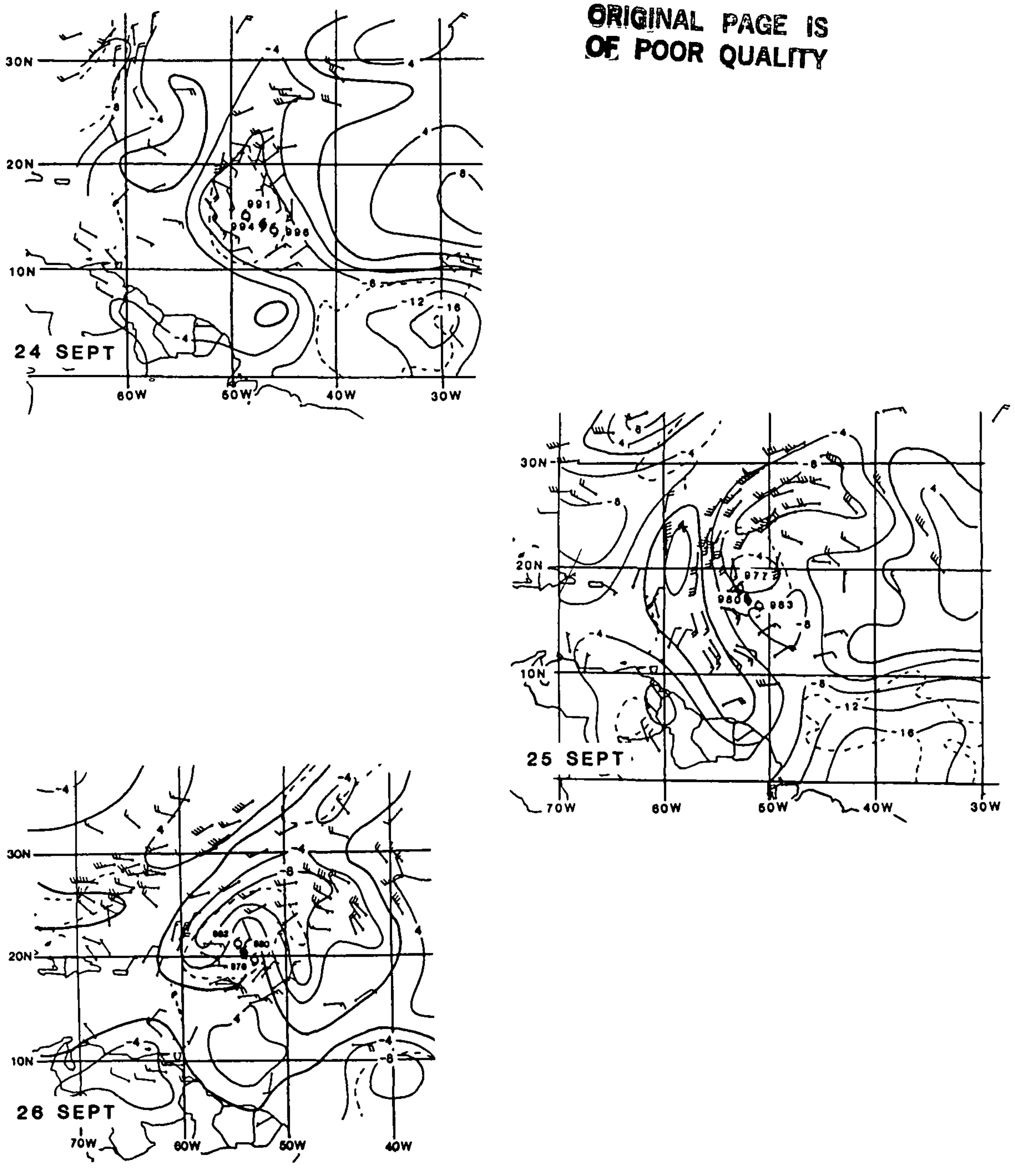

Fig. 3.2(1). Total Ozone Anomalies, Tropical Cyclone Irene-1981. Upper-tropospheric wind and total ozone anomalies for Tropical Cyclone Irene at ~1500 GMT 24-26 September 1981. Solid lines are total ozone anomaly at contour interval of 4 Dobson Units. Winds are at ~200 mb at 1200 GMT, where flag is 50 m s^{-1}, barb is 10 m s^{-1}, and half barb is 5 m s^{-1}. Eye position at observation time (solid hurricane symbol) and 3 h before and after (open hurricane symbol) are shown together with minimum pressure in mb.

values of total ozone indicate low (high) tropopause. The major points that can be made from this figure are:

a) Upper-tropospheric trough west of Tropical Cyclone Irene is depicted by positive anomalies of total ozone.

b) Between 24 and 25 September, 1) Irene moves closer to upper-tropospheric trough, 2) upper-tropospheric trough deepens as depicted by increased total ozone anomalies (lowering tropopause), 3) deepening trough also reflected in stronger upper-tropospheric horizontal convergence (not shown), 4) gradient in tropopause height between Irene and trough becomes greater, 5) enhanced baroclinicity helps to strengthen the outflow jet, 6) stronger outflow jet and greater tropopause gradient enhances the generation of Irene's kinetic energy by down gradient flow which may have led to the storm's intensification, 7) an increase in total ozone near the center may reflect the intrusion of stratospheric air; this intrusion may help to further intensify Irene through subsidence warming and cyclonic spin-up by vortex stretching, 8) Irene's central core convection increases as indicated by GOES infrared data (not shown), and 9) Irene intensifies.

c) Between 25 and 26 September, 1) trough moves south of Irene as observed from the total ozone anomalies, 2) tropopause gradient relaxes, 3) outflow jet weakens, 4) down gradient flow weakens, thereby decreasing the generation of kinetic energy, 5) Irene's central core convection stays constant (not shown), and 6) Irene deintensifies.

CURRENT RESEARCH:

Intensity changes in response to upper-tropospheric forcing are being examined for four western Atlantic tropical cyclones: 1) Harvey (12-16 September 1981); 2) Irene (21-29 September 1981); 3) Beryl (30 August-3 September 1982); and 4) Debbie (13-17 September 1982). by emphasizing GOES VISSR/VAS, NOAA TOVS, and Nimbus-7 TOMS measurements. Intensity changes as well as the change in storm convection and outflow asymmetries are being monitored and related to upper-tropospheric environmental forcing. Environmental forcing will be related to the location and strength of upper-tropospheric troughs and jets and to the juxtaposition and coupling of these troughs and jets with the tropical cyclone. The index of upper-tropospheric trough strength will be ascertained by monitoring the troughs wind fields (horizontal divergent patterns), mass fields (thickness, geopotential height, and tropopause heights), and thermodynamic fields (precipitable water).

FUTURE RESEARCH:

The relationship between lower-/upper-tropospheric environmental forcing as it pertains to tropical cyclone strength/outer circulation (intensity) change will be examined for western Atlantic tropical cyclones between 1978-1984. Analysis of the tropical cyclone structure and environment will be obtained from satellite and in situ measurements. Satellites will provide cloud top temperature and upper- and lower-tropospheric wind fields from GOES VISSR measurements and tropopause height and the detection of the intrusion of stratospheric air from Nimbus-7 TOMS. Tropical cyclones will be stratified according to strength, outer circulation and/or intensity changes, and the following meteorological parameters will be examined:

a) strength and outer circulation changes—1) changes in the storm outer convective patterns and 2) lower-tropospheric angular momentum flux; and

b) intensity change—1) upper-tropospheric angular momentum flux, 2) upper-tropospheric flux and generation of kinetic energy, 3) changes in the central core convection, and 4) the intrusion of stratospheric air into the storm's eye region.

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Rodgers, E. B., J. Steranka, and J. Stout, 1985: Monitoring tropical cyclone environmental structure with satellite and conventional observations to indicate tropical cyclone intensity and motion changes. Preprints, 16th Tech. Conf. Hurricanes and Tropical Meteorology, Amer. Meteor. Soc., Houston, TX.

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Stout, J., and J. Steranka, 1984: Vertical displacements of the mid-tropospheric water vapor boundary in the tropics derived from the VISSR Atmospheric Sounder (VAS) 6.7 μm channel. Preprints, Conf. Satellite Meteorology/Remote Sensing and Applications, Amer. Meteor. Soc., Clearwater Beach, FL.

Stout, J., E. B. Rodgers, and E. Nuñez, 1985: Upper atmospheric dynamics of hurricanes Allen and Irene as revealed by total ozone and water vapor measurements. Preprints, 16th Tech. Conf. Hurricanes and Tropical Meteorology, Amer. Meteor. Soc., Houston, TX.

3.3 Analysis of the Inflow and Air-Sea Interactions in Hurricane Frederic
(W. Frank - Penn St)

RESEARCH OBJECTIVES:

This project is a continuation of ongoing research on the properties of Hurricane Frederic (1979).

The specific objectives of this study are to: 1) determine the effective heights of the satellite wind vectors; 2) integrate satellite, aircraft, rawinsonde, and surface wind measurements into a three-dimensional analysis of the storm inflow layer over water; 3) construct similar analyses of the thermodynamic fields in the inflow layer; 4) perform diagnostic budget analyses of moisture, sensible heat, kinetic energy, and momentum in the inflow layer; and 5) examine air-sea interactions from residuals in the budget analyses.

SIGNIFICANT ACCOMPLISHMENTS:

During the first year of the project, the primary achievement was the completion of the task of data processing. The data set consists of rawinsonde, aircraft, surface, and satellite wind vector data. After eliminating those data which were found to be inconsistent with neighboring values, a final data set consisting of 64 rawinsonde soundings, 177 aircraft data points (30-second averages), 237 satellite wind vectors, and 198 surface reports was compiled. All of the data were plotted in storm-relative coordinates. It was found that the vertical and horizontal distributions of data from each individual source were highly variable.

The rawinsonde data provided excellent vertical resolution, although the distribution was rather poor. Eight data levels extending from the surface to 500 mb were extracted from each rawinsonde sounding. The height of each level was calculated using the hypsometric equation and the 850, 700, and 500 mb heights were compared to those plotted on conventional NMC upper air charts. The depth of the Planetary Boundary Layer (PBL) was estimated by examining the moisture and temperature profile of each sounding. Since the rawinsondes were all launched from land stations, only data from levels above the PBL were considered. The horizontal distribution of rawinsonde data was asymmetric about the storm center with a minimum of data coverage existing southwest of the storm center. All rawinsonde data used fell between 300 and 1000 km radius from the storm's center.

The vertical resolution of the aircraft data was quite variable, while the horizontal resolution was minimal. In regions where there were flights at different levels, the resolution was naturally superior to those areas where there was only data at a single level. The elevation of each data point was determined by the radar altimeter. While the aircraft elevation varied, no aircraft datum used had an elevation in excess of approximately 1700 m or less than 250 m. Morever, the majority of the data was clustered near 600 and 1600 m. The horizontal distribution of aircraft data was relatively symmetric about the storm center with all data points falling between 150 and 275 km radius. Surface ship and buoy data were at the 10 m level and were distributed throughout most portions of the storm.

The horizontal distribution of the satellite wind vectors was rather uniform, and all of the satellite winds used in this study were between 150 and 1000 km from the center of Frederic. Satellite wind vectors over land were not used so that land-induced friction could not contaminate the wind fields.

To aid in determining the heights of satellite wind vectors, radial and tangential winds and inflow angles were calculated in storm-relative coordinates at each data point. The resulting values were divided into two groups such that the winds and inflow angles obtained on 11 September (period 1) were separated from those obtained from data on 12 September and early 13 September 1979 (period 2). This procedure was employed to minimize smoothing of small-scale or transient features in the wind field.

In addition to completing the above data analysis tasks, we have also obtained the available stereo-imagery analyses and a copy of Powell's (1982) boundary layer model. These are being used to assist in determining the heights of the wind vectors.

CURRENT RESEARCH:

At the present time, subjective and objective analysis techniques are being used to determine the heights of the satellite wind vectors. The first step consists of objectively analyzing the tangential, radial, and inflow wind components separately in limited regions. This procedure is carried out independently for the data using a Cressman objective analysis scheme. The analysis grid measures 2730 km in the north-south direction and 2030 km in the east-west direction, and the grid spacing is 70 km. The purpose of this initial objective analysis is to smooth data in local areas only.

In the second step used in determining the heights of the satellite wind vectors, subjective analysis techniques are employed. In areas where there is multiple-level data coverage, the satellite wind vector heights are assigned after comparing the radial and tangential winds and inflow angles of the satellite wind vectors to the respective components from the other data sources.

Because multiple-level data do not exist in many areas during either period 1 or period 2, the heights of many satellite wind vectors cannot be assigned directly. To alleviate this problem, satellite wind vector heights from periods 1 and 2 are being combined to obtain a map of satellite wind vector heights for the 41-hour period beginning 1100 GMT on 11 September 1979. We are assuming that, although the wind velocity of a given satellite wind vector is less variable over the same time period; that is, the heights of the satellite wind vectors are assumed to be more conservative than the values of their wind components or inflow angles.

FUTURE PLANS:

The heights of all satellite-derived wind vectors will be estimated within the near future. We will then proceed to the remaining tasks: 1) adjust the satellite winds to the primary analysis levels; 2) perform the integrated three-dimensional analysis of the inflow layer kinematic fields using a cylindrical coordinate compositing technique; 3) determine the inflow layer thermodynamic fields; 4) perform diagnostic budget analyses of moisture, sensible heat, kinetic energy, and momentum; 5) examine air-sea interactions, including surface stresses and heat and moisture fluxes as budget residuals; and 6) synthesize findings and publish the results.

REFERENCES:

Powell, M. D., 1982: The transition of the Hurricane Frederic boundary-layer wind field from the open Gulf of Mexico to landfall. Mon. Wea. Rev., 12, 1912-1932.

JOURNAL PUBLICATIONS:

Frank, W. M., and E. B. Rodgers, 1984: Kinematic analysis of Hurricane Frederic (1979) using satellite, aircraft and rawinsonde data. Final Report on NASA Grant NAG5-102.

3.4 Convection Modeling and Application to Severe Storms (J. Simpson and M. McCumber - GSFC)

RESEARCH OBJECTIVES:

The goals are to understand, diagnose, and predict the dynamics, precipitation, and severe weather activities of cumulus-type clouds and cloud systems. An aim is to provide a framework for relating space and remote observations to internal cloud processes, thereby to obtain more extensive and accurate information on convective precipitation systems from existing and future space data.

The research is being conducted mainly with modifications of Schlesinger's three-dimensional cumulus model, together with tropical and mid-latitude storm observations. Close collaboration (and nonduplication) is maintained with Schlesinger's own efforts to improve his model and with the multiple cloud modeling by Dr. Tao.

SIGNIFICANT ACCOMPLISHMENTS:

A hypothesis concerning cumulus-scale parent vortices and their intensification to waterspout strength has been developed using a combination of GATE observations and an improved high-resolution version of Schlesinger's model with a Kessler-type precipitation scheme. A paper on this research has been accepted by the Journal of the Atmospheric Sciences (see bibliography). Model results were presented showing that cumulus outflows, particularly two or more outflows approaching intersection, can alter the cumulus environment to create (rarely) the special combination of thermal, moisture, and wind stratifications in low levels required for strong, vertically coherent cumulus-scale vortices to develop to the vorticity magnitudes of mid-latitude mesocyclones. The convective invigoration and convergence associated with the intersecting outflows has also been shown, by a simplified vorticity calculation, to be adequate to intensify the cumulus vortex to funnel intensity in the 5-10 minute time window allowed by updraft lifetime. The hypothesis is illustrated schematically in Fig. 3.4(1), with some observational support from satellite evidence in Fig. 3.4(2). Fig. 3.4(1) has the features of a typical cumulus merger situation with a cloud "bridge" generated between two approaching outflows. The lower layers are destabilized with intensified wind shear, while the cumulus convection is invigorated above the developing vortex (hatched), allowing the development of the low pressure core (dashed lines) which will soon be made visible as a funnel by condensation. The dark ring signature on the ocean surface has been shown by tank experiments at Wallops (Huang et al., 1985) to correspond to a wind speed (at 10 m elevation) of 7-8 m s^{-1}

Three waterspouts were sighted on two GATE days. Many cloud simulations using the soundings for these two days revealed a narrow range of optimal conditions for the development of intense near-surface vortices. On day 186, low-level thermal instability was moderate and convection was shallow

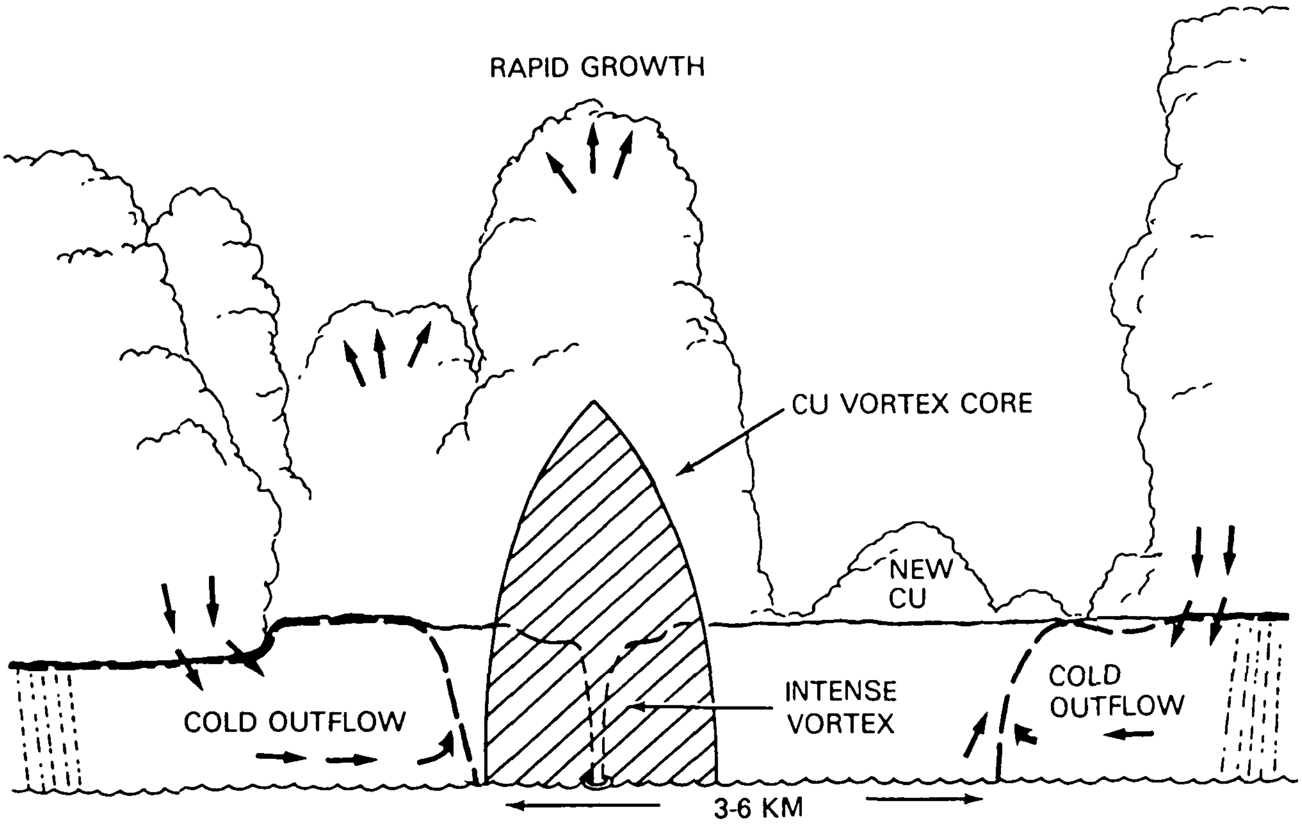

Fig. 3.4(1). Hypothesis: Vortex Intensification. Schematic illustration of cumulus outflow interactions in relation to cumulus vortex (hatched) and intensifying central core (vertical dashed) which will soon be visible as a condensation funnel.

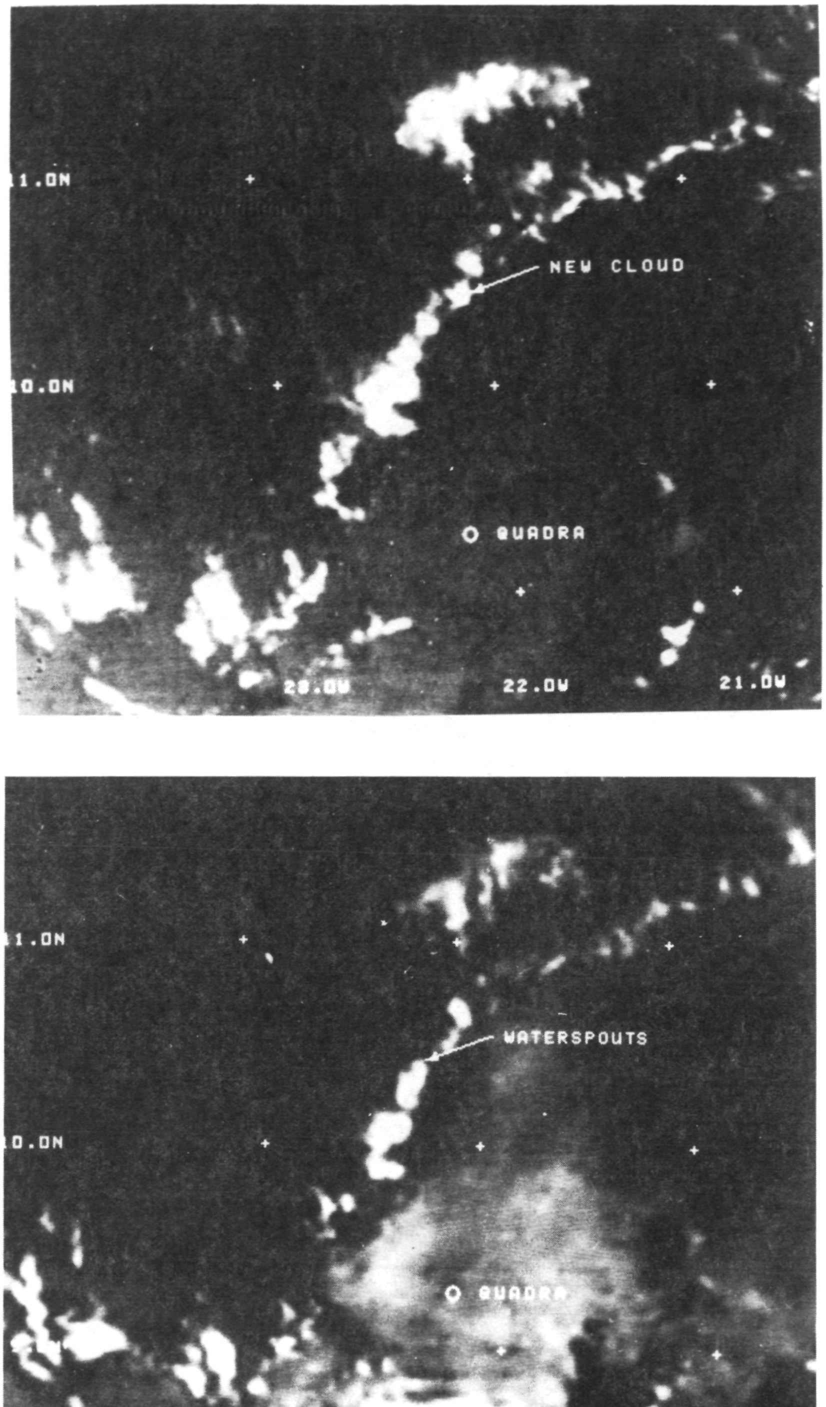

Fig. 3.4(2). GOES Visible Images on GATE Day 186. GOES visible images at 1200 and 1230 GMT on GATE day 186 showing new bright cloud overhead 30 min after waterspout sightings, supporting hypothesized "rapid growth" cumulus in Fig. 3.4(1).

(observed and modeled cloud tops less than 4 km). Shear was varied in many ways; only when strong shear coincided with the level of maximum instability did strong, vertically erect low-level vortices develop. The atmosphere on day 261 was more stable and drier at low levels and it was less strongly sheared. Clouds grew taller (as observed) and strong mid-cloud vortcies developed, but they extended only weakly to the surface. Modifications were tried to simulate gust front influences; model surface vortices were strong only when both the lowest 500 m of the sounding was lifted and the wind hodograph was rotated.

CURRENT RESEARCH:

Increased CYBER memory and stretched vertical grid permit higher-resolution examination of essential cloud processes, which is necessary to clarify funnel genesis and also cloud top interactions with environment. The advection scheme is being improved and an ice phase will be added to permit high towers and anvils to be examined and to relate dynamic and radiative cloud models.

FUTURE PLANS:

Examination and comparison of model-predicted and observed rainfall in tropical and subtropical areas using GATE, SPACE/MIST, and other data sets. Examination of effects of cumulus outflows on higher-resolution model clouds' rainfall, top development, vorticity using SPACE/MIST, and Florida data sets with improved model. Continued model development will include trajectory computations, mesoscale forcing, and grid nesting.

JOURNAL PUBLICATIONS:

Simpson, J., B. R. Morton, M. C. McCumber, and R. S. Penc, 1986: Observations and mechanisms for GATE waterspouts. J. Atmos. Sci. (Accepted.)

Tao, W.-K., and J. Simpson, 1984: Cloud interactions and merging: Numerical simulations. J. Atmos. Sci., 41, 2901-2917.

CONFERENCE PUBLICATIONS:

McCumber, M. C., and R. S. Penc, 1985: Vortex development in tropical marine cumuli. Preprints, 16th Tech. Conf. Hurricanes and Tropical Meteorology, Amer. Meteor. Soc., Houston, TX.

Simpson, J., A. F. Hasler, and B. R. Morton, 1985: On the role of cumulus outflows in the development of tropical waterspouts and tornadoes. Poster Session, 16th Tech. Conf. Hurricanes and Tropical Meteorology, Amer. Meteor. Soc., Houston, TX.

Tao, W.-K., and J. Simpson, 1985: A numerical study of cloud interactions and merging: Three-dimensional experiments. *Preprints, 16th Tech. Conf. Hurricanes and Tropical Meteorology*, Amer. Meteor. Soc., Houston, TX.

3.5 Modeling of Cloud Systems (W. Tao - GSC and J. Simpson - GSFC)

RESEARCH OBJECTIVES:

The objective of this research is to understand the development of organized convective systems with varying large-scale influence by means of a fully three-dimensional multi-cloud model. Primary emphasis to date has been on identifying those dynamical processes which contribute to the merger of clouds.

SIGNIFICANT ACCOMPLISHMENTS:

a) The three-dimensional numerical multi-cloud model has been vectorized for the NASA CYBER 205 vector processor. The current version of the model has 32 x 64 grid points in the horizontal, with a grid spacing of 1 km. A vertical stretched coordinate is used. The grid interval is 200 m in the lowest level and about 1000 m at the highest level, which corresponds to a depth of 15 km with 27 grid points. Only 1.6 sec of computer time is needed for each 10 sec time step simulation.

b) The philosophy behind the study is to generate several convective clouds randomly inside the model domain and, then, to observe and analyze the interactions and merging between the simulated clouds.

To date, we have applied the three-dimensional model to the deep convection observed over the GATE A/B-scale ship array on August 12, 1984. Two cases involving mergers have been studied through examining the temperature, moisture, pressure, and wind fields prior to, during, and following the merging model clouds. The first case involves two older clouds and a younger one [Fig. 3.5(1)]. The younger cloud develops vigorously as its nearby low-level convergence is enhanced. This substantial increase of low-level convergence is the consequence of the approach of two older clouds' cold outflows [Fig. 3.5(2)]. Another case involved only two clouds with differential propagation speeds. The relatively fast-moving one catches and merges with the second one. Based on model results, we found that the fast propagation of a cloud is simply the result of discrete generation of new convection along the cold outflow.

The same case has been studied through our two-dimensional version of the model (Tao and Simpson, 1984). It is found that the results from the two- and three-dimensional experiments showed more similarities than differences.

CURRENT RESEARCH:

Current work is being conducted to apply the model to other tropical and mid-latitude storm observations. For example, temperature, mixing ratio, and wind profiles of two other well-documented GATE cases, July 5 (day 186) and September 18 (day 261), will be used as the initial conditions. Also,

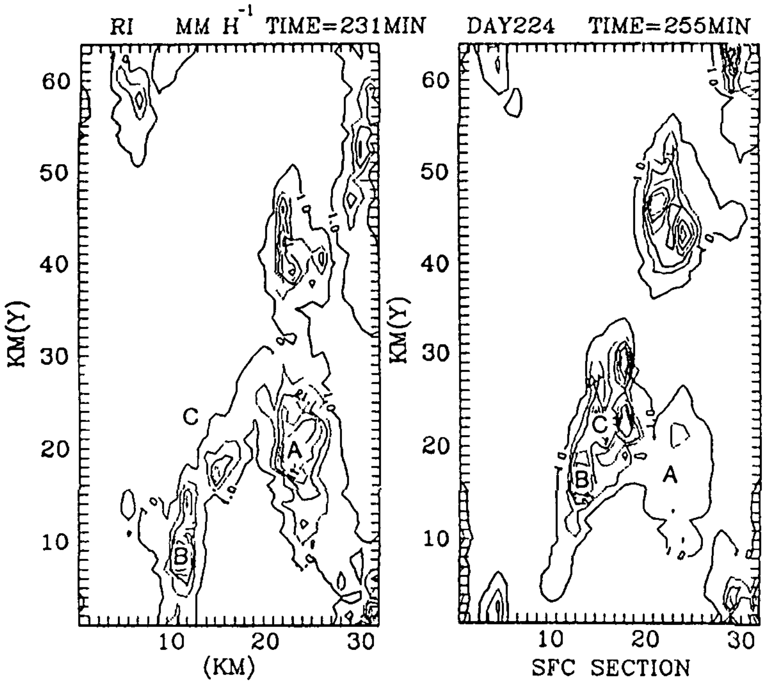

Fig. 3.5(1). Merger of Model Clouds Shown by 24 Minute Rain Rate Change. The estimated rainfall rate over the horizontal domain is shown at t = 231 and t = 255 min. Contour intervals are 10 mm h^{-1}.

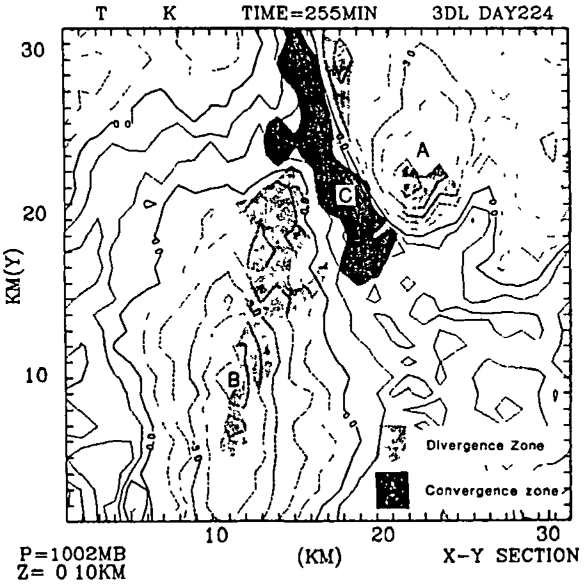

Fig. 3.5(2). Low-Level Analysis Illustrating Model Cloud Merger. This is a map of potential temperature deviation with a contour interval of 1 K degree. The dark shading denotes the convergence region (>-1 x -10^{-3} s^{-1}) and the light shading denotes divergence (>1 x 10-3 s-1).

the role of a parameterized two-classes ice phase microphysics on the structure of cold outflow is in progress; some preliminary results from our two-dimensional version of the model have been obtained. A comparison study is being made between the behavior of severe storms with the presence of a parameterized ice-phase and without it in the same mid-latitude storm environment.

FUTURE PLANS:

Based on model results, we found that the simulated clouds form into cloud bands which align predominantly with the direction of the lower-tropospheric wind shear. The cold outflow associated with the cloud band is also elongated with the shear. Observations show that the vertical shear of the horizontal wind is normal to the leading edge of convection in the fast-moving convective lines, but parallel to the leading edge of the slow-moving cloud lines. The relationships of the vertical wind shear to the direction of alignment of the convective line as well as the structure of the cold outflow will be our next task.

There will be continued development of the three-dimensional multi-cloud model. Two major modifications of the model will be considered. The first modification is the treatment of lateral boundary conditions, which is important for a limited-area model and to the results of the simulation of convective storms. The other is to include a more sophisticated three-class ice phase, which could be important for mid-latitude severe storms and tropical deep convective systems.

JOURNAL PUBLICATIONS:

Soong, S.-T., and W.-K. Tao, 1984: A numerical study of the vertical transport of momentum in a tropical rainband. J. Atmos. Sci., 41, 1049-1061.

Tao, W.-K., and J. Simpson, 1984: Cloud interactions and merging: Numerical simulations. J. Atmos. Sci., 41, 2901-2917.

Soong, S.-T., and W.-K. Tao, 1985: The statistical properties of a cloud ensemble: A numerical study. (In preparation.)

Tao, W.-K., and S.-T., Soong, 1985: A study of the response of deep tropical clouds to mesoscale processes: Three-dimensional numerical experiments. J. Atmos. Sci. (Submitted.)

CONFERENCE PUBLICATIONS:

Tao, W.-K., and J. Simpson, 1985: A numerical study of cloud interactions and merging: Three-dimensional experiments. Preprints, 16th Tech. Conf. Hurricanes and Tropical Meteorology, Amer. Meteor. Soc., Houston, TX.

3.6 Anvil Structure of Severe Thunderstorms (G. Heymsfield - GSFC, S. Schotz, and R. Blackmer - GSC)

RESEARCH OBJECTIVES:

The goals are to document and quantify severe thunderstorm cloud top and anvil structure using satellite, Doppler radar, and supporting data. Emphasis is placed on relating the satellite-observed thunderstorm observations to the environmental wind and internal storm structure. Specific data sets being analyzed are: a) SESAME and non-SESAME cases during the period 1979-1981; b) a severe (non-tornadic) thunderstorm on 1 August 1981 during CCOPE; and c) May 1984 ER-2 aircraft experiment data. A simple kinematic particle trajectory model is used to gain insight on the "V" pattern observed in the IR observations.

ACCOMPLISHMENTS:

a) The analysis of five SESAME and three non-SESAME severe storm cases to document and quantify features of thunderstorm tops was continued. Satellite observation and storm environmental soundings were analyzed in more detail for the different cases. While the visual characteristics (anvil lateral width and orientation) were obtainable for all the cases, the IR structure varied in complexity among the different cases. Quantities which were derived from the satellite observations included: width and orientation of both the "V" and anvil; ΔT and ΔX; the temperature difference and distance between the warm and cold areas comprising the thermal couplet; the distance between the distant warm region (when present); and the cold area of the couplet. Lateral widths of the anvils and "V"'s showed a large variability both among the cases and within the cases (due to growth with time). In addition, the larger anvils had more pronounced "V" shapes. The size of the anvil did not, however, have any bearing on whether storms developed tornadoes. These various quantities were plotted or compared against each other and against quantities obtained from the available environmental wind soundings.

b) The upper-level airflow structure associated with a hail-producing thunderstorm which occurred over the Doppler radar network on 1 August 1981 during CCOPE is being studied. Although this case does not have a "V" pattern in the satellite IR observations, it does have a more complete Doppler data set in the upper portions of the storm than previous studies. We are, therefore, examining the upper-level storm interaction with the environment such as mixing, blocking, etc., and differences in structure across the anvil as may be related to the IR "V" pattern. Doppler analyses indicate an elongated updraft perpendicular to the winds at upper levels with a maximum magnitude of about 30 m s^{-1} and highly divergent winds in the outflow region. Preliminary air trajectory calculations made from the data indicate that air directly downwind of the cloud summit in the interior of the anvil originates primarily from the downwind side of the updraft at lower levels. Air present along the outer portions of the anvil appears to originate from within and along the upwind side of the updraft core. Thus, the air across the anvil has different origins, implying temperature differences across the anvil. In addition, there is evidence that ice particles are being sent out in a "V" shape in the anvil.

c) Work has begun on analyzing 1984 field experiment data. This includes ER-2 remote measurements and the supporting data associated with some of the flight days. The May 19, 1984, case will be looked at in more detail because overflight measurements were coordinated with in situ and radar measurements. May 7 and May 25 cases will be examined to answer questions about cloud top structure. These studies are being done collaboratively with J. Spinhirne and R. Adler. In addition, collaborative work has been initiated with the University of North Dakota to analyze ER-2-coordinated microphysical in situ measurements on three of the flight days.

FUTURE PLANS:

Work on case studies of severe storm anvils will be completed. Analysis of CCOPE Doppler data will be continued and attempts will be made to retrieve thermal structure of anvil. Development of simple conceptual and numerical models to explain observational results will be continued. Intensive analysis of 1984 field program data will continue.

JOURNAL PUBLICATIONS:

Heymsfield, G. M., and S. Schotz, 1985: Structure and evolution of a severe Oklahoma squall line. Mon. Wea. Rev., 113. (In press.)

Ulanski, S. L., and G. M. Heymsfield, 1985: Meso-β scale perturbations in the wind field by thunderstorm cells. (Submitted.)

CONFERENCE PUBLICATIONS:

Heymsfield, G. M., and R. H. Blackmer, 1985: Characteristics of Midwest severe storm anvils. 14th Conf. Severe Local Storms, Amer. Meteor. Soc., Indianapolis, IN.

Spinhirne, J. D., W. L. Hart, S. P. Palm, G. M. Heymsfield, and R. F. Adler, 1985: Analysis of the radiative and structural characteristics of storm tops from aircraft, lidar and radiometer observations. 14th Conf. Severe Local Storms, Amer. Meteor. Soc., Indianapolis, IN.

3.7 Lidar and Radiometer Observations of Thunderstorm Tops (J. Spinhirne - GSFC and W. D. Hart - SSAI)

RESEARCH OBJECTIVES:

Techniques are being developed to observe high clouds with advanced instrumentation and analysis concepts. The goal is to lead to an improved understanding of the observed characteristic of thunderstorms and other clouds and to also lead to the definition of improved spaceborne sensors for storm and cloud observations.

SIGNIFICANT ACCOMPLISHMENTS:

a) The Cloud Lidar System (CLS) and Multispectral Cloud Radiometer (MCR) were developed as advanced airborne instruments for cloud remote sensing. They have been operated in the past several years from high-altitude aircraft. The CLS provides absolute ranges to cloud tops and also density structure and particle phase inference within cloud tops. The MCR provides high-resolution observations of visible, near IR, and thermal radiation and includes specific channels for passive cloud top height and particle size and phase determination. Extensive analysis work has gone into the interpretation of data results, and individual case studies for the CLS and MCR have been examined in detail. These include observation of multiple cloud layers, cirrus, and marine stratus which were acquired during an experiment in 1983 that included combined *in situ* measurements.

b) A combined analysis of the active lidar data coupled to passive radiance data has been developed. Attempts have been made in recent years to apply satellite infrared observations for studies of the evolution of severe storm systems. The correct interpretation of the infrared image structure is in question. The thermal radiation structure of storm tops is related to the particle density and temperature structure of the cloud top. It may be shown that the nature of the thermal radiation structure may be directly determined from combined lidar and radiometric observations. The cloud top height is directly given by the lidar measurement. In addition, the density structure into a cloud top may be obtained from lidar return profiles. The lidar-derived density structure may then be related to the differential emissivity within the cloud top, and the radiative influence of overlying layers and diffuse areas of the cloud top structure thus determined. The most recent experiment to observe severe storm tops was with the NASA ER-2 aircraft in May 1984. During the aircraft observations, rapid-scan GOES images of the storms were obtained. Intense storm systems were observed on May 7 and May 25. An interpretation of the thermal radiation structure of the storm tops from the lidar and radiometer observations has been developed. The particle density at the top of convective cells penetrating the tropopause is found to be such that the observed brightness temperature gives an accurate measurement of the cloud top temperature. The penetrating cells are surrounded by diffuse anvil structure for which components of the upward radiation at the cloud top may arise from several kilometers into the cloud. Isolated cirrus layers are at times observed within the stratosphere overlying the main anvil structure. These layers are typically too thin to have an effect on the observed thermal brightness. The aircraft observations of the storm systems have been obtained over several hours of storm evolution.

FUTURE PLANS:

Work on analysis technique with combined lidar-radiometer measurements will be completed. Intensive application to 1983 and 1984 field program data will continue.

JOURNAL PUBLICATIONS:

Spinhirne, J. D., M. Z. Hansen, and J. Simpson, 1983: The structure and phase of cloud tops as observed by polarization lidar. J. Appl. Meteor., 22, 1319.

CONFERENCE PUBLICATIONS:

Spinhirne, J. D., 1985: Remote sensing of clouds and boundary layer structure using airborne lidar. Conf. Optical Remote Sensing of the Atmosphere, Op. Soc. of Amer., Lake Tahoe, NV.

Spinhirne, J. D., W. D. Hart, and S. P. Palm, 1985: Structure and radiative characteristics of high clouds from a U-2 aircraft experiment. Joint IAMAP/IAPSO Assembly, Honolulu, HI.

Spinhirne, J. D., W. L. Hart, S. P. Palm, G. M. Heymsfield, and R. F. Adler, 1985: Analysis of the radiative and structural characteristics of storm tops from aircraft, lidar and radiometer observations. Preprints, 14th Conf. Severe Local Storms, Amer. Meteor. Soc., Indianapolis, IN. (In press.)

3.8 Modeling of Midwest Severe Thunderstorms (R. Schlesinger - U of Wisc)

RESEARCH OBJECTIVES:

Since March 1980, this project has been using a three-dimensional anelastic numerical cloud model, developed at the University of Wisconsin and residing in NCAR's scientific computing facility, to address two main areas relevant to infrared and visible geostationary satellite observations of severe convective storms such as occur in the Midwest and Great Plains:

1) the dynamics of "close-in" cold/warm cloud-top thermal couplets such as have been observed atop some severe storms with strong internal rotation; and

2) whether significant differences exist in cloud-top height/temperature structure between storms with and without strong internal rotation.

The main novel feature of this modeling project has been the diagnosis of cloud top features as well as the cloud interior, in order to look for possible correlations between patterns at cloud top and further down where radar or in situ sensors can provide other storm-scale data.

For further background, we note that one of the journal publications done under this project (Schlesinger, 1984; JAS, 41, 1551-1570) describes four comparative model experiments that were run in 1981, using a 27 x 27 x 20 uniform grid with 2.0-km horizontal resolution and 0.90-km vertical resolution. The experiments, designated Cases A-D, featured moderate to strong low-level vertical wind shear in Cases A-C and weak shear in Case D. A persistent "close-in" cold/warm thermal couplet developed on the cloud top in Cases A-C, bearing considerable resemblance to satellite observations of severe storms (Heymsfield et al., 1983; JAS, 40, 1739-1755), although with smaller amplitude and horizontal scale. The dynamics of the cloud-top couplet were extensively analyzed for Case B during parts of 1982 and 1983, via backward and forward air parcel trajectories through selected locations in and directly beneath the couplet.

SIGNIFICANT ACCOMPLISHMENTS:

a) The following changes in model numerics and physics have been tried:

1) Improved advection schemes have been adopted for heat and moisture. Formerly, the "modified upstream" scheme (Soong and Ogura, 1973; JAS, 30, 879-893) advected water vapor, liquid water, and perturbation potential temperature. Water substance is now advected using a two-step scheme of Smolarkiewicz (1983; MWR, 111, 479-486) with corrections for "cross-space" error (Smolarkiewicz, 1984; J. Comput. Phys., 54, 325-362) and phase error. Heat is advected using a flux-conservative version of the similarly corrected Crowley scheme that has been used in non-conservative form to advect momentum in the model (Schlesinger, 1984). Both the "modified

upstream" and Smolarkiewicz advection schemes are flux-conservative as well as positive-definite (no negative values are generated in an initially non-negative field), but the Smolarkiewicz scheme has much smaller implicit diffusion than "modified upstream." While the modified Crowley scheme is not positive-definite, it does hold numerical oscillations to low amplitudes, and the implicit diffusion is yet weaker than in the Smolarkiewicz scheme.

2) Changes have been made in the first-order "K-theory" parameterization of subgrid-scale turbulence. Formerly, the eddy coefficient K depended only on "large-eddy" deformation, computed after deducting areal averages of the horizontal wind components as an *ad hoc* way of keeping K small outside the main convective disturbance. In the alternative K small formulation, adapted from the approaches of Lilly (1962; *Tellus*, *14*, 148-172), Hill (1974; *JAS*, *31*, 646-673), and Clark (1979; *JAS*, *36*, 2191-2215), K is jointly proportional to the full deformation and to a function of a local Richardson number, Ri, in which the stability is taken relative to the dry (moist) adiabatic lapse rate at unsaturated (saturated) grid points, except that only a small variable background diffusivity without dependency on Ri is assumed wherever Ri is supercritical (larger than approximately 1/3). These changes were made to help avoid excessive turbulent mixing, particularly in strongly stable regions such as the stratosphere.

3) The microphysical parameterization of Takeda (1966; *J. Meteor. Soc. Japan*, *44*, 1-11) has been replaced by that of Kessler (1969; *Meteor. Monogr.*, *10*, No. 32) as used by Klemp and Wilhelmson (1978; *JAS*, *35*, 1070-1096). Takeda's formulation entails prediction of only the total liquid water, followed by a diagnostic breakdown into cloud and rain components, whereas Kessler's scheme predicts the two parts separately, with explicit terms for autoconversion, accretion, and rainwater evaporation.

The impact of the above model alterations has been assessed via reruns of the first 48 min of the aforementioned 60-min experiment Case B, with no change in initial or boundary conditions, and using the new advection schemes for heat and moisture in each instance. The principal findings have been: (1) The new advection schemes preserved the quasi-steady nature of the mature updraft, but increased its speed by about 30%. The updraft split at lower and middle levels, rather than elongating excessively without splitting as it had done under the old schemes. The low-level downdraft was also enhanced, and the cloud-top thermal couplet had about 30% more amplitude. (2) The alternative turbulence scheme, when tuned to produce mature updraft speeds about the same as for the old turbulence scheme, resulted in some slight further downdraft enhancement, more noticeable small-scale variability in model fields, and a further 30-40% enhancement of cloud-top thermal couplet amplitude along with a more pronounced "V" shape for the upshear cold area. (3) Replacing Takeda's microphysical parameterization by Kessler's had little effect on updraft strength or morphology, but resulted in a weaker low-level downdraft, larger maximum cloud and rainwater contents, and much more widespread surface rainfall. (4) Kessler's parameterization tended to yield very little cloud water in the anvil, a difficulty which was ameliorated by modifying the accretion term in accordance with a lower collection efficiency, either uniform or temperature-dependent, rather than the customary uniformly high collection efficiency.

b) Using the new advection schemes and turbulence parameterization, though retaining the Takeda microphysics package, the model has since been used to investigate the effects of stratospheric lapse rate on cloud top height/temperature structure. Three comparative 60-min experiments were performed using the same vertical profiles of wind, relative humidity, and tropospheric temperature as in Case B, though extending the model upward another 1.8 km via two more vertical grid levels (27 x 27 x 22 instead of 27 x 27 x 20). The assumed stratospheric temperature profiles in the three experiments were isothermal, a 3 $C^{o}km^{-1}$ lapse and a 3 $C^{o}km^{-1}$ inversion.

Kinematic storm structure was very similar in all cases, especially in the troposphere. A strong quasi-steady updraft evolved, splitting into a dominant cyclonic overshooting rightmover and a weaker anticyclonic left-mover. Strongest downdrafts occurred at low to middle levels between the split updraft regions and, in the lower stratosphere, a few kilometers upshear or downshear of the updraft summit.

Cloud summit height became lower as stratospheric stability was increased. A cloud-top thermal couplet, coldest near and upshear of the summit and with a "close-in" warm region downshear, occurred in all cases. Both cold and warm regions became warmer, and with significant changes in their appearances, as stratospheric stability was increased, though with little effect on the amplitude.

Overall, the cold region was offset most strongly upshear of the summit in the inversion run. It showed at least a transient "U" or "V" shape, with the arms pointing downshear, though persistently so only for the inversion.

With the 3 $C^{o}km^{-1}$ lapse (weakest stratospheric stability), the warm region was small and separated into two spots with secondary cold spots further downshear, but became larger and remained single for increased stratospheric stability. In each experiment, the warm regions were not accompanied by corresponding cloud-top height minima, except very briefly.

These modeling results have been submitted for consideration as a possible presentation at the American Meteorological Society's Fourteenth Conference on Severe Local Storms at Indianapolis, Indiana, during 28-31 October 1985.

FUTURE PLANS:

a) Cloud top dynamics, for one or more of the stratospheric lapse rate experiments just described, are to be further investigated by computing backward and possibly forward air parcel trajectories through selected parts of the cold and warm regions, using the same basic techniques as in the diagnostic study of Case B (Schlesinger, 1984).

b) As has already been done to some extent during this past year, selected NCAR code listings of the University of Wisconsin cloud model and/or associated diagnostic programs will be sent to GLA programmer Mike McCumber, who has been instrumental in setting up a higher-resolution modified version of the model on the CYBER 205. The anticipated listings include the trajectory diagnostics (backward and forward parcel trajectory computation and interpolation of diagnostic quantities to points along trajectories), cloud-top height/temperature diagnostics, and a model source listing with the stability-dependent turbulence formulation. In this manner, alterations and/or diagnostic programs already incorporated into the NCAR model package can be worked into the GLA version. Listings sent to GLA this past year have included the modified Crowley scheme for momentum advection, as well as the improved heat and moisture advection schemes.

c) After the various model improvements and diagnostic programs have been adapted to the CYBER, it is hoped to access the CYBER remotely, in order to run comparative experiments geared toward investigating differences in cloud-top structure between storms evolving in various assumed wind shear regimes, characterized by various combinations of Beltrami-like lower-tropospheric veering hodographs and/or upper-level shear featuring a (quasi-) unidirectional tropopause-level jet. Of particular interest will be whether cloud-top structure differs significantly in storms which do and do not produce strong mesocyclones in the lowest levels, the importances of lower- and upper-level shear to cloud-top structure, and the representativeness of divergence/vorticity fields computed on the generally sloping anvil surface.

JOURNAL PUBLICATIONS:

Schlesinger, R. E., 1984: Mature thunderstorm cloud-top structure and dynamics: A three-dimensional numerical simulation study. J. Atmos. Sci., 41, 1551-1570.

Schlesinger, R. E., 1984: Effects of the pressure perturbation field in numerical models of unidirectionally sheared thunderstorm convection: Two versus three dimensions. J. Atmos. Sci., 41, 1571-1587.

Schlesinger, R. E., 1985: Effects of upstream-biased third-order space correction terms on multidimensional Crowley advection schemes. Mon. Wea. Rev., 113. (Accepted.)

3.9 Satellite Detection of Severe Thunderstorms (R. Adler - GSFC, R. Mack, and M. Markus - GSC)

RESEARCH OBJECTIVES:

The objective of this research is to 1) increase our understanding of convective cloud top structure and evolution and 2) use this information to develop and test techniques to detect severe thunderstorms with satellite data.

SIGNIFICANT ACCOMPLISHMENTS:

a) Testing of TI technique. The testing of a Thunderstorm Index (TI) technique using parameters calculated from GOES IR observations has been completed (Adler et al., 1985). These parameters are rates of T_B decrease (both in the upper troposphere and the stratosphere), rate of T_B isotherm expansion (at $T_B \leq 226$ K), and storm lifetime minimum T_B (T_{min}, a measure of storm maximum height). Each parameter has been shown to be statistically related to the occurrence of severe weather (tornadoes, hail) on four case study days.

The four parameters have been combined into a Thunderstorm Index (TI), varying from values of one to nine. Storms with TI $\geq$ 6 have a much higher probability of having severe weather reports and there is a potential warning lead time of 15 min for the first report of hail and 30 min for the first tornado report. The results have been confirmed with an independent case.

The appearance of a "V"-shaped IR cold feature with an embedded warm point (a cold-warm couplet) has also been shown to be correlated with severe weather reports and with the satellite intensity estimates. Most storms (75%) with the "V" shape have severe weather, but many severe storms (45%) do not have the feature.

Limitations of using satellite IR data to detect severe thunderstorms have been detailed, including the diffficulty of storm identification during certain stages, limitations due to the coarse field-of-view on current geosynchronous satellites, and limitations due to cloud top T_B height ambiguities.

b) Automated detection of severe thunderstorms. Based on the positive statistical results of the TI technique and on knowledge gained on the limitations of the current GOES data, an automated procedure to 1) enhance and correct the IR data for thunderstorm analysis, 2) detect the location of thunderstorms, and 3) calculate pertinent parameters and identify features related to storm intensity and severe weather.

First, the raw image data is improved in two ways. The cold end of the IR brightness temperature (T_B) data (at T_B < 226 K) is recalibrated to eliminate the data voids commonly occurring in this range of brightness eliminate the data voids commonly occurring in this range of brightness temperature. Next, the effect of the lag in the instrument response is removed by using a linear lag removal algorithm.

In the next step, points of relative minimum in T_B are defined and determined to be thunderstorms if they pass a certain criteria designed to eliminate both thin cirrus and small perturbations of brightness temperature in anvil debris. These tests are based on a slope or gradient parameter around the minimum brightness temperature point.

Once the technique has defined a thunderstorm, it corrects for the coarse GOES Instantaneous Field-Of-View (IFOV). The need for such a correction has been established by comparing thunderstorm top GOES minimum T_B to near simultaneous observations with TIROS-N AVHRR data (1 km resolution) and aircraft overflight data. These comparisons indicate that for mature storms penetrating the tropopause, the miminum T_B is overestimated from 3 to 10 degrees due to the GOES IFOV. Immature storms below the tropopause have their minimum brightness temperature overestimated by as much as 30 degrees due to the same IFOV problem.

In this study, an empirical technique has been developed to use the GOES minimum T_B point and the slope of T_B around that minimum point to determine the necessary correction for the field-of-view. The technique has been tested on GOES data and verified against AVHRR and aircraft data. The correction is then applied for each identified thunderstorm and this new corrected cloud top temperature (T_c) is incorporated back into the image. The final step taken is to smooth the entire image so that the blockiness associated with the GOES infrared data disappears and the image and sequences of images are easier to interpret.

For each mature penetrating thunderstorm that has been defined (as indicated by a slope parameter less than a critical value), the amount of penetration above the tropopause (in terms of temperature) is determined in the following way. The neutral point temperature, T_n, is assumed to equal the anvil mode T_B (in an 80 km x 80 km block centered on the thunderstorm top). This procedure is based on similar calculations by Adler et al. (1985). With this neutral point temperature determined, the amount of penetration is merely ($T_n - T_c$). This ΔT parameter becomes the primary measure of thunderstorm intensity in the present technique and has been shown to be correlated with the occurrence of severe weather (Adler et al., 1985).

Since the appearance of a "V"-shaped cold feature or a cloud top cold-warm T_B couplet has been related to the occurrence of severe weather (e.g., Adler et al., 1985), an algorithm has also been developed that successfully searches out the vicinity of the defined thunderstorms for the existence of a significant warm point, thereby defining the existence of the cold-warm couplet and the "V"-shaped feature.

Initial examination of case studies using this approach [e.g., in Fig. 3.9(1)] indicates that thunderstorms are well detected by the algorithm. Small growing thunderstorms corrected for the field-of-view have a T_c much

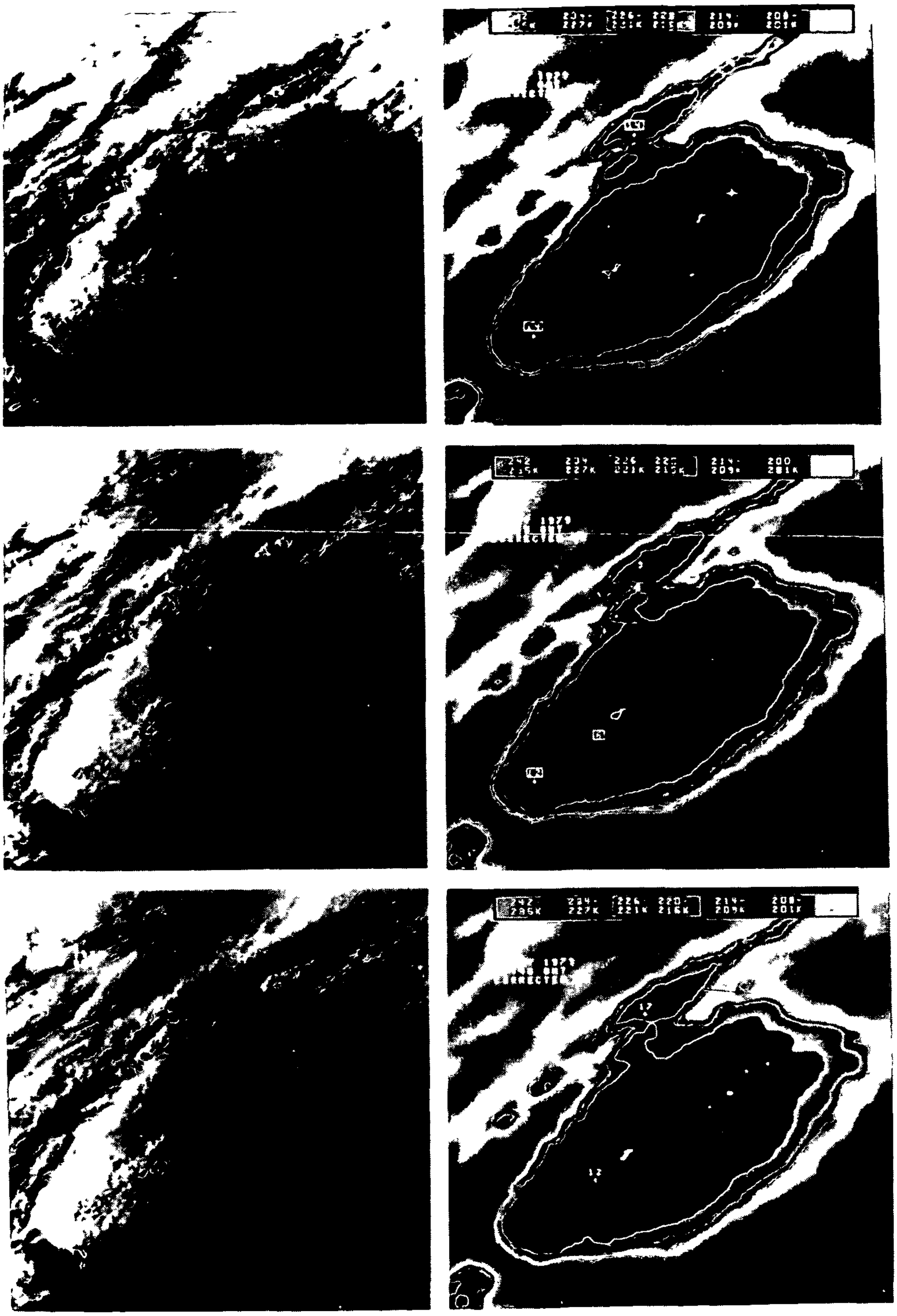

Fig. 3.9(1). Thunderstorm Detection Case Study for May 9, 1979. A sequence of visible and corresponding corrected IR imagery pairs at 3 minute intervals beginning at 23:42 Z are shown. Numbers above the mature storms are the ΔT parameter. A box enclosing the ΔT value indicates an objectively determined presence of a cold-warm couplet.

more appropriate to their actual height as compared to the original GOES observations. The most intense mature thunderstorms are emphasized and are easily located. The ΔT penetration parameter and the existence of the cold-warm couplet have been shown to be useful in identifying severe thunderstorms in these case studies.

c) Cloud top parcel model for thunderstorms. To aid in understanding cloud top T_B minimum (T_{min}) and maximum height (Z_{max}) values in relation to thunderstorm (updraft) intensity and to help in explaining observed cold-warm IR couplets in severe thunderstorms, a cloud top parcel model has been developed.

The Lagrangian model is applicable to the overshooting region of thunderstorm tops and is used to describe the temperature height path taken by updraft core parcels as they penetrate above the tropopause, reach their maximum height, and descend in the periphery of the convective tower. The model is run under a variety of ambient and in-cloud conditions in order to simulate certain temperature-height relationships observed in satellite observations. An example of such a simulation is shown in Fig. 3.9(2).

In the majority of observed storm tops, the satellite-observed cold point in the IR brightness temperature (T_B) field is collocated with the highest point in the convective overshooting region and the temperature-height relation is close to adiabatic (approximately 8 K/km), indicating cloud top mixing is relatively unimportant for this type of storm. The parcel model quantitatively reproduces this type of relationship for model runs where the mixing parameter is relatively small.

In a second type of intense storm often associated with accompanying severe weather, a cold "V"-shaped feature appears in the IR image with a point of relative maximum in T_B inside the "V" shape. This resulting close-in, cold-warm couplet has a dimension of approximately 20-40 km. Satellite stereo height patterns do not show a "V"-shaped or high-low couplet, but indicate a typical pattern of concentric height contours. A collection of storm top minimum T_B's and maximum heights from a series of storms under these conditions indicates a temperature-height relationship closer to ambient than adiabatic in contrast to the previous described set of storms. In some cases of "V"-shaped storms, the cold point is clearly located upwind of the high point. Model runs have been made to reproduce a number of these salient features for these types of storms. With larger mixing parameters, the model produces temperature height relationships that are, of course, much closer to ambient than to adiabatic. The larger mixing parameter is interpreted as being related to larger storm relative ambient flow in the overshooting region. With the larger mixing parameter, the cold-high offset is also produced, for model runs having a relatively large initial vertical velocity and occurring under conditions of a strong inversion. Under the same mixing conditions, it is shown that the amount of the cold-high offset is a direct function of the strength of the inversion.

The cause of the close-in warm point is also explored with the simple model. As has been shown in three-dimensional cloud model results by

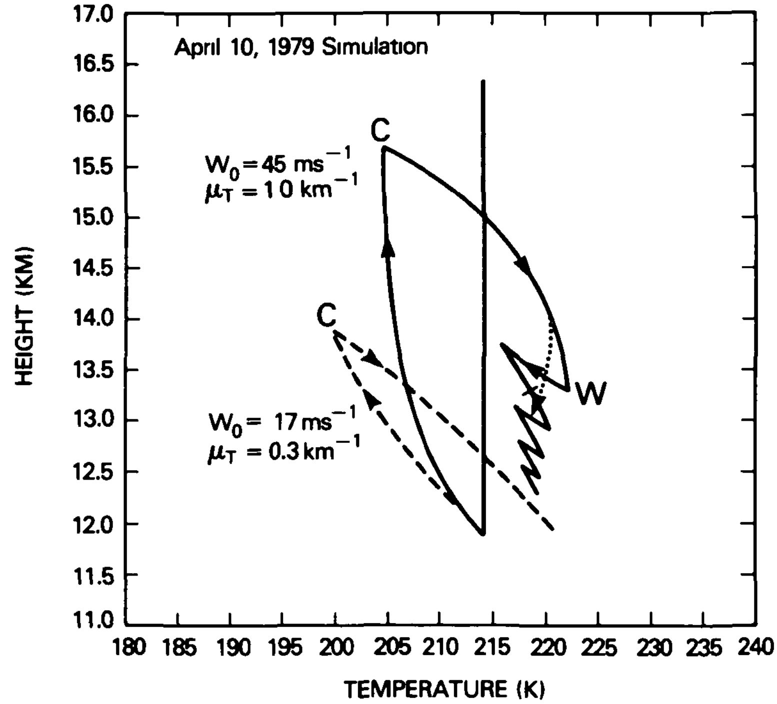

Fig. 3.9(2). Cloud Top Parcel Model Run for April 10, 1979. Parcel model run number 14 simulates a Wichita Falls, Texas, storm (solid line) and an interior storm without the cold-warm couplet.

Schlesinger, the warm point in the cold-warm couplet can be related to internal cloud subsidence on the downwind side in association with mixing with the environment. This effect is also reproduced in the parcel model with the warm point being related to conditions of an intense updraft, an inversion, and strong mixing. The model also points to parcels subsiding and overshooting the ambient lapse rate on the downwind side and then coming into equilibrium at a relatively high level above the tropopause on the downwind side. This type of effect may be related to the presence of cirrus at and downwind of the warm point as has been observed by a number of investigators.

FUTURE PLANS:

The automated detection of severe thunderstorm techniques will be refined and tested on pre-STORM (1985), SPACE/MIST (1986), and other historical cases and compared to severe weather reports and radar observations. Knowledge gained from the parcel model work and other work at GSFC (Heymsfield) will be used to estimate storm top height and tropopause penetration when appropriate and relate the amount of penetration to W_{max}, the maximum updraft velocity. A feature tracking algorithm will also be instituted so that time evolution and rate of change parameters can be calculated and used in a revised TI approach.

JOURNAL PUBLICATIONS:

Adler, R. F., M. J. Markus, and D. D. Fenn, 1985: Detection of severe midwest thunderstorms using geosynchronous satellite data. Mon. Wea. Rev., 113, 769-781.

Adler, R. F., and R. A. Mack, 1985: Thunderstorm cloud top dynamics as inferred from satellite observations and a cloud top parcel model. J. Atmos. Sci. (Submitted.)

CONFERENCE PUBLICATONS:

Adler, R. F., and R. A. Mack, 1984: Thunderstorm cloud top dynamics as inferred from satellite observations and models. Preprints, Conf. Satellite/Remote Sensing and Applications, Amer. Meteor. Soc., Clearwater Beach, FL, 115-120.

Adler, R. F., and M. J. Markus, 1985: Objective detection of severe thunderstorms using GOES IR observations. 14th Conf. Severe Local Storms, Amer. Meteor. Soc., Indianapolis, IN.

Adler, R. F., and R. A. Mack, 1985: A cloud top parcel model for thunderstorms—Comparison with satellite observations. 14th Conf. Severe Local Storms, Amer. Meteor. Soc., Indianapolis, IN.

3.10 Severe Storm Detection With Passive 37 GHz Observations (R. Spencer, M. Howland, and D. Martin - U of Wisc)

RESEARCH OBJECTIVES:

To determine the information content of satellite passive 37 GHz brightness temperatures on the severity of thunderstorms, through the measurement of the attenuation (scattering) signature of precipitation.

SIGNIFICANT ACCOMPLISHMENTS:

The severe storm detection potential of satellite-observed passive 37 GHz radiances was evaluated by comparing Nimbus-7 Scanning Multichannel Microwave Radiometer (SMMR) data to reports of severe weather contained in the NSSFC severe weather log for calendar years 1979 and 1980 over the United States east of the Rocky Mountains. Heavy thunderstorms have a characteristic signature in the form of localized, very low 37 GHz T_B from scattering by precipitation-size ice particles (thick cirrus being transparent at this frequency).

The local noon and midnight "snapshots" taken by the SMMR on alternating days (with incomplete areal coverage of the United States on any given day) were scanned to find cases of strong scattering by precipitation, revealed by large differences between the 18 and 37 GHz brightness temperatures, the 37 GHz T_B being at least 20°C lower than the 18 GHz T_B. The value of the 37 GHz T_B was then compared to severe weather reports within one hour of the SMMR observation time, in the vicinity of the SMMR-observed storm. It was found that the degree to which the T_B were lowered was a fairly good indicator of the probability that the storm was severe. Of 263 storms observed by the SMMR during 1979 and 1980, 54% had severe weather associated with them for a T_B below 203 K, while 8% of those above this threshold were severe. This led to a probability of detection (POD) of 0.54, a false alarm ratio (FAR) of 0.45, and a critical success index (CSI) of 0.375. For 1980 alone, these numbers improved significantly to a POD of 0.60, FAR of 0.29, and a CSI of 0.48.

While competitive with published skills for radar detection of severe storms, these skills are difficult to compare to those of radar because (1) radar offers nearly continuous monitoring, while the SMMR observes any given storm for only an instant, (2) radar methods are typically derived only during the severe weather season and in areas prone to severe thunderstorms, whereas this study involved all seasons and the eastern two-thirds of the United States, and (3) the poor spatial resolution of the SMMR 37 GHz channels (27 km) is not optimum to observe cores of thunderstorms. In view of these differences and the results of the SMMR-severe reports comparisons, there is sufficient evidence to pursue the possibility that geostationary passive microwave observations would be an important severe storm detection tool in the future, especially if synthetic aperture techniques or other technological improvements allow imaging at high spatial resolutions at frequencies low enough to allow the monitoring of precipitation-induced effects only (generally below 50 to 90 GHz). Alternatively, high-frequency measurements (near 200 GHz) might provide information beyond what is currently available with infrared observations, though at the expense of poorer resolution.

CURRENT RESEARCH:

A case study of intense convection is being carried out with comparisons between SMMR T_B and time lapse WSR-57 radar data to better determine the height and types of precipitation hydrometeors responsible for the strong T_B signatures observed at 37 GHz.

FUTURE PLANS:

Additional comparisons will be made between SMMR T_B and severe weather reports subsequent to 1980.

JOURNAL PUBLICATIONS:

Spencer, R. W., W. S. Olson, W. Rongzhang, D. W. Martin, J. A. Weinman, and D. A. Santek, 1983a: Heavy thunderstorms observed over land by the Nimbus-7 Scanning Multichannel Microwave Radiometer. J. Clim. Appl. Meteor., 22, 1041-1046.

Spencer, R. W., D. W. Martin, B. B. Hinton, and J. A. Weinman, 1983b: Satellite microwave radiances correlated with radar rain rates over land. Nature, 304, 141-143.

Spencer, R. W., B. B. Hinton, and W. S. Olson, 1983c: Nimbus-7 37 GHz radiances correlated with radar rain rates over the Gulf of Mexico. J. Clim. Appl. Meteor., 22, 2095-2099.

Spencer, R. W., 1984: Satellite passive microwave rain rate measurement over croplands during spring, summer, and fall. J. Clim. Appl. Meteor., 23, 1553-1562.

Spencer, R. W., and D. A. Santek, 1985: Measuring the global distribution of intense convection over land with passive microwave radiometry. (Accepted.)

Spencer, R. W., 1985: An improved satellite passive 37 GHz method for measuring oceanic rainfall. (Submitted.)

3.11 Soil Moisture and Evapotranspiration Estimates Based on Satellite Data

(P. Wetzel - GSFC, R. Woodward - GSC, and J. Chang - SASC)

RESEARCH OBJECTIVES:

To develop an accurate, verifiable land surface/vegetation/evapotranspiration model for remote sensing applications and as a parameterization for use in the Kaplan MASS model for two purposes: 1) to simulate the response of the boundary layer to variations in surface characteristics, such as soil moisture and land use; and 2) to apply these models to the estimation of surface soil moisture and evapotranspiration and to study the effects of the surface on convective storm initiation.

SIGNIFICANT ACCOMPLISHMENTS:

a) Statistical analysis of two case studies on the estimation of soil moisture using GOES infrared data in conjunction with vegetation index data provided by J. Tucker (Code 623) and an atmospheric water vapor correction algorithm written by D. Chesters (Code 613) confirms that about four classes of soil moisture are distinguishable using our simple two-step linear regression technique. The method is more sensitive to soil moisture differences in dry soil where the thermal response is larger. Fig. 3.11(1) shows a five-day average of computed and estimated soil moisture (square of the fractional soil moisture deficit), the difference between the two. A scatter plot of all points in the data set appears in Fig. 3.11(2). The largest errors are in southwestern and north-central Kansas. In the latter region, a possible erroneous value of vegetation index may be the source of the error.

b) The GSFC version of the MASS model has been upgraded to include an improved PBL parameterization and evapotranspiration/land use model (see below). Benchmark tests with versions similar to the LaRC model show excellent agreement between the models. Further analysis of MASS model simulations of the Grand Island tornado case of 3 June 1980 confirms the presence of a sea breeze-like thermal circulation which develops along a sharp soil moisture gradient in the vicinity of Grand Island and enhances the upward motion at the time and place of observed storm development.

c) A relatively simple, verifiable model of regional evapotranspiration has been developed which is designed specifically for application to heterogeneous surface cover conditions and which incorporates a number of potentially remotely sensed input parameters (surface temperature, vegetation index, soil moisture, and surface roughness). The model is being verified against in situ data sets and is being incorporated into the MASS model.

FUTURE PLANS:

a) Verification and sensitivity tests of the evapotranspiration model will continue. The model will also be tested using remote sensing data to determine its usefulness in remotely estimating evapotranspiration.

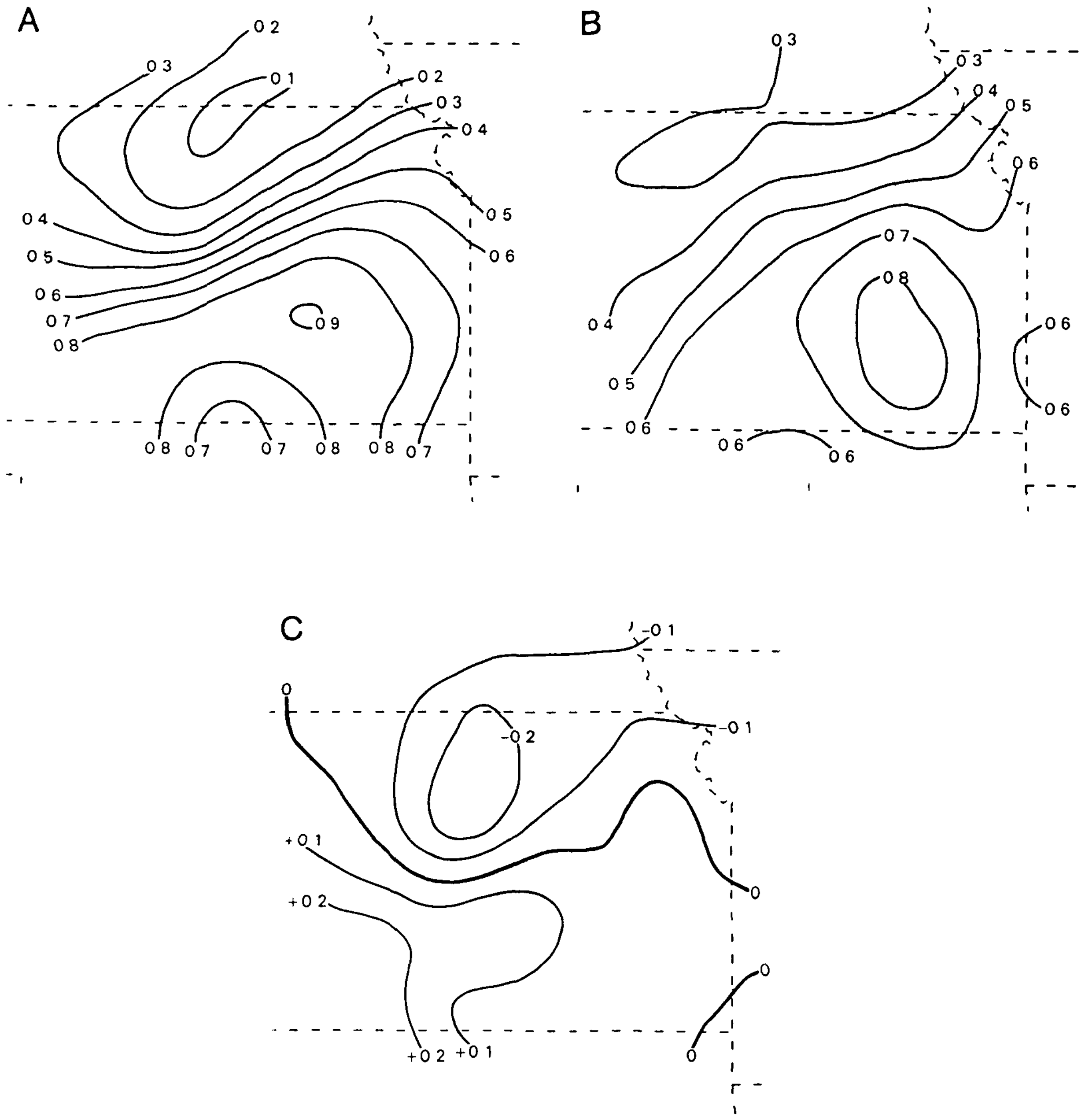

Fig. 3.11(1). Soil Moisture Deficit: Estimate and Verification. Five-day mean values of $m = (1-\omega)^2$, the square of the fractional soil moisture deficit for 24-28 July 1978 over eastern Kansas: a) as computed from antecedent precipitation index (API); b) as estimated using GOES thermal-infrared surface temperatures, NDVI, and wind speed data, with all data objectively analyzed onto a common grid; and c) the difference between the computed and estimated fields. Figures are from Wetzel and Woodward (1985).

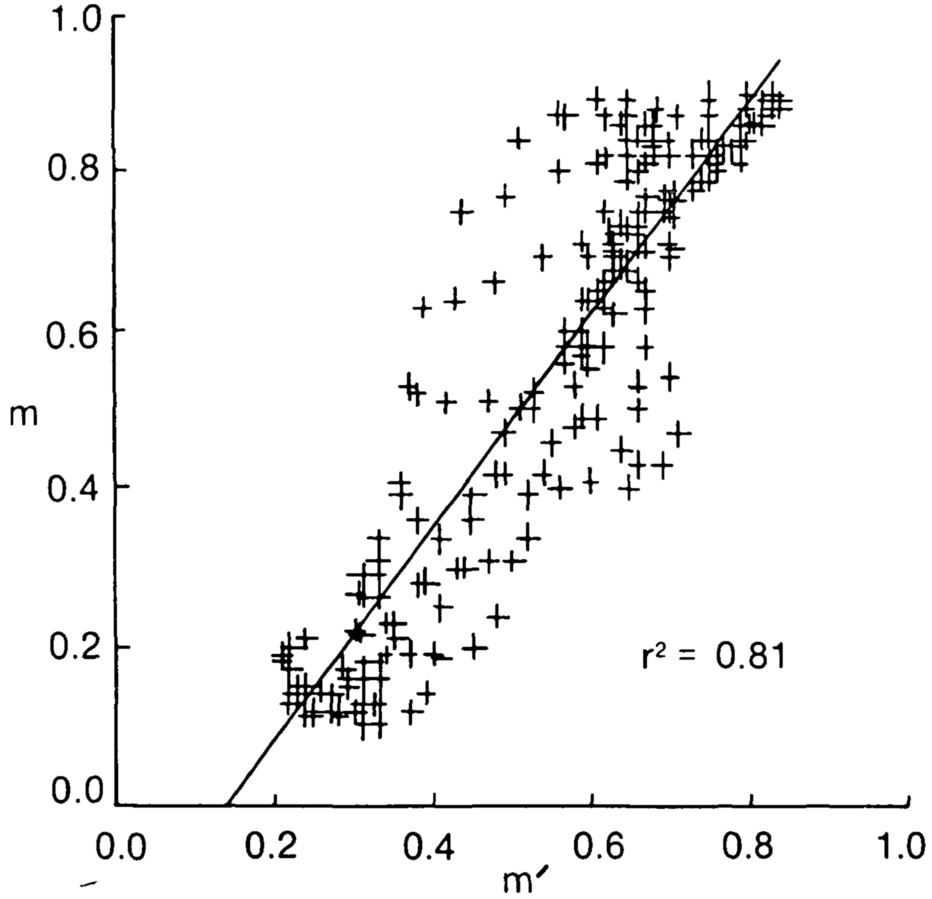

Fig. 3.11(2). Soil Moisture Deficit Verification Data. Scatter plot of grid point data from Fig. 3.11(1), comparing the observed field, m, from Fig. 3.11(1a) with the satellite estimate, m′ from Fig. 3.11(1b).

b) Sensitivity tests will be performed to determine the effect of vegetation, roughness, soil moisture, and evapotranspiration on the development of the Grand Island tornadic storm using the MASS model. A second case of apparent storm initiation along a soil moisture boundary is also under consideration.

c) A series of comparative tests is planned in collaboration with P. Sellers (Code 624) in which his "simple biosphere" model (SiB) will be used to verify our relatively simpler evapotranspiration model and to determine which of the many parameters in SiB have significant impact on the evolution of the PBL and lower atmosphere. These will take the form of idealized tests using a one-dimensional PBL model and perhaps some limited testing with the MASS model.

JOURNAL PUBLICATIONS:

Wetzel, P. J., D. Atlas, and R. H. Woodward, 1984: Determining soil moisture from geosynchronous satellite infrared data: A feasibility study. J. Clim. Appl. Meteor., 23, 375-392.

Wetzel, P. J., and R. H. Woodward, 1985: Soil moisture estimation using GOES-VISSR infrared data: A case study with a simple statistical method. J. Clim. Appl. Meteor. (Submitted.)

CONFERENCE PUBLICATIONS:

Wetzel, P. J., and R. H. Woodward, 1985: Regional evapotranspiration from combined satellite and conventional data. Preprints, 6th Conf. Hydrometeorology, Amer. Meteor. Soc., Indianapolis, IN.

Wong, V. C., G. D. Coats, J. W. Zack, and M. L. Kaplan, 1984: A numerical investigation of the effect of land-surface evapotranspiration on mesoscale forecasting. Preprints, 10th Conf. Weather Forecasting and Analysis, Amer. Meteor. Soc., Clearwater Beach, FL.

3.12 Estimation of Convective Rainfall from Visible and Infrared Satellite Data (A. Negri and R. Adler - GSFC)

RESEARCH OBJECTIVES:

a) Using 11.6 μm infrared (IR) and 0.5 μm visible (VIS) data from a geostationary satellite, estimate the rate, area, and duration of convective rainfall on scales of 100-300 km^2 and 15-30 min.

b) Develop the technique for convective rainfall estimates from basic physical principles, cloud modeling results, and statistics based on radar/satellite analysis.

c) Determine the sensitivity of these estimates to variations/deletions in the parameters, and test the results against other schemes and against ground truth.

SIGNIFICANT ACCOMPLISHMENTS:

a) Five days during the second Florida Area Cumulus Experiment (FACE-2) have been analyzed using GOES 15-30 min interval VIS and IR data. In addition, low-level reflectivity data from the WSR-57 radar at Miami have been processed (using RADPAK on AOIPS/2) into rain rate in satellite coordinates using a suitable Z-R relationship.

b) Applications programs have been written (which interface with AOIPS/2 software) to compute satellite-based parameters and relate them to radar-estimated rainfall. These include radiance parameters (visible brightness, IR blackbody temperature), gradient parameters (IR slope), and structure parameters (spatial variance).

c) A one-dimensional cloud model has been adapted to relate the height of model clouds growing in different thermodynamic environments to their precipitation production, a key relationship in making satellite-based techniques transportable across regions and seasons.

d) Formulation of a three-tiered approach to rain area estimation:

1) Threshold technique: Any grid square whose temperature is below a pre-set threshold is a candidate rain area grid square. This is appealing because of its simplicity, and may serve as a control or baseline against which other schemes may be tested.

2) Modified Griffith-Woodley technique (non-life history): Clouds (defined by the 253 K isotherm) are divided into their 10% and 50% coldest areas. The fraction of the grid square containing pixels in these areas becomes a parameter to test. This is appealing because the threshold temperature at which it is raining in young, growing clouds will not be the same as in mature clouds with large anvils.

3) Minimum temperature method: The pixel (or cluster of pixels) colder than its surrounding pixels become a candidate rain area. This is appealing because it will tend to identify rain maxima, around which lighter rain may be "modeled."

Methods 1-3 (above) may be enhanced by the addition of parameters designed to discriminate among thin cirrus, anvil cirrus, and active convection. These may include a slope parameter from the IR data, or a visible structure parameter derived from the distribution of pixel differences within a grid square.

e) A "t" test on the difference in means of rain classes is performed at each stage to test the separability of rain classes using satellite parameters. An example of the separability of three parameters using the minimum temperature of every cloudy grid square (method 1) is shown in Table 3.12A. [See caption for a complete description.]

Table 3.12A. Rain Parameter Separability. An example of the separability of three rain parameters using the minimum temperature of every cloudy (16 x 16 km) grid square. For each class, the sample size (n), mean (m), and standard deviation (s) are indicated. The tabular entries are the statistics:

$$[\ (m(i) - m(j))/\ \hat{s} - t(v,a)\ ] \text{ and } v\ ;$$

where m(i) and m(j) are the means for the ith and jth classes (i>j),
s is the combined standard deviation,
t is the "t" statistic for v degrees of freedom in a one-tailed test with significance level a, and
v = (n(i) + n(j) - 2) where n(i) and n(j) are the sample sizes.

A positive entry denotes the separability of the classes is statistically significant. Half-hour data from one day (1600-2200 GMT) have been used.

```
                                          MINIMUM TEMP (K)
                                (T STATISTIC - T_COMPUTED) / DEG. FREEDOM

            MAX RAINRATE (MM/H)                     MEAN RAINRATE (MM/H)                      FRACTIONAL AREA PPT

      0.- 2.  2.- 6.  6.-24. 24.-50. 50.-     0.0-0.5 0.5-1.7 1.7-6.7 6.7-14. 14.-      0.0-0.2 0.2-0.4 0.4-0.6 0.6-0.8 0.8-

N   488.00  116.00  147.00  127.00   36.00    415.00  157.00  182.00  106.00   54.00    625.00   89.00   74.00   52.00   74.00
M   215.81  208.87  209.35  208.12  206.03    216.77  208.97  208.96  209.46  206.72    215.15  209.67  206.19  205.12  204.20
S     9.77    6.46    7.65    6.70    6.21      9.85    6.15    7.03    8.23    6.80      9.59    6.32    4.35    2.18    2.98

        0       1       2       3       4         0       1       2       3       4         0       1       2       3       4

1    5.622                                     7.604                                     3.578
   /   602                                   /   570                                   /   712
2    5.711  -2.179                             8.023  -1.620                             6.289   2.349
   /   633 /   261                           /   595 /   337                           /   697 /   161
3    6.714  -0.759  -0.246                     5.385  -2.192  -2.196                     5.877   3.349  -0.016
   /   613 /   241 /   272                   /   519 /   261 /   286                   /   675 /   139 /   124
4    4.262   0.667   0.758   0.024             5.619   0.603   0.412   0.450             8.110   5.156   1.576   0.222
   /   522 /   150 /   181 /   161           /   467 /   209 /   234 /   158           /   697 /   161 /   146 /   124
```

Results show that for the parameter's maximum and mean rain rate, only the lightest and heaviest raining classes are discernible from the other three; classes 1, 2, and 3 are statistically inseparable under these assumptions (i.e., the grid square is potentially raining because it has a pixel colder than a given threshold, and its rain rate is a function of the coldest temperature in the grid square). The fraction of the 256 km^2 grid square covered by rain (1 mm/h) is almost completely separable by this parameter. However, a range of only 11 K separates the highest and lowest classes.

FUTURE PLANS:

a) The most critical problem is the normalization of each parameter so that data from all times of the day may be pooled. This is necessary due to both the changing solar illumination and the life cycle of the convection. For example, it may be necessary to reference the computed visible structure parameter to its mean or maximum value over all the cloudy pixels in the image. Similarly, IR temperatures may be normalized by the coldest pixel in each image, provided that the thermodynamic structure of the area is homogeneous.

b) Develop and test a hierarchy of schemes to make half-hourly to daily estimates of precipitation from satellite measurements. The relative merits and demerits of each methodology must be evaluated in a systematic manner. It must be demonstrated which results are statistically significant, and which parameters contribute to the reduction of variance.

c) The use of visible channel data has not been exploited in any type of quantitative manner, despite the obvious information one extracts when subjectively viewing imagery. This must be accomplished, and the degradation of results without the visible data noted.

d) The most physically appealing method remains the definition of candidate rain cells by the location of local temperature minima, perhaps screened by a secondary parameter such as IR slope or VIS structure. It is in this area that the bulk of the research will lie.

e) Analyze satellite and rainfall data sets from the SPACE/MIST experiment, to be conducted in the Huntsville, AL, area during the summer of 1986.

JOURNAL PUBLICATIONS:

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CONFERENCE PUBLICATIONS:

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Negri, A. J., and R. F. Adler, 1985: A statistical analysis of the separability of rain classes using visible and infrared satellite data. Preprints, 6th Conf. Hydrometeorology, Amer. Meteor. Soc., Indianapolis, IN. (In preparation.)

3.13 High-Frequency Microwave Observations of Convective Precipitation

(R. Adler - GSFC, I. Hakkarinen, R. Mack, J. Firestone - GSC, and G. Szejwach - USRA)

RESEARCH OBJECTIVES:

The purpose of this research is to investigate high-frequency microwave (92 and 183 GHz) observations to deduce their potential and limitations for observing convective and stratiform precipitation.

SIGNIFICANT ACCOMPLISHMENTS:

The Advanced Microwave Moisture Sounder (AMMS) developed by T. T. Wilheit of Code 670 is a four-channel passive scanning radiometer. Three channels of the AMMS are centered on the 183 GHz water vapor absorption line with side bands of ±2, ±5, and ±9 GHz. The fourth channel is located at 92 GHz in an atmospheric window. The radiometer scans ±45° across the track of the aircraft and has a ground resolution from 18 km altitude of 350 m (700 m) in the 183 (92) GHz channels.

Over the past few years, we have been analyzing images and data from the AMMS instrument in coordination with observations at visible and 11 micron wavelengths from the Multi-channel Cloud Radiometer (MCR), observations from the Cloud Lidar System (CLS), and ground-based radar. Results indicate that distinct convective features can be seen in the visible and 11 micron channels and also at the 92 and 183±9 GHz channels as areas of cold (100-230 K) microwave T_B. The cold T_B values have been shown to be related to scattering by the precipitation ice in the convective cloud. In addition, the microwave channels have identified convective features that do not appear in either the visible or IR images because of overlying clouds. Based partially on lidar observations, one of these features is indicated to be a small convective turret overlain by cirrus which is obscuring the feature in the visible and in the IR. However, the feature is distinct in the microwave images, indicating that these microwave frequencies may prove useful in delineating convection embedded in a large cirrus shield.

Similar very cold features with intense convection have also been noted with an ocean background, despite the somewhat lower emissivity of the ocean at this frequency. However, when examples of very shallow or weak convection are examined with an ocean background, the results indicate that the brightness temperature is actually a positive anomaly from a background surface brightness temperature. With increasing depth of the convection, these warm anomalies rapidly changed to cold brightness temperature anomalies.

The aircraft observations from the 1979 Florida flights, the CCOPE flights in Montana,` and more recently the spring 1984 flights in the Midwest clearly indicate that the 92 and 183 GHz channels can delineate cores of active convection. For anyone familiar with PPI radar data, the AMMS features are very similar. Upwind, they show very tight brightness temperature gradients, and downwind, relatively loose or weak brightness temperature gradients. There were early qualitative indications that the more intense the cell (as perhaps indicated by the 11 micron brightness temperature), the lower the microwave brightness temperature. Since Spencer et al. (1983) had empirically shown a brightness temperature-rain rate relationship for 37 GHz SMMR data, our next step was to determine if such a relationship also existed at 92 and 183 GHz from the aircraft data.

Figs. 3.13(1) and 3.13(2) give plots of brightness temperature vs. radar-determined rain rate for 92 and 183+9 GHz, respectively. The dots connected by the solid line are calculated values of brightness temperature from a radiative transfer model of Wu and Weinman (1984). They assumed realistic ice and liquid water profile for various intensities of convection and rain rates. The x's, triangles, and circles represent a combination of AMMS aircraft observations and ground-based radar estimated rain rates. The observations and the Wu and Weinman modeling results agree fairly well with a sharp drop in brightness temperature with increasing rain rate, especially between rain rates of 15 and 50 mm h^{-1}. The observations seem to reproduce the range of brightness temperatures from approximately 280 K to below 100 K that the radiative transfer calculations also show. In Fig. 3.13(2) (92 GHz), it can be seen that the relationships between brightness temperature and rain rate are essentially independent of whether one is over a land or ocean background, except for a slight increase in brightness temperature from the no-rain situation over ocean to the very light rain rate (approximately 1.5 mm h^{-1}) situation. However, there are indications in both diagrams that there might be significant differences between the various locations or climatological regimes that may have to be taken into account by a more detailed examination of the relationships between rain rate, amount of cloud ice, etc. These two graphs represent the first observational results linking 92 and 183 GHz brightness temperature to observed rain rates. It should be understood, however, that the link between microwave brightness temperature at these frequencies and rain rate at the bottom of the convective cloud is indirect. The upwelling radiance in these frequencies is a function of the amount and depth of ice in the cloud and is primarily coming from the upper few kilometers of the cloud, not the precipitating layer at the bottom of the cloud.

FUTURE PLANS:

The research described in this summary has potential application for upcoming satellite missions such as DOD's SSMI and also NOAA's AMSU (Advanced Microwave Sounding Unit). This research could also be helpful in planning the passive microwave instrument for EOS, that is, the HMMR. However, these frequencies also have potential use in geosynchronous orbit, especially the 183 GHz, which with a 4 m antenna would give 20 km resolution from geosynchronous altitude.

The current research effort is focusing on linking radiative transfer models at microwave frequencies from 19 to 183 GHz to dynamic cloud models

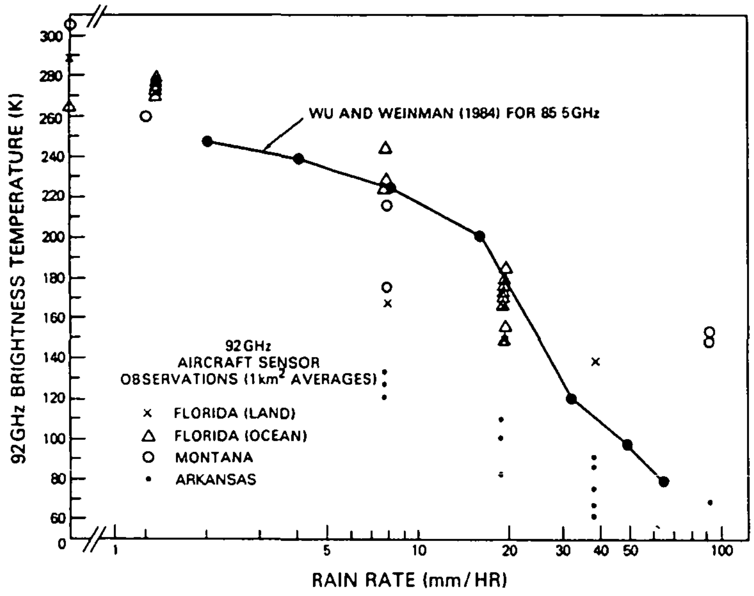

Fig. 3.13(1). 92 GHz Brightness Temperature Versus Rain Rate.

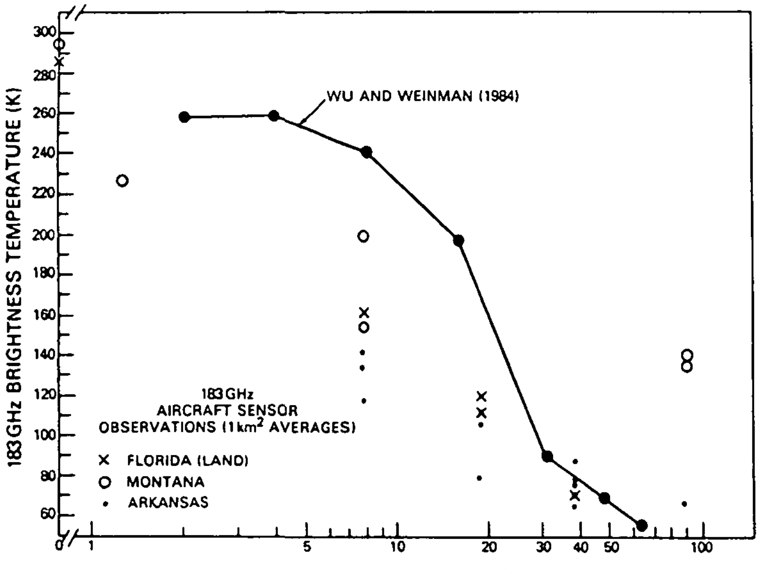

Fig. 3.13(2). 183 GHz Brightness Temperature Versus Rain Rate.

which include both liquid and ice phase. This is being done for a one-dimensional time-dependent cloud model (Cheng-Houze), a three-dimensional single cloud model, and a three-dimensional multi-cloud model (the Tao model). By linking an upwelling radiative transfer model to these cloud models, we can determine the sensitivity of the brightness temperature-rain rate relationships to various environmental conditions, such as stability, etc., and also to internal cloud conditions. We have already produced cloud model runs for the Cheng-Houze model for both Florida summer (tropical) conditions and Midwest springtime conditions. These cloud model results are being utilized to calculate the upwelling brightness temperature at a number of microwave frequencies. This linking of the radiative transfer model to the dynamic cloud model will allow us to produce rain rate-brightness temperature curves for different environmental regimes. We expect these results will indicate that we need to take into account the environmental differences in relating brightness temperature to rain rate and that this type of modeling approach may serve as the basis for a technique to estimate precipitation from brightness temperatures at various microwave frequencies. We are also continuing to analyze radar and aircraft data from the previous experiments, especially the 1981 CCOPE experiment and the spring 1984 Midwest flights. This should enable us to add substantially more points to the two graphs of brightness temperature vs. rain rate previously shown. We are also anticipating valuable data to be obtained during the GALE experiment in the winter of 1986 when the AMMS will fly on the ER-2. This should give us our best quantitative look at cool season stratiform precipitation with the AMMS data along with high-quality radar data. We also are looking forward to obtaining data during the 1986 summer in the SPACE/MIST field experiment in northern Alabama and southern Tennessee. With the high-quality radar data available there also, we should be able to verify the rain estimation technique we will have developed by that time.

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CONFERENCE PUBLICATIONS:

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3.14 Aircraft Observations of Marine Atmospheric Boundary Layer During Cold Air Outbreaks (S. Chou - GSFC, E. Yeh - USRA, and J. Firestone - GSC)

RESEARCH OBJECTIVES:

a) Analyze the NOAA P-3 aircraft data set measured during the Mesoscale Air-Sea EXchange (MASEX) experiment to study the dynamics and the evolution of the Marine Atmospheric Boundary Layer (MABL) during cold air outbreaks.

b) Further develop and validate Chou-Atlas (1982) remote sensing technique for ocean-air heat and moisture fluxes from the results of (a).

SIGNIFICANT ACCOMPLISHMENTS:

a) The structure and kinetic energy budget of turbulence in the convective MABL as observed by the NOAA P-3 aircraft during a cold air outbreak on 20 January 1983 have been studied using mixed layer scaling. The results are significantly different from those of previous studies under conditions closer to free convection (Caughey and Wyngaard, 1979; Lenschow et al., 1980). The normalized turbulent kinetic energy and turbulent transport are about twice those found during the Air Mass Transformation EXperiment (AMTEX). This implies that, for a given surface heating, this case is dynamically more active. The difference is mainly due to the greater importance of wind shear in the present case. This case is closer to the roll vortex regime while AMTEX observed mesoscale celluluar convection, which is closer to free convection. Shear generation is found to provide a significant energy source in addition to buoyancy production to maintain a larger normalized turbulent kinetic energy and to balance a larger normalized dissipation. The interaction between turbulent pressure and divergence (i.e., pressure scrambling) is found to transfer energy from the vertical to the horizontal components, and is expected to be stronger in roll vortices than in mesoscale cellular cells.

b) The heat flux, $\overline{w\theta}$, was found to fit well with a linear vertical profile in a clear or sub-cloud PBL, which is in good agreement with that of Lenschow (1974). According to the linear curve, the heat flux ratio between the PBL top and the surface is about -0.15, which is in good agreement with that derived from the lidar data for the same case (Melfi et al., 1985). Near the PBL top, the heat flux is negative due to entrainment and its magnitude is larger at the center than at both the top and the bottom of the entrainment zone. This is consistent with those of Deardorff (1979) and Deardorff et al. (1980). On the other hand, the humidity flux, $\overline{wq}$, appears to be disorganized in the vertical. The vertical profiles of $\overline{w\theta}$, θ^2, $\overline{wq}$, and q^2 suggest that the potential temperature is well mixed in the vertical; but the humidity is not.

c) The vertical wind shear and shear generation computed from the surface layer similarity of Businger et al. (1971) were found to be smaller than those estimated from the adjacent flight-level data using a simple finite difference method. Also, the surface layer similarity appears to overestimate the wind speed at the 50 m level of all the crosswind flight legs by 12-36% with a mean of 27%. This suggests that surface layer similarity might overestimate wind shear (and shear generation) below the 50 m level and underestimate it above that level. Since the surface layer similarity of Businger et al. (1971) was derived from the observations over land, it might not be valid over the ocean, especially when air-sea interaction is very intense. It is planned to investigate this problem further.

CURRENT RESEARCH:

a) The four flight days of MASEX observed regions of cloud streets, mesoscale cellular convection, the transition between them, and the Gulf stream. We are extending the analysis to the other three flight days (16, 18, and 19 January 1983) to validate the analysis on 20 January 1983 and to further explore the differences in the circulations and the associated mechanisms of turbulence generation. In addition, the effect of the Gulf stream on the MABL development will be studied.

b) The results of 16 and 18 January 1983 will be used to verify and further develop the Chou-Atlas (1982) remote sensing technique for the ocean-air heat and moisture fluxes.

FUTURE PLANS:

a) Investigate the characteristics of the marine atmospheric surface layer for situations with strong air-sea interactions.

b) Study the interaction of boundary-layer clouds with radiation from MASEX measurements.

c) Develop a remote sensing technique for the ocean-air heat and moisture fluxes for cloudy regions.

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Deardorff, J. W., G. E. Willis, and B. H. Stockton, 1980: Laboratory studies of the entrainment zone of a convectively-mixed layer. J. Fluid Mech., 100, 41-64.

Lenschow, D. H., 1974: Model of height variation of the turbulence kinetic energy budget in the unstable planetary boundary layer. J. Atmos. Sci., 31, 465-474.

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Chou, S.-H., D. Atlas, and E.-N. Yeh, 1985: Turbulence in a convective marine atmospheric boundary layer. J. Atmos. Sci. (Submitted.)

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3.15 Three-Dimensional/Perspective Display Techniques for Meteorological Data Sets (A. Hasler - GSFC and H. Pierce - GSC)

RESEARCH OBJECTIVES:

Develop three-dimensional perspective presentation techniques which allow the display of the massive, complex data sets typical of meteorology in a manner which makes it easier to detect and understand significant features.

SIGNIFICANT ACCOMPLISHMENTS:

Perspective display techniques have been applied to meteorological data sets to aid in their interpretation. The display procedure has been applied to satellite and aircraft visible and infrared image pairs and to stereo cloud top height analyses. The procedure uses a sophisticated shading algorithm that produces perspective images with greatly improved comprehensibility when compared with the wire-frame perspective displays that have been used in the past. The example shown in Fig. 3.15(1) is scheduled to appear on the July cover of the Bulletin of the American Meteorological Society with an accompanying article by Hasler et al. (1985).

By changing the "eye-point" and "view-point" inputs to the program in a systematic way, movie loops have been made which give the impression of flying over or through the data field. Several examples have been completed which show how different kinds of meteorological data fields are more effectively illustrated using the perspective technique.

FUTURE PLANS:

More sophisticated illumination algorithms will be investigated which model atmospheric scattering and which should improve the infrared-only presentation. If the perspective program can be made to run much faster, ideally at standard television refresh rates of 1/30 of a second, and operate under control of a joystick or similar device, it would be an even more powerful data set examination and analysis tool. Access to public domain software with better speed will also be investigated. An ideal application of the technique would be for the display numerical model results. This will be accomplished in the coming year.

JOURNAL PUBLICATIONS:

Hasler, A. F., H. Pierce, and J. Dodge, 1985: Meteorological data fields "in perspective." Bull. Amer. Meteor. Soc., 66, 795-801.

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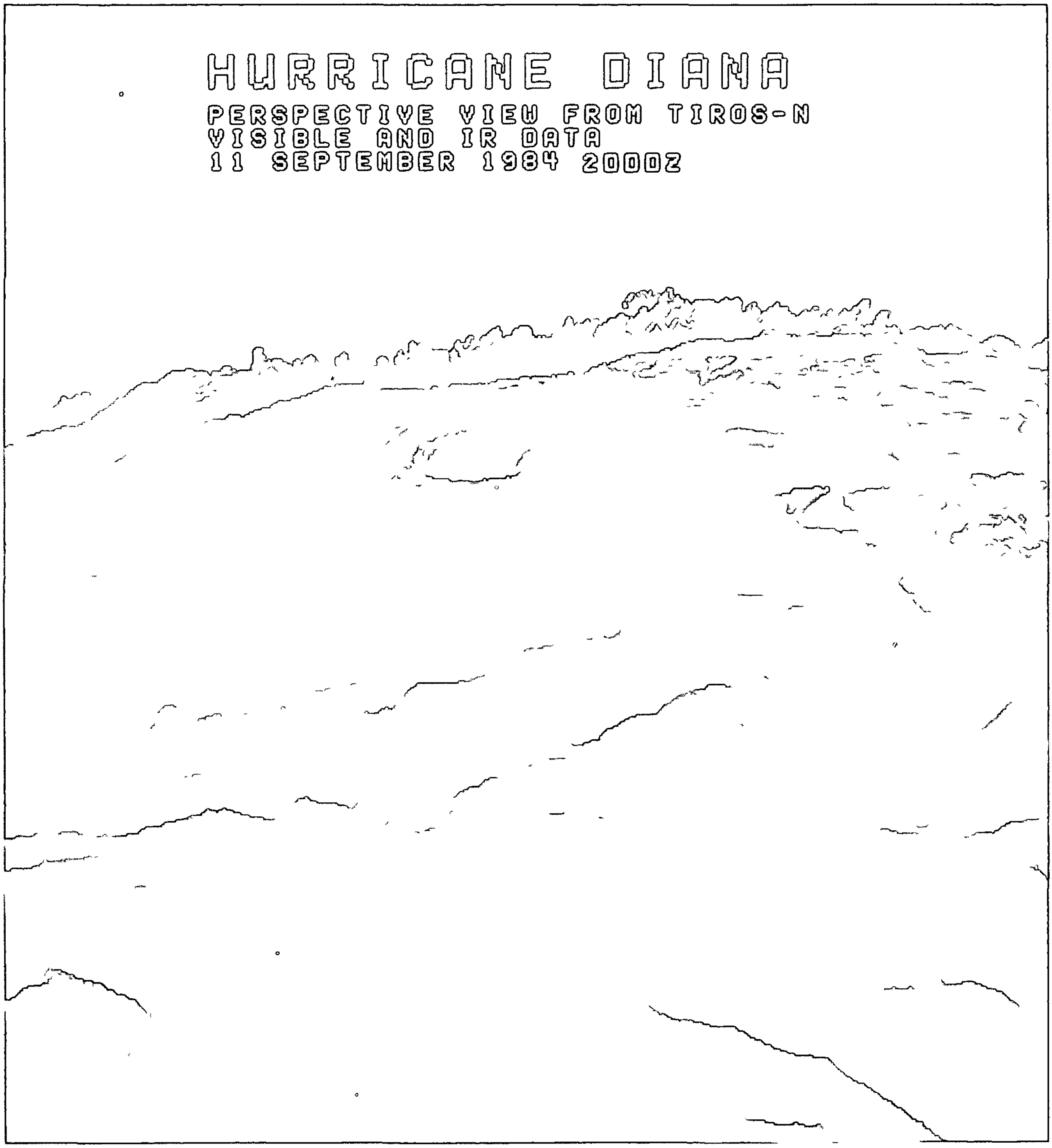

Fig. 3.15(1). Perspective View of Hurricane Diana. This image of Diana at 2000 GMT on September 11, 1984, was derived from a 1 km-resolution visible and infrared AVHRR image pair from the NOAA operational satellite. The computer program which produces this image requires specification of a view-point, an eye-point, and a vertical scaling factor.

4. MESOSCALE ANALYSIS AND MODELING RESEARCH (L. Uccellini and Staff)

4.1 Review of VAS Demonstration (L. Uccellini, H. Montgomery, D. Chesters, R. Petersen - GSFC)

RESEARCH OBJECTIVES:

The VAS Demonstration was a four-year research effort designed to develop sounding algorithms based on the use of VAS radiances, test the validity (statistical accuracy) of VAS soundings, and assess the usefulness of VAS imagery and moisture and temperature retrievals in the analysis of the pre-convective environment for severe convective storm systems.

SIGNIFICANT ACCOMPLISHMENTS:

a) The VAS Demonstration has been summarized with reports which 1) describe the instrument and its operating modes, 2) prove that VAS meets radiometric specifications, 3) present promising meteorological results, and 4) offer archived VAS data sets for research. Many presentations have been made to demonstrate the potential usefulness of VAS.

b) VAS image data has been used to diagnose the vertical, horizontal, and temporal evolution of tropopsheric water vapor in several cases. Overlays of mid-level 6.7 μm imagery with low-level 11/12 μm "split window" imagery clearly identify regions of potential convective instability where dry air overlays moist.

c) A sounding algorithm was developed which combines VAS radiances with surface temperature and dewpoints. The combination of VAS and surface data proved to be effective in yielding temporally coherent mesoscale fields which proved to be useful in the analysis of severe storms.

d) A thorough analysis of VAS temperature and dewpoint retrievals has shown that they contain quantitative information about the potential for instability in a pre-convective environment which cannot be otherwise discovered from the operational surface and radiosonde reports. Significant limitations were demonstrated in VAS' vertical resolution and in VAS' coverage of cloudy regions.

FUTURE PLANS:

The VAS Demonstration ended in 1984; current research is discussed in Sections 4.2 and 4.3.

JOURNAL PUBLICATIONS:

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Petersen, R. A., L. W. Uccellini, D. Chesters, and A. Mostek, 1983: The use of VAS satellite data in weather analysis, prediction and diagnosis. Nat. Wea. Digest, 8, 12-23.

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Petersen, R. A., D. A. Keyser, A. Mostek, and L. W. Uccellini, 1983: Severe storm analysis and forecasting techniques using VAS satellite data. Preprints, 13th Conf. Severe Local Storms, Amer. Meteor. Soc., Tulsa, OK.

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4.2 Nowcasting Applications of VAS (R. Petersen - GSFC and J. Homan - GSC)

RESEARCH OBJECTIVES:

a) Develop procedures to use detailed objective analyses of radiosonde data with simple forecasting procedures to provide 6-12 h wind forecasts.

b) Incorporate VAS image moisture data into forecast model to isolate areas of convective instability changes for convective outlooks.

SIGNIFICANT ACCOMPLISHMENTS:

a) A simple, isentropic forecast procedure has been developed which maintains the resolution of its detailed initial analysis throughout a 12-h cycle. The technique is computationally efficient and has been adapted to the VAX computing system.

b) Forecasts of upper-level trajectories emanating from a jet streak in a case of strong baroclinicity and curved flow have been obtained. The trajectories, while experiencing substantial energy changes, agreed well with trajectories obtained from the observed radiosonde data. These results may have implications for upper-level aviation wind forecasts.

c) Three-dimensional forecasts have been obtained for the 29 August 1984 severe storm development. Properly isolated location and movement of regions of greatest tropopause heights, maximum mid-level P.V.A., and low-level moisture transport 9 to 12 h prior to storm development [see Fig. 4.2(1)].

d) Three- to 12-h forecasts of simulated VAS 6.7 μm and "split window" imagery were produced for the 13 July and 20 July 1981 cases [see Fig. 4.2(2)]. The forecast images captured the progression of low-level moisture maxima and mid-level dryness bands observed in the initial image data using horizontal advection and adiabatic warming. When combined, the two-level moisture forecasts isolated areas of developing convective instability. The magnitude of the instability was less than observed in some cases, however, due to the lack of surface data and boundary layer parameterization at low levels.

CURRENT RESEARCH:

Hourly updated surface data (temperature, moisture, winds, clouds, moisture convergence, frontogenesis) are being incorporated to improve low-level nowcasting capabilities.

FUTURE PLANS:

a) Forecasts of low-level trajectories and convergence fields will be made using mass field forecasts which incorporate updated surface observations.

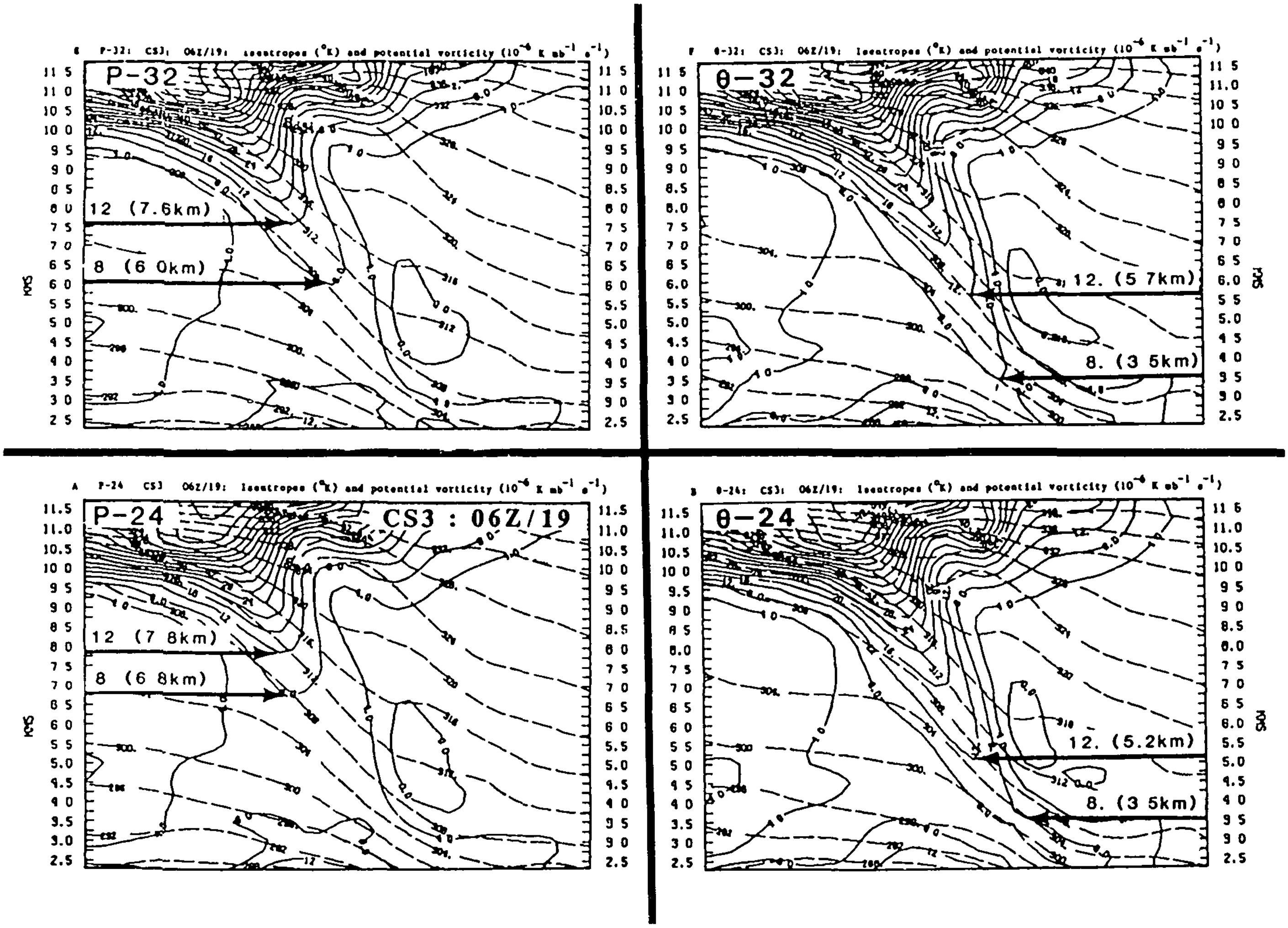

Fig. 4.2(1). Cross Sections Showing a Simulated Tropopause Fold. These cross sections show a simulated tropopause fold in terms of potential vorticity (10^{-6} K mb^{-1} s^{-1}, solid) and potential temperature (K, dashed) computed from MASS model output for a valid time of 0600 GMT 19 February 1979. These cross sections are from four different simulations: P-32 is a simulation using 32 sigma layers in the model and initialized with data analyzed on pressure surfaces; P-24 is a simulation with 24 layers initialized on pressure surfaces; θ-32 has 32 levels, but was initialized on isentropic surfaces; θ-24 has 24 levels and was initialized on isentropic surfaces. Bold arrows with heights in kilometers show the points of deepest penetration into the troposphere of the 8 and 12 contours of potential vorticity. The greater structural detail provided by initial data analyzed on isentropic surfaces (θ) results in a deeper simulated tropopause fold than that simulated using initial data analyzed on pressure surfaces (P). This is true for both 24- and 32-layer simulations. The model simulations were initialized at 0000 GMT 18 February 1979. The cross sections extend along a straight line from 50°N, 80°W, to 28°N, 85°W, as drawn on a north polar stereographic projection true at 90°N.

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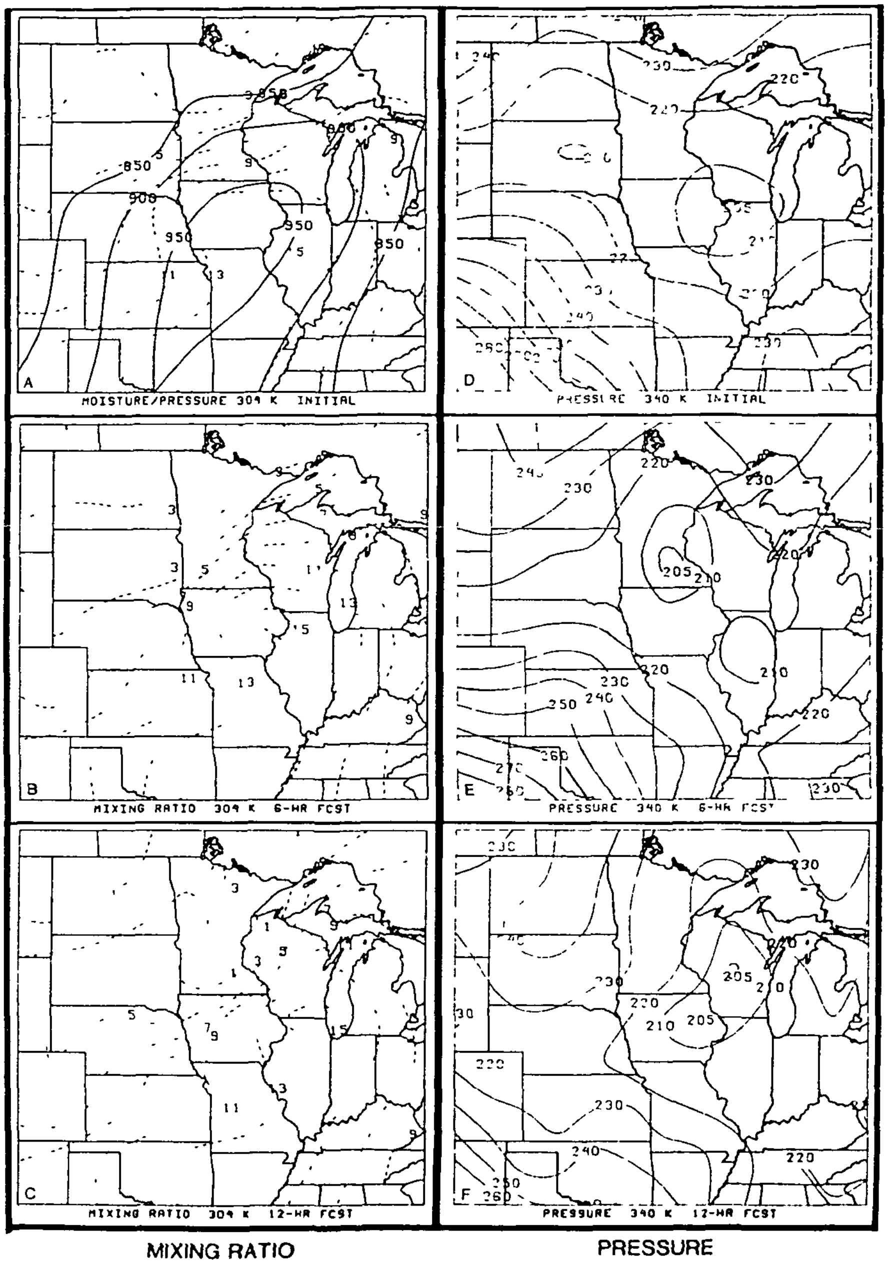


Fig. 4.2(2). Low-Level Moisture and Upper-Level Pressure Forecasts for Case Study of 29 August 1984. Six- and twelve-hourly forecasts of mixing ratio (left - A, B, and C) in g/kg and pressure (right - D, E, and F) in mb at 304 and 340 K levels, respectively, initialized at 1200 GMT 29 August 1984. Note movement of low-level moisture maximum (initially 15 g/kg at 950 mb - panel A) into southern Wisconsin coupled with an increasing tropopause height (lower pressure) over the same area. Severe convection develops over southern Wisconsin around 2100 GMT.

CONFERENCE PUBLICATIONS:

Petersen, R. A., and J. H. Homan, 1983: A simple Lagrangian forecast system with aviation forecast potential. *Preprints, 9th Conf. Aerospace and Aeronautical Meteorology*, Amer. Meteor. Soc., Omaha, NE, 123-128.

Petersen, R. A., J. H. Homan, and D. A. Keyser, 1984: Advective forecasts of VAS imagery for use in anticipating convective destabilization. *Preprints, 10th Conf. Weather Forecasting and Analysis*, Amer. Meteor. Soc., Clearwater Beach, FL.

Petersen, R. A., and J. H. Homan, 1985: The use of a simplified isentropic model to forecast convective destabilization using VAS moisture imagery. *Preprints, 7th Conf. Numerical Weather Prediction*, Amer. Meteor. Soc., Montreal, Quebec, Canada. (In press.)

Homan, J. H., and R. A. Petersen, 1985: The use of a simplified isentropic model for short-term aviation forecasting. *Preprints, 2nd Intl. Conf. Aviation Weather System*, Amer. Meteor. Soc., Montreal Quebec, Canada. (In press.)

Homan, J. H., and R. A. Petersen, 1985: The use of a simplified isentropic model for nowcasting convective development. *Preprints, 14th Conf. Severe Local Storms*, Amer. Meteor. Soc., Indianapolis, IN. (In press.)

4.3 Recent VAS Imaging/Sounding Research (D. Chesters, L. Uccellini, R. Petersen - GSFC, D. Keyser, A. Mostek, W. Robinson - GSC, and D. Larko - RDS)

RESEARCH OBJECTIVES:

The general objective of this study is to evaluate the mesoscale temperature and moisture information content of VAS data in case studies of convective storm environments using data sets collected during the OSIP-sponsored VAS Demonstration (1980-1983). Specific research objectives are:

1) to conduct an objective statistical evaluation of the accuracy of VAS retrievals for the NASA-sponsored VAS/AVE satellite/radiosonde special network experiment of 1982;

2) to develop qualitative analysis techniques for VAS image data which display the space-time behavior of convective stability fields at mesoscale resolution in near real-time; and

3) to implement and test a physically based retrieval algorithm for calculating stability parameters from VAS radiances.

SIGNIFICANT ACCOMPLISHMENTS:

Case studies of VAS retrievals have proven that optimum use of the VAS radiances can indeed measure stability values in convective environments and can resolve many otherwise unobserved mesoscale features within the coarse synoptic network. Specific accomplishments corresponding to the objectives are:

1) Regression-based VAS retrievals (trained with synoptic data) were statistically compared to the ground truth network experiment of 6 March 1982. While the synoptically trained VAS soundings capture the general regional features, these satellite retrievals were unable to resolve thin layers of temperature or moisture anomalies in the troposphere. However, the VAS low-level moisture soundings were more self-consistent than the conventional radiosondes.

2) Two experiments have been successfully completed which optimize the useful properties of VAS observations:

a) The optimum procedures for retrieving precipitable water (PW) from VAS data were explored. Regression-based retrievals which include VAS channels 5, 6, 7, and 8 and conventional surface dewpoint reports were found to yield most of the information about PW [Fig. 4.3(1)]. However, physically based retrievals using the two channels of the VAS "split window" provide superior PW fields when one is limited to VAS MSI data or to little radiosonde training.

b) A VAS data-presentation technique was invented with two unique features: 1) irregularly located ancillary data (such as conventional surface reports or satellite measurements of ozone) are interpolated into VAS satellite coordinates for use as high-resolution "channels" of additional information which can be displayed like GOES images; and b) entire fields of meteorological parameters are retrieved by applying a regression matrix to all VAS radiances and ancillary data at every field-of-view [Fig. 4.3(2)]. This enormous number of quantitative soundings can be vividly displayed as color-coded GOES-like images of atmospheric stability parameters such as PW, LI [see Fig. 4.3(3)], Φ, and θ_e.

3) The physical model for calculating PW from the VAS "split window" channels was refined by including horizontal averaging of the radiances to 30 km resolution, and by demonstration that channel-to-channel misregistration in the VAS MSI mode is detrimental to accuracy. A physical transmittance model was developed for retrieving surface temperature from the VAS 11 μm window channel, for use in soil moisture studies.

FUTURE PLANS:

Current work is focused on three remaining objectives:

1) to investigate the usefulness of ancillary TOMS ozone data in retrieving upper-air parameters in a regression-based algorithm;

2) to better define the optimum resolution and accuracy of VAS temperature and moisture retrievals which can be calculated using regression for the VAS/AVE experiment of 6 March 1982; and

3) to develop and test a physical algorithm for retrieving stability parameters from VAS dwell sounding radiances.

JOURNAL PUBLICATIONS:

Chesters, D., A. Mostek, and D. A. Keyser, 1985: VAS sounding images of atmospheric stability parameters. J. Clim. Appl. Meteor. (Submitted.)

Robinson, W. D., D. Chesters, and L. W. Uccellini, 1985: Optimized retrievals of high resolution precipitable water fields from combinations of VAS satellite and conventional surface observations. J. Geophys. Res. (Submitted.)

Mostek, A., L. W. Uccellini, R. A. Petersen, and D. Chesters, 1985: Assessment of VAS soundings in the analysis of a pre-convective environment. Mon. Wea. Rev. (Accepted.)

TECHNICAL PUBLICATIONS:

Chesters, D., 1984: Calculations of atmospheric transmittance in the 11 μm window for estimating skin temperature from VISSR infrared brightness temperatures. NASA TM 86105, 35 pp.

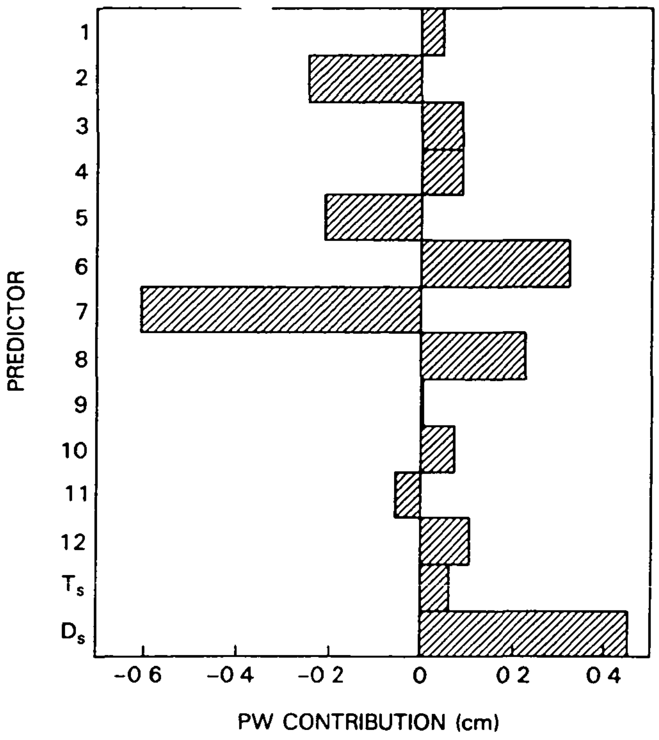


Fig. 4.3(1). VAS Channel Contributions to Precipitable Water Retreivals. Statistical contributions of VAS channels [1 through 12 and surface temperature (T_s) and dewpoint (D_s) reports] to regression retrievals of precipitable water (PW) are shown for the case study of 13 July 1981.

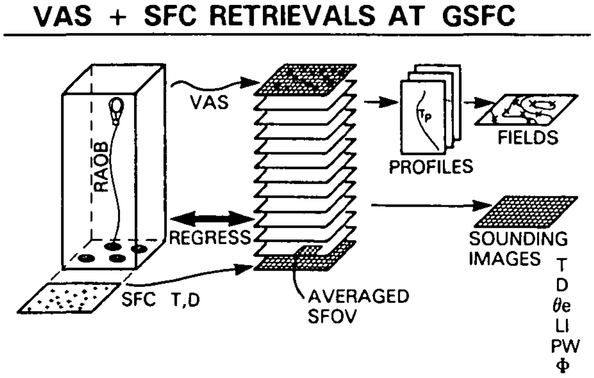
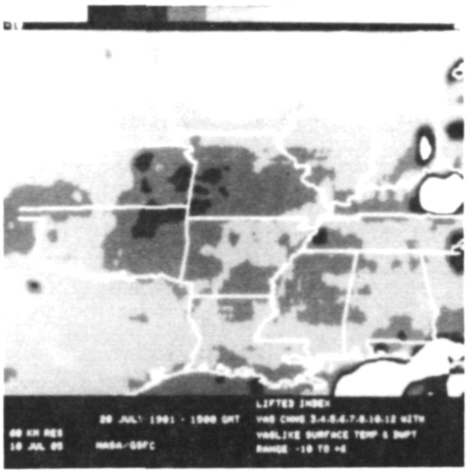
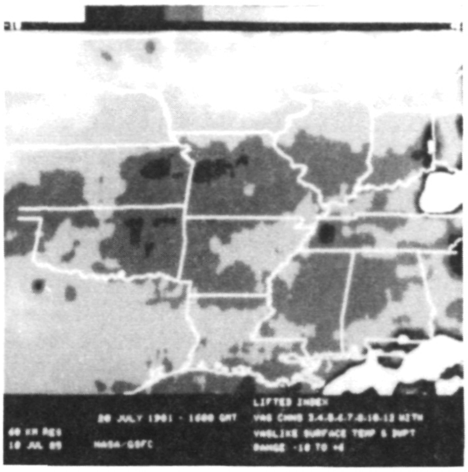
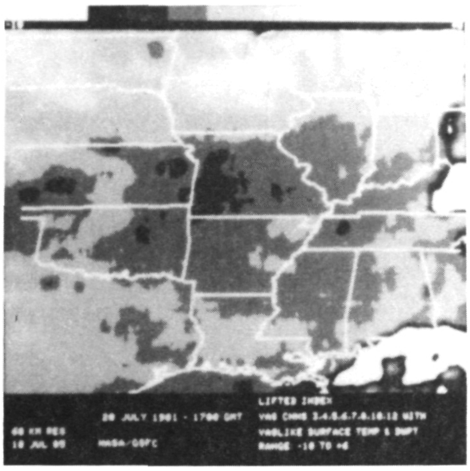
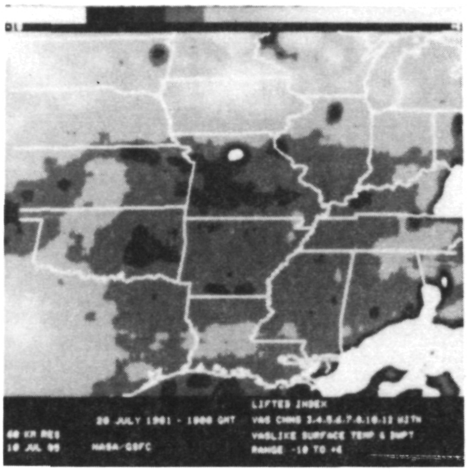


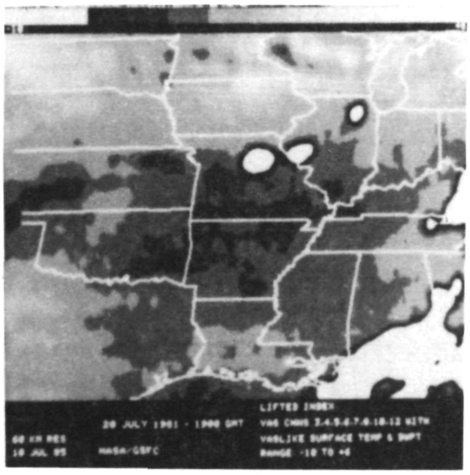
Fig. 4.3(2). Schematic Data Flow of the Data Processing for VAS Sounding Images. Conventional low-resolution radiosonde data observe the three-dimensional atmosphere and are used in regression with high-resolution two-dimensional VAS plus gridded surface data. Random noise can be decreased by horizontally averaging sounding fields-of-view (SFOV). Traditionally, remote soundings are retrieved at manually selected points as vertical temperature-dewpoint profiles which must be converted to stability indices and then analyzed. Current digital technology makes it practical to produce entire fields of indices at satellite resolution.

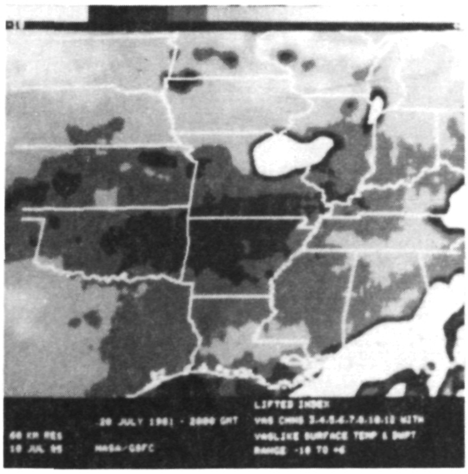

LIFTED INDEX
20 JULY 1981 - 1500 GMT
VAS CHNS 3-4-5-6-7-8-10-12 WITH
60 KM RES
VASLIKE SURFACE TEMP & DWPT
10 JUL 85
NASA/GSFC
RANGE -10 TO +6


LIFTED INDEX
20 JULY 1981 - 1600 GMT
VAS CHNS 3-4-5-6-7-8-10-12 WITH
60 KM RES
VASLIKE SURFACE TEMP & DWPT
10 JUL 85
NASA/GSFC
RANGE -10 TO +6


LIFTED INDEX
20 JULY 1981 - 1700 GMT
VAS CHNS 3-4-5-6-7-8-10-12 WITH
60 KM RES
VASLIKE SURFACE TEMP & DWPT
10 JUL 85
NASA/GSFC
RANGE -10 TO +6


LIFTED INDEX
20 JULY 1981 - 1800 GMT
VAS CHNS 3-4-5-6-7-8-10-12 WITH
60 KM RES
VASLIKE SURFACE TEMP & DWPT
10 JUL 85
NASA/GSFC
RANGE -10 TO +6


LIFTED INDEX
20 JULY 1981 - 1900 GMT
VAS CHNS 3-4-5-6-7-8-10-12 WITH
60 KM RES
VASLIKE SURFACE TEMP & DWPT
10 JUL 85
NASA/GSFC
RANGE -10 TO +6


LIFTED INDEX
20 JULY 1981 - 2000 GMT
VAS CHNS 3-4-5-6-7-8-10-12 WITH
60 KM RES
VASLIKE SURFACE TEMP & DWPT
10 JUL 85
NASA/GSFC
RANGE -10 TO +6

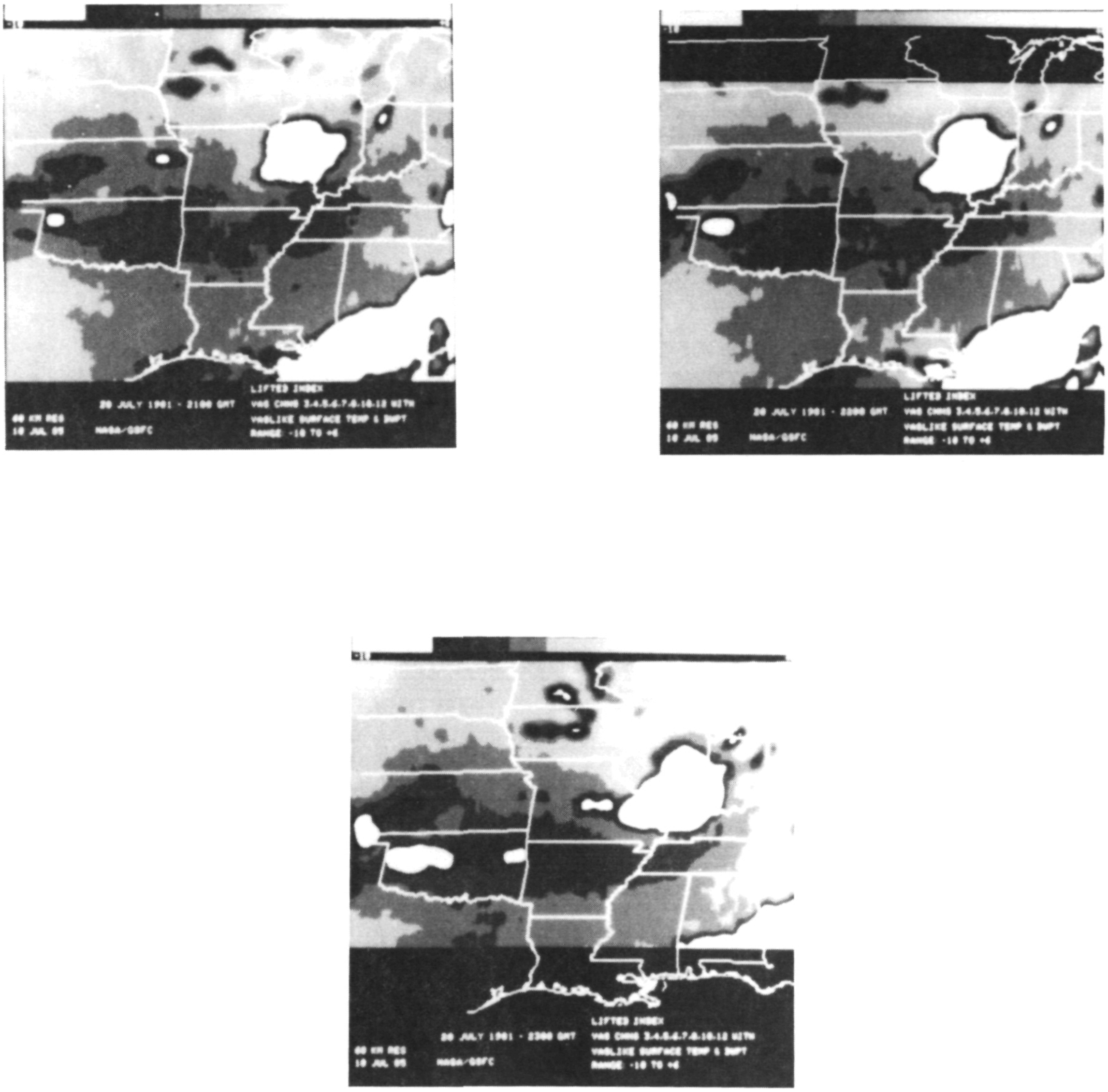


Fig. 4.3(3). Hourly VAS Images for Lifted Index. These panels demonstrate the resolution and continuity in VAS sounding images for lifted index (LI) at hourly intervals on 20 July 1981. The darker shades indicate more negative (unstable) values for LI in areas with a greater thermodynamic potential convective instability. Significantly unstable values are reliably obtained in the Midwest prior to the development of thunderstorms over Missouri at midday and over Oklahoma-Arkansas by evening.

Robinson, W. D., D. Chesters, and L. W. Uccellini, 1985: Optimized retrievals of high resolution precipitable water fields from combinations of VAS satellite and conventional surface observations. NASA TM. (In press.)

Mostek, A., L. W. Uccellini, R. A. Petersen, and D. Chesters, 1985: Assessment of VAS soundings in the analysis of a pre-convective environment. NASA TM 86205.

CONFERENCE PUBLICATIONS:

Chesters, D., and A. Mostek, 1984: High resolution images of atmospheric conditions computed directly from VAS satellite radiances. *3rd Conf. Interactive Meteorological Processes*, NASA/GSFC, Greenbelt, MD.

Chesters, D., T. H. Lee, A. Mostek, and D. A. Keyser, 1984: The accuracy of mesoscale temperature and dewpoint fields retrieved from VAS satellite and conventional surface data. *Preprints, Conf. Satellite Meteorology/ Remote Sensing and Applications*, Amer. Meteor. Soc., Clearwater Beach, FL, 226-231.

Uccellini, L. W., R. A. Petersen, and D. Chesters, 1984: The application of VAS imagery and soundings to the analysis of convective storms. *Intl. Conf. Mesoscale Meteorology*, Amer. Meteor. Soc., Melbourne, Australia.

Chesters, D., and A. Mostek, 1985: High resolution images of atmospheric parameters computed directly from VAS satellite radiances and conventional surface data. *Preprints, Intl. Conf. Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology*, Amer. Meteor. Soc., Los Angeles, CA, 261-268.

4.4 A Simulation Experiment on the Impact of Geostationary Temperature Retrievals in Numerical Models (T. Gal-Chen - U of Okla, B. Schmidt - GSC, and L. Uccellini - GSFC)

RESEARCH OBJECTIVES:

The objective of this research effort is to 1) develop a four-dimensional assimilation approach based on a variational technique which can be used to insert VAS data into numerical models and 2) test the technique on simplified models using simulated VAS data.

SIGNIFICANT ACCOMPLISHMENTS:

a) A variational assimilation technique was developed that has the unique characteristic that only the vertically averaged temperature is inserted from VAS, while the model retains its own higher-frequency modes. The technique allows for "time-continuous" assimilation. In this way, the approach takes advantage of a strength of VAS (increased temporal resolution) while avoiding a major weakness (poor vertical resolution).

b) A simulation experiment has been completed using a baroclinically unstable wave (specified analytically) as a control. The experiment shows that the insertion of mean temperatures, comparable to those observed by VAS, has greater impact if multiple insertions are used rather than just inserting the VAS data at one time. Nevertheless, all impact is lost if cloud cover is assumed to prevent soundings from VAS near the developing storm center.

JOURNAL PUBLICATIONS:

Gal-Chen, T., 1983: Initialization of mesoscale models: The possible impact of remotely sensed data. Mesoscale Meteorology, Theories, Observations, and Models, D. K. Lilly and T. Gal-Chen, Eds., Reidel, 157-171.

Johnson, D. R., and L. W. Uccellini, 1983: A comparison of methods for computing the sigma-coordinate pressure gradient force for flow over sloped terrain in a hybrid theta-sigma model. Mon. Wea. Rev., 111, 870-886.

Schlesinger, R. E., L. W. Uccellini, and D. R. Johnson, 1983: On the effects of the Asselin time filter upon numerical solution to the linearized shallow-water wave equations. Mon. Wea. Rev., 111, 455-467.

Gal-Chen, T., B. D. Schmidt, and L. W. Uccellini, 1985: Simulation experiments for testing the assimilation of geostationary satellite temperature retrievals into a numerical prediction model. Mon. Wea. Rev., 113. (Accepted.)

CONFERENCE PUBLICATIONS:

Gal-Chen, T., B. D. Schmidt, and L. W. Uccellini, 1985: An initialization procedure for assimilating geostationary satellite data into numerical weather prediction models. *Preprints, 7th Conf. Numerical Weather Prediction*, Amer. Meteor. Soc., Montreal, Quebec, Canada. (In press.)

4.5 VAS/Model Impact Study (R. Aune, M. Kaplan, J. Cram - SASC, and L. Uccellini - GSFC)

RESEARCH OBJECTIVES:

The objective of this research is to test several assimilation techniques (based on the variational approach) that can be used to insert VAS data into mesoscale numerical models. The experimental design is structured to determine if the temporal resolution of VAS soundings is an important element for improving mesoscale forecasts.

SIGNIFICANT ACCOMPLISHMENTS:

a) Impact studies have been conducted for the 20 July 1981 case using a four-dimensional assimilation scheme based on a variational approach (without vertical coupling). The largest impact on the simulation of developing convective instability was found when successive insertions of VAS data over a 6-h period better resolved the mesoscale structure of the temperature and moisture fields.

b) A technique has been developed for assimilating VAS thickness data based on a technique developed by Gal-Chen that preserves small-scale features in the temperature field, while replacing the large-scale features with VAS observations. A three-dimensional variational-type approach was used to minimize imbalances generated by the VAS observations. A Newtonian nudging technique was used between assimilation times to effectively increase the frequency of the assimilated VAS data.

CURRENT RESEARCH:

Conducting impact studies using the Gal-Chen scheme.

FUTURE PLANS:

Complete impact studies using the Gal-Chen scheme.

JOURNAL PUBLICATIONS:

Cram, J. M., and M. L. Kaplan, 1985: Variational assimilation of VAS data into a mesoscale model: Assimilation method and sensitivity experiments. Mon. Wea. Rev. (Accepted.)

CONFERENCE PUBLICATIONS:

Cram, J. M., and M. L. Kaplan, 1984: VAS data assimilation into a mesoscale model. Preprints, Conf. Satellite Meteorology/Remote Sensing and Applications, Amer. Meteor. Soc., Clearwater Beach, FL, 254-259.

Cram, J. M., and M. L. Kaplan, 1984: Variational assimilation of VAS data into the MASS model. *Preprints, 10th Conf. Weather Forecasting and Analysis*, Amer. Meteor. Soc., Clearwater Beach, FL, 373-379.

4.6 Utilization of Satellite Data in Mesoscale Modeling of Severe Weather

(T. Warner - Penn St)

RESEARCH OBJECTIVES:

Determine how VAS-derived temperature and moisture data can be most effectively utilized in mesoscale numerical models.

1) Determine the effect of the VAS data on the structure of temperature and moisture analyses that also employ radiosonde data.

2) Utilize analyses that are based on various methods of combining VAS and radiosonde data for a static initialization of the mesoscale model and assess the impact.

3) Utilize a dynamic initialization procedure to initialize the forecasts and compare the forecast skill with that resulting from the static initializations.

4) Determine the impact of the use of the VAS data on the noise characteristics of the model solution.

SIGNIFICANT ACCOMPLISHMENTS:

Numerical simulations that have been initialized with and without VAS data have been performed on four cases. One is the 20 July 1981 case and three are North Pacific cyclogenesis cases. For the 20 July 1981 case, VAS showed a slight improvement in forecast skill for temperature and moisture, with no improvement in wind and surface-pressure fields. Dynamic initialization of the forecast was as effective as the static initialization; i.e., it produced a very similar response in the forecast skill in the different variables. Only static initializations have been used thus far for the Pacific cases and it is premature to draw conclusions at this stage.

CURRENT RESEARCH:

a) 20 July 1981 case. New verification techniques for assessing impacts on predictive skill are being utilized. One or two more static and dynamically initialized forecasts are planned.

b) North Pacific cases. Static and dynamic initialization procedures are being compared in forecasts with and without VAS data.

c) Manuscripts are being prepared for submission to professional journals that deal with research completed under NASA sponsorship.

FUTURE PLANS:

The VAS impact studies with the four cases will be completed and appropriate manuscripts prepared for submission to peer-reviewed journals.

JOURNAL PUBLICATIONS:

Warner, T. T., T. C. Tarbell, and S. W. Wolcott, 1982: An example of the use of satellite cloud and surface rainfall data to initialize a numerical weather prediction model. Nowcasting: A New Approach to Observing and Forecasting the Weather, Academic Press.

Warner, T. T., D. Keyser, and L. W. Uccellini, 1983: Some practical insights into the relationship between initial state uncertainty and mesoscale predictability. Predictability of Fluid Motions, G. Holloway and B. J. West, Eds., American Institute of Physics Conference Proceedings No. 106, 271-286.

Salmon, E. M., and T. T. Warner, 1985: The impact of the diagnostic initialization of divergence on short-term precipitation forecasts provided by a mesoscale model. (In preparation.)

Lanicci, J. M., T. N. Carlson, and T. T. Warner, 1985: Sensitivity of the severe-storm environment to soil moisture distribution: Some numerical experiments from AVE-SESAME IV. (In preparation.)

Lakhtakia, M. N., and T. T. Warner, 1985: A real-data numerical simulation of a severe local-storm environment: The SESAME-IV case. (In preparation.)

CONFERENCE PUBLICATIONS:

Nappi, A. J., and T. T. Warner, 1983: A numerical investigation of the Presidents' Day storm of February 18-19, 1979. Preprints, 6th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Omaha, NE, 298-305.

Salmon, E. M., and T. T. Warner, 1983: The impact of the diagnostic initialization of divergence on short-term precipitation forecasts produced by a mesoscale model. Preprints, 6th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Omaha, NE, 166-170.

Aune, R. M., and T. T. Warner, 1983: Impact of SEASAT wind data on a statically initialized numerical model. Preprints, 6th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Omaha, NE, 220-225.

Lanicci, J. M., T. N. Carlson, and T. T. Warner, 1984: Sensitivity of the severe storm environment to soil moisture distribution: Some numerical experiments from AVE-SESAME IV. Preprints, Intl. Conf. Mesoscale Meteorology, Amer. Meteor. Soc., Melbourne, Australia.

Salmon, E. M., and T. T. Warner, 1984: The impact of the diagnostic initialization of divergence on short-term precipitation forecasts produced by a mesoscale numerical model. Preprints, Intl. Conf. Mesoscale Meteorology, Amer. Meteor. Soc., Melbourne, Australia.

Modica, G. M., and T. T. Warner, 1985: The error associated with the use of various forms of the divergence equation to diagnose geopotential and temperature. Preprints, 7th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Montreal, Quebec, Canada. (In press.)

Beauchamp, J. G., and T. T. Warner, 1985: Dynamic and static initialization of a mesoscale model using VAS satellite data. Preprints, 7th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Montreal, Quebec, Canada. (In press.)

Warner, T. T., and L. E. Key, 1985: The impact of data density and data error on the evolution of mesoscale forecast error. Preprints, 7th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Montreal, Quebec, Canada. (In press.)

Lakhtakia, M. N., and T. T. Warner, 1985: Circulation in the vicinity of an elevated mixed layer. Preprints, 2nd Conf. Mesoscale Processes, Amer. Meteor. Soc., University Park, PA. (In press.)

4.7 Role of Jet Streaks and Boundary Layer Processes in Organizing a Pre-Convective Environment (K. Brill - GSC, J. Zack - SASC, L. Uccellini, P. Kocin - GSFC, and T. Warner - Penn St)

RESEARCH OBJECTIVES:

The objective of this research is to study jet streak-induced circulations that influence the pre-convective environment using a case study approach based on radiosonde data and mesoscale numerical simulations. The research also includes determining the means and extent to which boundary layer processes enhance the jet-induced circulations and influence convective development.

SIGNIFICANT ACCOMPLISHMENTS:

a) Numerical simulations have been completed for the May 10, 1973, case used by Uccellini and Johnson to introduce the "coupling" of upper- and lower-tropospheric jet streaks. The model results show that the low-level jet (LLJ) develops in the exit region of the upper-level jet as a response to the mass-momentum adjustments associated with an indirect transverse circulation. The strength of the LLJ is also shown to be directly related to the magnitude of the along-stream wind variation in the exit region of the upper-level jet.

b) Analysis of the SESAME I case has been completed, showing that jet-induced circulations could be identified as at least one process that significantly influenced the pre-convective environment. The main findings are that the LLJ is forced primarily by the changing pressure gradient force (isallobaric) and that transverse circulations associated with jets can evolve over a very short time frame (3-6 h). The 3 h time resolution of the SESAME data sets was crucial to the proper diagnosis of their processes.

c) Mesoscale numerical experiments have been completed for the SESAME I cases which show that jet-induced circulations and boundary layer heating combined to yield a pre-convective environment which supported the development of the Wichita Falls tornado outbreak.

CURRENT RESEARCH AND FUTURE PLANS:

Complete journal papers on these topics.

JOURNAL PUBLICATIONS:

Brill, K. F., L. W. Uccellini, R. P. Burkhart, T. T. Warner, and R. A. Anthes, 1985: Numerical simulations of a transverse indirect circulation and low-level jet in the exit region of an upper-level jet. J. Atmos. Sci., 42, 1306-1320.

Zack, J. W., M. L. Kaplan, and V. C. Wong, 1985: Numerical simulations of the subsynoptic features associated with the AVE-SESAME I case. Part I: The preconvective environment. Mon. Wea. Rev., 113. (Submitted.)

CONFERENCE PUBLICATIONS:

Uccellini, L. W., and P. J. Kocin, 1981: Mesoscale aspects of jet streak coupling and implications for the short term forecasting of severe convective storms. Preprints, IAMAP Symp., Hamburg, Germany, 375-380.

Kocin, P. J., L. W. Uccellini, and R. A. Petersen, 1982: The role of jet streak "coupling" in the development of the 10-11 April 1979 Wichita Falls tornado outbreak. Preprints, 12th Conf. Severe Local Storms, Amer. Meteor. Soc., San Antonio, TX, 560-563.

4.8 Impact of Soil Moisture in Organizing a Severe Storm Outbreak

(G. Coats, J. Zack, and M. Kaplan - SASC)

RESEARCH OBJECTIVES:

The objective of this research is to evaluate the importance of incorporating soil moisture in a mesoscale atmospheric simulation system when forecasting the severe convective storm environment.

SIGNIFICANT ACCOMPLISHMENTS:

a) MASS simulations of the pre-convective environment were found to be sensitive to the initial soil moisture specification.

b) Simulations with soil moisture based on an observed Antecedent Precipitation Index (API) were found to be superior to those based on a uniform distribution of soil moisture.

c) Simulations with soil moisture based on a climatological API, however, were found to be slightly better than those based on the observed API. This may indicate the need for incorporating the effects of varying vegetation types or densities.

d) Nested-grid simulations produced a stronger local inland sea breeze circulation near observed soil moisture gradients which produced an environment more favorable for convective development.

CURRENT RESEARCH:

Current research includes: 1) implementation of the "Wetzel" surface evaporation scheme in the MASS model; and 2) development of the initial soil moisture data base for and execution of the nested 3 June 1980 Grand Island severe storm simulations. This experiment is designed to determine the magnitude and/or importance of the "inland sea breeze" effect hypothesized to exist along soil moisture gradients.

FUTURE PLANS:

Incorporate other variable surface characteristics into MASS, such as vegetation, and improve the surface roughness specification in order to better specify fluxes of heat and moisture from the surface for areas in which soil moisture variations are large.

JOURNAL PUBLICATIONS [see listing for Section 4.10]

CONFERENCE PUBLICATIONS:

Coats, G. D., V. C. Wong, J. W. Zack, and M. L. Kaplan, 1984: A numerical investigation of the effect of soil moisture gradients on the regional severe storm environment. Preprints, 10th Conf. Weather Forecasting and Analysis, Amer. Meteor. Soc., Clearwater Beach, FL, 506-512.

4.9 Role of Frontal Circulations and Gravity Waves in Initiating Convective Storm Systems (S. Koch, W. Skillman - GSFC, R. Golus - GSC, and J. McQueen - SASC)

RESEARCH OBJECTIVES:

a) Determine whether a mesoscale frontogenetical circulation in the vertical plane transverse to a cold front in Kansas on 16 April 1982 was responsible for triggering development of a frontal squall line.

b1) Determine role of internal gravity waves in organizing precipitation and cloud fields in 11 July 1981 CCOPE case.

b2) Use stereoscopic and brightness-enhanced GOES data, radar vertical cross sections, and surface mesonetwork time series to study vertical structure of the waves. Also determine whether upper-level cloud motions can be used as tracers of the wave-induced divergence fields to help in analysis of wave's vertical structure.

SIGNIFICANT ACCOMPLISHMENTS:

a1) Satellite signature of low-level frontogenetical circulation was identified. Note the developing frontal line convection and 60 km wide post-frontal clear zone as illustrated in Fig. 4.9(1). Surface and upper air data were used to infer likely existence of a frontogenetical circulation capable of producing vertical motions strong enough to generate the mesoscale clear zone and frontal line convection, and ultimately the squall line.

a2) Observations suggest superposition of synoptic-scale wind deformation field and the cross-frontal variation in surface sensible heat flux resulting primarily from the mesoscale cloud cover distribution was responsible for generation of the mesoscale frontogenetical circulation.

b1) Spectral and bandpass analyses of the CCOPE surface data have revealed presence of two coherent wave modes, displaying horizontal wavelengths of 150 km and 70 km and similar phase velocities. The two gravity wave systems appeared to generate new convective cells and intensify existing ones as the wave ridges passed over the cells.

b2) Initial satellite estimates of cloud top heights have been made, which when combined with radar vertical cross sections and bandpass surface analyses seem to suggest possible wave tilt. Question remains whether we actually have a tilted gravity wave or whether we are seeing the effects of vertical wind shear upon falling precipitation (and consequential hydrostatic pressure changes measured at the surface).

b3) Shearing instability of the upper-level jet appears to be a plausible source mechanism for the waves. It is also interesting that the waves developed in the strongly anticyclonically sheared exit region of the

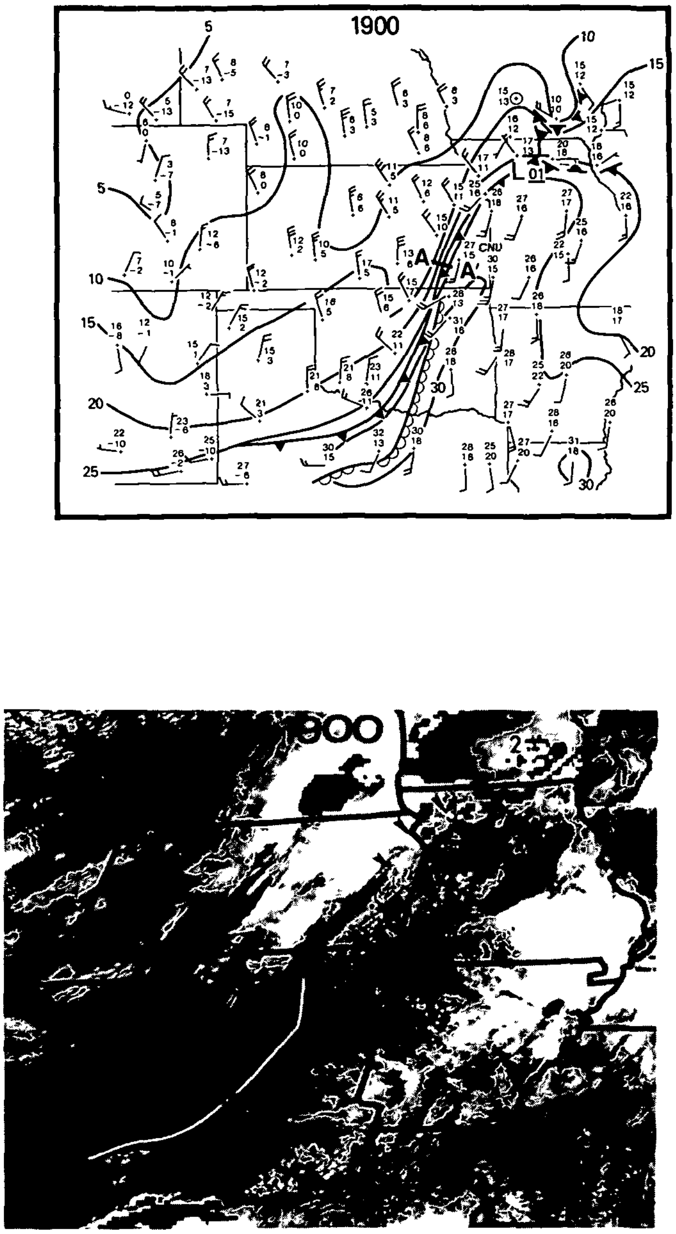


Fig. 4.9(1). Mesoscale Frontogenetical Forcing of a Squall Line. The surface temperature and frontal analysis are shown for the time corresponding with the satellite image. The line convection and clear zone features are indicated on the satellite image.

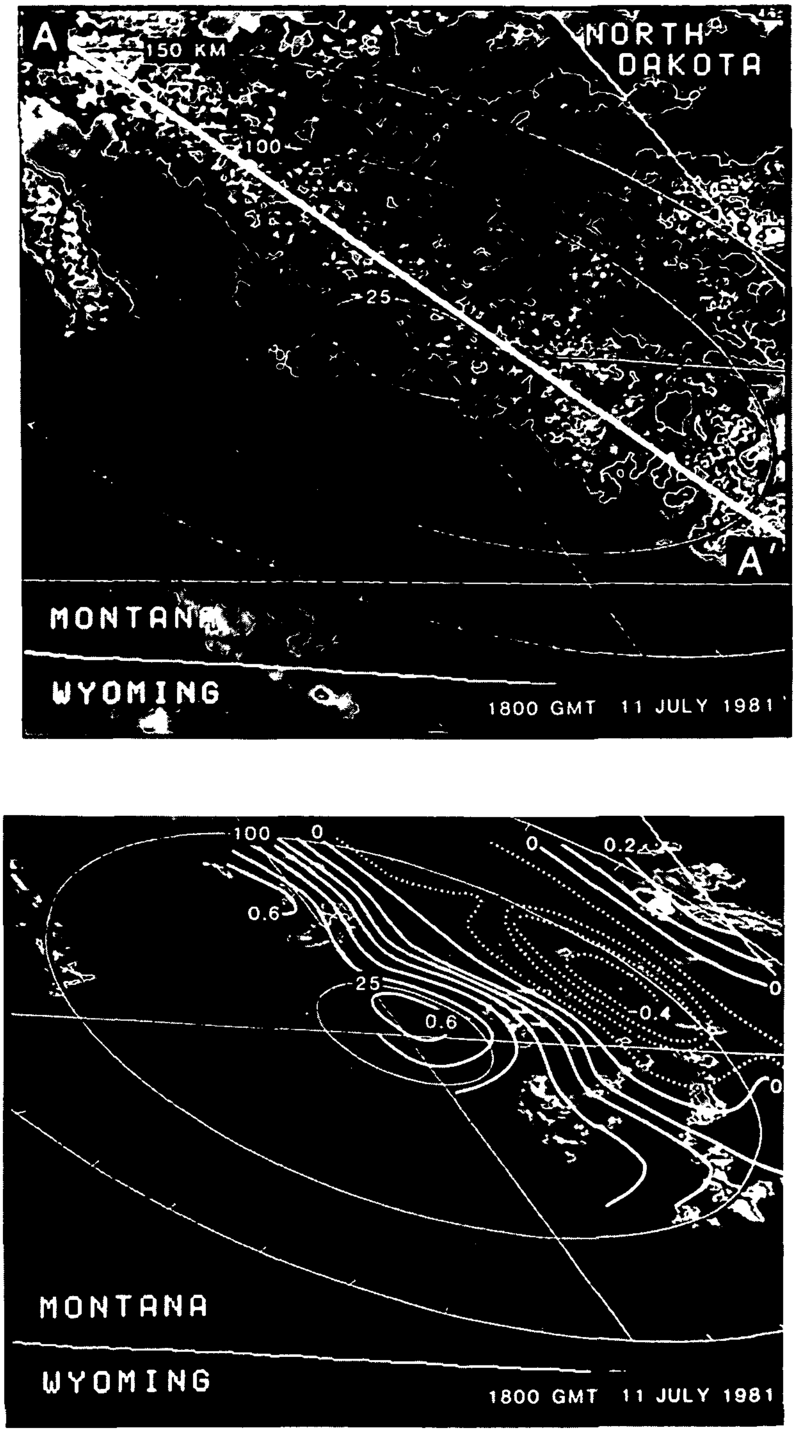


Fig. 4.9(2). Gravity Wave Organization of Clouds and Precipitation. The upper image is brightness-enhanced GOES-W visible imagery for the same time as the 5 km CAPPI radar reflectivity/surface p′ image below. Pressure perturbations (p′) were obtained from spectral analysis of surface mesonet data. Note that the axis of cloud band A-A′ (upper figure) lies along the p′ ridge as predicted by gravity wave theory.

upper-level jet. Furthermore, as the shear intensified that evening, the wave amplitudes increased and convection became severe.

b4) Cross-spectral analysis and Barnes time-to-space conversion map analysis programs have been written and are ready for implementation.

FUTURE PLANS:

a1) Run the MASS mesoscale model on the 16 April 1982 data set with various combinations of horizontal resolution, satellite-observed cloud cover, and soil moisture. The latter two quantities are the most important parameters in the surface energy budget equation, and are thus needed to test the given hypothesis (a2) above.

a2) Calculate Petterssen frontogenetical function fields for large number of "line convection-clear zone" cases and ascertain its frequency of association with surface frontogenesis as functions of season, geography, and synoptic situation. Do likewise for "rope cloud" cases to see which of the two phenomena is most often associated with diagnosed frontogenesis.

b1) Apply cross-spectral analysis program to surface mesonet data to obtain better estimates of wave phase velocity and other properties.

b2) Apply Barnes scheme to mesonet data to obtain more accurate positions of pressure and wind perturbations induced by wave passage, needed to examine wave vertical structure.

b3) Complete stereographic analysis of cloud top heights, and conduct cloud tracking exercise. This will make possible completion of wave vertical structure (tilt) and energetics studies.

b4) Conduct quantitative shear instability analysis using both rawinsonde data and analytical model(s). Also, relate observations of evolving wave-convection interactions to Wave-CISK theory.

JOURNAL PUBLICATIONS:

Koch, S. E., M. desJardins, and P. J. Kocin, 1983: An interactive Barnes objective map analysis scheme for use with satellite and conventional data. J. Clim. Appl. Meteor., 22, 1487-1503.

Stobie, J., F. Einaudi, and L. W. Uccellini, 1983: A case study of gravity wave-convective storm interactions: May 9, 1979. J. Atmos. Sci., 40, 2804-2830.

Koch, S. E., 1984: The role of an apparent mesoscale frontogenetical circulation in squall line initiation. Mon. Wea. Rev., 112, 2090-2111.

Koch, S. E., W. C. Skillman, P. J. Kocin, P. J. Wetzel, K. F. Brill, D. A. Keyser, and M. C. McCumber, 1985: Synoptic scale forecast skill and systematic errors in the MASS 2.0 model. Mon. Wea. Rev. (November issue.)

Koch, S. E., 1985: Ability of a regional scale model to predict the genesis of intense mesoscale convective systems. Mon. Wea. Rev. (November issue.)

Peslen, C. A., S. E. Koch, and L. W. Uccellini, 1985: The effect of the arbitrary level assignment of satellite cloud motion wind vectors on wind analyses for a pre-thunderstorm environment. J. Clim. Appl. Meteor. (Accepted.)

TECHNICAL PUBLICATIONS:

Koch, S. E., W. C. Skillman, P. J. Kocin, P. J. Wetzel, K. F. Brill, D. A. Keyser, and M. C. McCumber, 1983: Evaluation of the synoptic and mesoscale predictive capabilities of a mesoscale atmospheric simulation system. NASA TM 84995, 103 pp.

Peslen, C. A., S. E. Koch, and L. W. Uccellini, 1985: The effect of the arbitrary level assignment of satellite cloud motion wind vectors on wind analyses in the pre-thunderstorm environment. NASA TM 86186, 56 pp.

CONFERENCE PUBLICATIONS:

Koch, S. E., M. desJardins, and P. J. Kocin, 1983: The GEMPAK Barnes interactive objective map analysis scheme. Preprints, 9th Conf. Aerospace and Aeronautical Meteorology, Amer. Meteor. Soc., Omaha, NE, 34-39.

Koch, S. E., W. C. Skillman, P. J. Kocin, P. J. Wetzel, and K. F. Brill, 1983: An evaluation of the synoptic and mesoscale predictability of the mesoscale atmospheric simulation system (MASS 2.0) model. Preprints, 6th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Omaha, NE, 16-23.

Golus, R. E., and S. E. Koch, 1983: Gravity wave initiation and modulation of strong convection in a CCOPE case study. Preprints, 13th Conf. Severe Local Storms, Amer. Meteor. Soc., Tulsa, OK, 105-108.

Koch, S. E., and D. Burgess, 1983: Severe convection forecasting potential of the mesoscale atmospheric simulation system. Preprints, 13th Conf. Severe Local Storms, Amer. Meteor. Soc., Tulsa, OK, 342-345.

Peslen, C. A., S. E. Koch, and L. W. Uccellini, 1984: The effect of wind and moisture gradients on the arbitrary assignment of cloud motions to a vertical coordinate system in two SESAME cases. Preprints, Conf. Satellite Meteorology/Remote Sensing and Applications, Amer. Meteor. Soc, Clearwater Beach, FL, 234-239.

Koch, S. E., and P. J. Kocin, 1985: Some examples of severe weather events predicted by a mesoscale model. 14th Conf. Severe Local Storms, Amer. Meteor. Soc., Indianapolis, IN. (Accepted.)

Koch, S. E., and R. E. Golus, 1985: Observed interactions between strong convection and internal gravity waves. 14th Conf. Severe Local Storms, Amer. Meteor. Soc., Indianapolis, IN. (Accepted.)

4.10 Meso-β Scale Numerical Simulations of the Jet Streak Adjustments which Organized the Carolina Tornado Outbreak and the Subsequent Explosive Coastal Cyclogenesis (M. Kaplan, J. Zack, and V. Wong - SASC)

RESEARCH OBJECTIVES:

There are two basic objectives of this research activity: 1) continue the development of a comprehensive cloud and mesoscale numerical modeling systems; and 2) study the spectrum of adiabatic and diabatic processes which is responsible for the organization of mesoscale circulation systems that influence East Coast and other convective storms.

SIGNIFICANT ACCOMPLISHMENTS:

The following scenario has been isolated using meso-α scale simulations of severe storm events:

1) Upper-tropospheric inertial-advective effects associated with jets contribute to upper-level divergence and increasingly unbalanced flow.

2) The resulting imbalance yields significant values of time tendency of divergence, shearing and stretching deformation, low-level isallobaric response, and initial upward motion.

3) Mid-tropospheric frontogenesis occurs as the temperature field is stretched and contracted due to deformations; mid-tropospheric isallobaric adjustments result.

4) Mid- and lower-tropospheric warm advection, strong low-level isallobaric response, rapid increase in upward motion, and destabilization are directly linked with these upper-level adjustments and help establish a pre-convective environment conducive to the development of severe local storms.

5) The mesocyclone and tornado family development will require an imbedded three-dimensional cloud model interacting with meso-β scale MASS model.

CURRENT RESEARCH:

Areas of ongoing research include the following: 1) general model development of the Mesoscale Atmospheric Simulation System (MASS), including improved numerics, new PBL, improved cumulus parameterization, and dynamical initialization techniques, with special emphasis on nested-grid (meso-β scale) modeling; 2) the development and testing of the three-dimensional TASS cloud model; 3) work in the area of cloud/mesoscale interactions; 4) studies into the role of planetary boundary layer processes (including mesoscale variations in surface sensible heat flux due to soil moisture variations) in modifying mesoscale circulation systems; and 5) using the TASS cloud model to improve existing cumulus parameterization schemes and study the effects of convective heating on mesoscale circulation system.

FUTURE PLANS:

Continue ongoing research described in the previous subsection as well as participate in meteorological field experiments such as the GALE experiment.

JOURNAL PUBLICATIONS:

Kaplan, M. L., J. W. Zack, V. C. Wong, and J. J. Tuccillo, 1982: Initial results from a mesoscale atmospheric simulation system and comparisons with an AVE-SESAME I data set. Mon. Wea. Rev., 110, 1564-1590.

Kaplan, M. L., V. C. Wong, and G. D. Coats, 1984: The interactive role of subsynoptic scale jet streak and planetary boundary layer adjustments in organizing an isolated convective complex. Mon. Wea. Rev., 112, 2212-2238.

CONFERENCE PUBLICATIONS:

Kaplan, M. L., J. W. Zack, V. C. Wong, and G. D. Coats, 1983: A nested-grid mesoscale numerical weather prediction model modified for space shuttle operational requirements. Preprints, 9th Conf. Aerospace and Aeronautical Meteorology, Amer. Meteor. Soc., Omaha, NE, 341-347.

Wong, V. C., J. W. Zack, M. L. Kaplan, and G. D. Coats, 1983: A nested-grid limited-area model for short term weather forecasting. Preprints, 6th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Omaha, NE, 9-15.

Zack, J. W., V. C. Wong, M. L. Kaplan, and G. D. Coats, 1983: A nested-grid mesoscale numerical simulation of an isolated tornadic convective complex. Preprints, 13th Conf. Severe Local Storms, Amer. Meteor. Soc., Tulsa, OK, 336-341.

Kaplan, M. L., J. W. Zack, V. C. Wong, and J. J. Tuccillo, 1982: A sixth-order mesoscale atmospheric simulation system applicable to research and real-time forecasting problems. Preprints, Symp. Mesoscale Models, CIMMS, Norman, OK, 38-48.

Wong, V. C., J. W. Zack, M. L. Kaplan, and S. L. Chuang, 1983: A numerical investigation of the effects of cloudiness on mesoscale atmospheric circulation. Preprints, 5th Conf. Atmospheric Radiation, Amer. Meteor. Soc., Baltimore, MD, 151-154.

Kaplan, M. L., 1984: Simulations of the effects of natural mesoscale convective complexes on transport processes and the possible similarities to firestorm-induced convective complexes. Preprints, Conf. Large Scale Fire Phenomenology, Gaithersburg, MD. (In press.)

Zack, J. W., M. L. Kaplan, and V. C. Wong, 1985: A comparison of the prognostic performance of several cumulus parameterizations in mesoscale simulations of the 10 April 1979 SESAME I case. Preprints, 7th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Montreal, Quebec, Canada. (In press.)

4.11 Sea Breeze-Induced Mesoscale Systems and Severe Weather (R. Pielke - CSU)

RESEARCH OBJECTIVES:

a) Characterize climatologically, thunderstorm activity over south Florida.

b) Describe the physical processes associated with the occurrence and patterning of satellite-observed deep convection over south Florida.

c) Utilize a mesoscale model of the sea breezes over the study area to investigate and explain the physical processes associated with sea breezes such as found over south Florida.

SIGNIFICANT ACCOMPLISHMENTS:

a) Using a satellite composite analysis procedure, deep cumulonimbus activity over south Florida on synoptically undisturbed days during the summer is demonstrated to be strongly focused in specific geographic regions of the peninsula. This result replicates the same conclusion previously made using radar and modeling analyses (McQueen, 1985).

b) Moisture availability on the synoptic scale is the single most important large-scale influence on the percent of coverage of cumulonimbus over the south Florida peninsula (McQueen, 1985).

c) The specific locations of thunderstorm activity over south Florida are controlled by both sea breeze convergence of $\theta_{es}-\theta_e$ and by sea breeze-induced vertical motion. The patterns of these sea breeze fields over the south Florida area are controlled by the different types of ground surfaces, and by the speed and direction of the synoptic flow (McQueen, 1985).

d) The afternoon thunderstorm activity is very well correlated with the satellite-observed deep offshore convection at 0800 EST and to deep cumulus convection over land at 1000 EST (McQueen, 1985).

e) The influence of wet soils or cloud-covered ground adjacent to drier or non-shadowed land, respectively, were found capable of generating mesoscale circulations almost as strong as a sea breeze. Even relatively small differences in soil moisture content were found to cause noticeable mesoscale flows (Kessler et al., 1984; Segal et al., 1984, 1985).

f) Optimal coastline curvatures exist which will maximize the convergence associated with the sea breeze during light synoptic flow. Using round islands as the idealized case, the merger of the sea breeze convergence zones in the afternoon generated along the coastline of about 30 km in radius in the subtropics provide optimal convergence (Mahrer and Segal, 1985).

g) Using surface observations of thunder along with principal component analyses, a relation between thunderstorm anomalies over peninsular Florida and the 500 mb height field has been found. In addition, a spatial shift in Florida convection from the 1950's to the current period and a related change in the 500 mb field have occurred (Michaels, 1985).

h) Using vectorization techniques on the CSU CYBER 205, a procedure has been developed that increases the efficiency of the computation of all one-dimensional routines in our model by up to 40 times (Song, 1984).

CURRENT RESEARCH:

a) Summarize the results of this phase of our study in two reports.

b) Implement the CYBER 205 vectorization into our general mesoscale model. By the end of 1985, we expect to perform 12 h simulations of 33 x 36 x 14 grid points with a grid resolution of 11 km at a cost of around $200 each.

c) Using manually digitized radar data over Florida with a 20 nautical mile resolution, the main patterns of daily deep convection are being analyzed statistically.

FUTURE PLANS:

a) Extend the model domain to the entire Florida peninsula in order to include the Kennedy Space Center area.

b) Incorporate a version of the Fritsch-Chappell cumulus parameterization scheme into the mesoscale model and compute sea breeze energetics with and without deep cumulus cloud effects.

c) Contrast the cumulus parameterization scheme with explicit cumulonimbus field calculations made using the CSU Regional Atmospheric Modeling System (RAMS). Determine if the parameterization scheme can represent changes in the mesoscale environment as are obtained during the RAMS system.

d) Using a series of cumulonimbus field simulations, determine if a "look-up table"-type of parameterization can be developed in which input information on mesoscale thermodynamic and wind structure is uniquely associated with specific grid-averaged cumulonimbus field responses, and therefore with specific changes to the mesoscale environment.

e) Relate our modeling work to the planned FY86 NASA field program and to the modeling work of M. Kaplan.

JOURNAL PUBLICATIONS:

Kessler, R. C., D. Eppel, R. A. Pielke, and J. McQueen, 1984: A numerical study of a large sandbar upon sea breeze development. Arch. Met. Geoph. Biokl. (In press.)

Mahrer, Y., and M. Segal, 1985: On the effect of islands geometry and size on inducing sea breeze circulation. Mon. Wea. Rev. (In press.)

Michaels, P. J., 1985: Anomalies of mid-tropospheric heights and persistent thunderstorm patterns over Florida. J. Clim., 5. (In press.)

Pielke, R. A., and M. Segal, 1985: Mesoscale circulations forced by differential terrain heating. Mesoscale Meteorology and Forecasting, P. Ray, Ed., Amer. Meteor. Soc.

Segal, M., and R. A. Pielke, 1985: On the effect of water temperature and synoptic flows on the development of surface flows over narrow-elongated water bodies. J. Geophys. Res. (In press.)

Segal, M., J. F. W. Purdom, R. A. Pielke, and Y. Mahrer, 1985: Evaluation of stratiform cloud shading effects on the generation and modification of mesoscale circulations. Mon. Wea. Rev. (Submitted.)

CONFERENCE PUBLICATIONS:

Segal, M., R. A. Pielke, and Y. Mahrer, 1984: Evaluation of surface sensible heat flux effects on generation and modification of mesoscale circulations. Preprints, 2nd Intl. Symp. Nowcasting, European Space Agency, Norrköping, Sweden, 263-269.

OTHER PUBLICATIONS:

McQueen, J. T., 1985: A numerical and climatological investigation of deep convective cloudiness patterns in south Florida. M.S. Thesis, Department of Atmospheric Science, Colorado State University, Fort Collins, CO, 155 pp.

Song, J.-L., 1985: The use of the CYBER 205 to construct operational atmospheric mesoscale models. Control Data PACER Fellowship proposal, submitted January 11.

4.12 East Coast Snowstorm Survey (P. Kocin and L. Uccellini - GSFC)

RESEARCH OBJECTIVES:

a) Describe the temporal and spatial characteristics of a large sample of major winter snowstorms that have paralyzed the heavily urbanized centers of the Northeast, utilizing snowfall, surface and upper-air rawinsonde observations, model simulations, and satellite imagery.

b) Provide a survey of the current literature on East Coast storms.

c) Construct a well-organized atlas of cases that could be of use to the research community (especially with regard to upcoming GALE and STORM projects) and to operational and university needs (especially geared to forecasters and students).

SIGNIFICANT ACCOMPLISHMENTS:

a) Eighteen cases from 1960 to the present (surface and upper-air analyses, available satellite imagery, and total snowfall charts) have been collected, organized, and analyzed. Cases were selected due to their impact on large metropolitan areas of the Northeast and/or large areal extent of snow accumulations exceeding 25 cm.

b) An atlas of cases has been catalogued for eighteen cases, complete with snowfall charts, six-paneled surface maps, 850 mb charts, infrared satellite imagery (where available), and upper-air maps, featuring 500 mb heights, isotachs, and axes of major jet systems.

c) A summary of the surface and upper-level characteristics of the eighteen cases has shown that these storms appear to result when boundary layer processes along the East Coast act to modulate or focus the response to a large variety of upper-level flow configurations into two basic types of surface cyclones, as discussed by Miller (1946). One type ("A") is the familiar "wave" cyclone that forms along the polar front, while the other cyclone type ("B") usually involves a secondary low center which generally forms along a coastal front. The case-to-case variability in upper-level forcing was demonstrated by differences in the scale of many systems, trough amplitude and wavelength, jet streak positions and times of amplification, and rates of motion, precluding an effort to effectively composite these systems. Among some of the common features found amongst these storms is the presence of upper-level confluence in southeastern Canada and in the northeastern United States that appears to influence the intensity and movement of surface anticyclones that provide a source of cold, low-level air. Other important characteristics include diffluence downstream of the jet core and trough axis during cases involving rapid cyclogenesis and the evolution of the trough axis into a negatively tilted configuration. The influence of transverse circulations (one associated with a confluent jet streak entrance region in the northeastern United States and the other in the diffluent exit region of a jet streak/trough system approaching the East Coast) on the production of heavy snowfall has also been demonstrated.

CURRENT RESEARCH:

a) Current work involves completion of a monograph containing a collection of eighteen cases and a summary outlining the findings. Disseminate copies of technical memorandum to potentially interested groups in research, academic, and operational communities, especially with regard to East Coast forecasting and the 1986 GALE program.

b) Continue work on detailed case and model studies of East Coast storms, including the Presidents' Day storm.

FUTURE PLANS:

a) Apply concepts in study to more detailed analyses of individual cases hopefully captured by GALE, especially with regard to jet streak coupling, stratospheric-tropospheric exchange, unbalanced flow, coastal frontogenesis, cold-air damming, and the influences of upper-level confluence/diffluence and associated transverse circulations on anticyclogenesis, the maintenance low-level cold air and heavy snow production.

b) Use the MASS or other mesoscale model to determine why some of these events are inherently more "forecastable" than others. Experiments using varying combinations of vertical resolution, diabatic physics, and surface characteristics will be run to help improve the forecasts.

JOURNAL PUBLICATIONS:

Kocin, P. J., 1983: An analysis of the "Blizzard of '88." Bull. Amer. Meteor. Soc., 64, 1258-1272.

Kocin, P. J., and L. W. Uccellini, 1985: A survey of major East Coast snowstorms. Meteor. Monogr. (Accepted.)

TECHNICAL PUBLICATIONS:

Kocin, P. J., and L. W. Uccellini, 1985: A survey of major East Coast snowstorms, 1960-1983. Part I: Summary of surface and upper-level characteristics. NASA TM 86195, 102 pp.

Kocin, P. J. and L. W. Uccellini, 1985: A survey of major East Coast snowstorms, 1960-1963. Part II: Case studies of eighteen storms. NASA TM 86196, 214 pp.

CONFERENCE PUBLICATIONS:

Kocin, P. J., and L. W. Uccellini, 1984: A review of major East Coast snowstorms. Preprints, 10th Conf. Weather Forecasting and Analysis, Amer. Meteor. Soc., Clearwater Beach, FL, 189-198.

4.13 Numerical Studies of Frontal Dynamics (D. Keyser - GSFC and M. Pecnick - GSC)

RESEARCH OBJECTIVES:

a) The first objective of this research consists of incorporating the frontogenetical mechanisms of confluence (stretching deformation) and horizontal shear (shearing deformation) into a mathematically consistent two-dimensional formulation suitable for a cross-section primitive equation (PE) model. This aspect of the research constitutes a generalization of previous two-dimensional frontogenesis models, in which the confluence and horizontal shear mechanisms were treated separately. Questions to be addressed include accounting for the structural differences between surface cold and warm fronts and the development of a realistic tropopause fold during upper-level frontogenesis.

b) The second objective involves determining the geostrophic adjustment characteristics of a statically stable, rotating, compressible atmosphere to initial imbalances in frontal systems. The outcome of this particular effort should serve as a basis for interpreting the results of initialization procedures developed for mesoscale PE models with sufficient resolution to resolve frontal-scale processes. This objective is timely in view of the widespread interest among the mesoscale modeling community in utilizing novel data sources such as VAS thermal profiles and Profiler winds for initializing mesoscale numerical weather prediction models.

c) The third objective of the research is concerned with diagnosing ageostrophic circulations in the PE frontal model. The applicability of filtered diagnostic approaches based upon the quasi- and semi-geostrophic theories, as well as a formulation based on the unfiltered primitive equations, will be tested using the model as a data source. The three diagnostic approaches should be valuable in interpreting the results of the frontal simulations obtained in support of the first objective, and the unfiltered version should be useful in analyzing the details of the geostrophic adjustment process in the PE model initialization experiments planned under the second objective.

SIGNIFICANT ACCOMPLISHMENTS:

Our recent efforts have concentrated on the first and third objectives described above. Specific accomplishments and their potential implications are described below:

a) The generalized two-dimensional PE model of frontogenesis including both the effects of confluence and horizontal shear has been formulated and applied to the study of upper-level frontogenesis. Horizontal shear effects are added by allowing the potential temperature to vary along the front, which is a characteristic of the observed structure of baroclinic waves. When the along-front variation of potential temperature is such that colder air is situated upstream in the upper troposphere, pronounced upper-level frontogenesis occurs and is accompanied by tropopause folding as lower-stratospheric air descends into the mid-troposphere. Upper-level frontogenesis is dominated by tilting effects associated with the cross-front variation of vertical motion, in which subsidence is maximized within and to the warm side of the frontal zone. In contrast, when the along-front variation of potential temperature is such that warmer air is situated upstream in the upper troposphere, although frontogenesis occurs at upper levels, tropopause folding occurs only to a limited extent. In this so-called "warm advection" case, as well as in the pure confluence case (along-front thermal advection is zero), upper-level frontogenesis is dominated by horizontal motions and opposed by tilting effects. In these latter two cases, subsidence and ascent are maximized to the cold and warm sides of the fronts so that the cross-front variation of vertical motion is in the opposite sense of that in the cold advection case. These results suggest that the frontogenetical aspects characteristic of three-dimensional baroclinic waves may be abstracted to a significant extent in a two-dimensional framework. These results also demonstrate that upper-level frontogenesis and tropopause folding can occur in the absence of three-dimensional curvature effects, commonly believed to be necessary for realistic upper-level frontogenesis.

c) Application of the approximated and PE forms of the diagnostic Sawyer-Eliassen equation for the transverse ageostrophic circulation shows that the frontogenetical subsidence configuration in the "cold-advection" case described above is primarily due to horizontal shear forcing, which consists of the effect of the vorticity field acting on the along-front gradient of potential temperature. The significance of such a result is that it suggests a positive feedback mechanism in the PE model that accounts for the upper-level frontal development in the cold advection case. The subsidence pattern is frontogenetical in the sense that it both generates frontal properties such as the cross-front gradient of potential temperature and the cross-front shear of the along-front wind component (vorticity) through tilting effects and transports these properties downward as they are generated. The vorticity is included in the horizontal shear forcing. Consequently, the frontogenetical subsidence pattern enhances the horizontal shear forcing, which, in turn, reinforces the frontogenetical subsidence and completes the positive feedback loop. It is possible that such a positive feedback or "instability" may contribute to upper-level frontogenesis in nature.

An implication of a feedback between the tilting effects in the vorticity equation and the forcing of frontogenetical subsidence is that tilting effects may have to be adequately resolved by numerical weather prediction models in order to accurately predict the evolution of upper-level short-wave troughs, which are often involved in the triggering of cyclogenesis. Numerical models with coarse vertical resolution may underestimate tilting effects because vertical motions may be weaker than observed and the magnitude of the vertical wind shear may be too small. Sufficient horizontal resolution is required as well in order to adequately resolve horizontal gradients of the vertical motion. An example of a case in which tropopause folding and upper-level frontogenesis accompanied the amplification of a mid-tropospheric short wave is the Presidents' Day storm of 1979, which was poorly handled by operational numerical weather prediction models. The link between upper-level frontogenesis and baroclinic wave amplification in advance of low-level cyclogenesis emphasizes the potentially significant role of upper-level frontogenesis in the dynamics of mid-latitude baroclinic waves.

CURRENT RESEARCH:

a) Experiments investigating the influence of along-front thermal variations on surface frontal structure and associated vertical circulations are in progress. Preliminary findings for cold and warm fronts respectively show rising motion located primarily in the warm air ahead of the surface frontal position and in the cold air behind the surface frontal position. These encouraging results address the issue of explaining the observation that cloud bands often tend to be oriented in the warm air ahead of cold fronts and on the cold side of warm fronts.

c) The differences in the vertical motion patterns between the simulated surface cold and warm fronts have been examined in a preliminary manner using the semi-geostrophic form of the Sawyer-Eliassen equation. In the cold front case, the direct circulation forced by confluence and centered within the frontal zone is reinforced by the effect of horizontal shear, resulting in rising motion in the pre-frontal warm air. In the warm front case, however, the effect of horizontal shear is to displace the center of the direct circulation associated with confluence toward the cold air, resulting in ascending motion within the frontal zone behind the surface frontal position. These results suggest that along-front thermal variations may exert a significant influence on the dynamics of observed surface frontal zones and may account for some of the observed structural differences between surface cold and warm fronts. These experiments may also clarify the designations of katafront and anafront proposed nearly 50 years ago by Bergeron to distinguish between cold fronts accompanied by pre- and post-frontal cloud bands.

FUTURE PLANS:

Further experiments are planned to clarify and extend the preliminary findings concerning the influence of along-front thermal variations on the structure and dynamics of surface frontal zones in a two-dimensional context [objectives (a) and (c)]. Research on the adjustment characteristics of frontal systems will be initiated later this year [objective (b)]. Of particular interest is investigating the formation and evolution of a significant "unbalanced" component of the flow that has been identified in the simulation of upper-level frontogenesis forced by along-front cold advection.

JOURNAL PUBLICATIONS:

Keyser, D., and R. A. Anthes, 1982: The influence of planetary boundary layer physics on frontal structure in the Hoskins-Bretherton horizontal shear model. J. Atmos. Sci., 39, 1783-1802.

Keyser, D., and R. A. Anthes, 1982: An alternative expression for the Eady wave growth rate. J. Atmos. Sci., 39, 1877-1881.

Hsie, E.-Y., R. A. Anthes, and D. Keyser, 1984: Numerical simulation of frontogenesis in a moist atmosphere. J. Atmos. Sci., 41, 2581-2594.

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Keyser, D., and M. J. Pecnick, 1985a: A two-dimensional primitive equation model of frontogenesis forced by confluence and horizontal shear. J. Atmos. Sci., 42. (In press.)

Keyser, D., and M. J. Pecnick, 1985b: Diagnosis of ageostrophic circulations in a two-dimensional primitive equation model of frontogenesis. J. Atmos. Sci., 42. (In press.)

Keyser, D., 1985: Atmospheric fronts: An observational perspective. Mesoscale Meteorology and Forecasting, P. S. Ray, Ed., Amer. Meteor. Soc., Chapt. 10. (Accepted.)

CONFERENCE PUBLICATIONS:

Keyser, D., D. G. Baldwin, and R. A. Anthes, 1982: Diagnosis of forced secondary circulations associated with a numerically simulated cold front. Collection of Lecture Notes on Mesoscale Models, Proceedings of the CIMMS Symposium, June 1-2, 1982, University of Oklahoma, Norman, OK, 227-248. (Invited paper.)

Warner, T. T., D. Keyser, and L. W. Uccellini, 1983: Some practical insights into the relationship between initial state uncertainty and mesoscale predictability. Predictability of Fluid Motions, AIP Conference Proceedings, No. 106, G. Holloway and B. J. West, Eds., American Institute of Physics, 271-286.

Pecnick, M. J., and D. Keyser, 1983: The effect of spatial resolution on the simulation of upper-tropospheric frontogenesis using a sigma-coordinate primitive equation model. Preprints, 6th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Omaha, NE, 134-140.

CONFERENCE PRESENTATIONS (conferences/meetings for which proceedings were not published):

Carlson, T. N., and D. Keyser, 1983: Transverse ageostrophic circulations in the vicinity of middle level fronts associated with elevated mixed layers. 1st Conf. Mesoscale Meteorology, Amer. Meteor. Soc., Norman, OK. (Presented by D. Keyser on May 31, 1983.)

Keyser, D., and M. J. Pecnick, 1983: A two-dimensional primitive equation model of upper-tropospheric frontogenesis forced by stretching and shearing deformation. 1st Conf. Mesoscale Meteorology, Amer. Meteor. Soc., Norman, OK. (Poster presentation.)

Keyser, D., and M. J. Pecnick, 1983: Diagnosis of ageostrophic circulations in a two-dimensional primitive equation model of frontogenesis. 4th Extratropical Cyclone Project Workshop, Madison, WI. (Presented by D. Keyser on November 4, 1983.)

Keyser, D., and M. J. Pecnick, 1984: Diagnosis of ageostrophic circulations in a two-dimensional model of frontogenesis forced by stretching and shearing deformation. Intl. Conf. Mesoscale Meteorology, Amer. Meteor. Soc., Melbourne, Australia. (Presented by L. Uccellini on February 8, 1984.)

OTHER PUBLICATIONS:

Emanuel, K., D. Keyser, and M. A. Shapiro, 1983: Theoretical studies of mesoscale circulations. The National STORM Program: Scientific and Technological Bases and Major Objectives, R. A. Anthes, Ed., UCAR, Boulder, CO, 2.1-2.32.

4.14 The Sensitivity of Mesoscale Cyclogenesis Forecasts to Detailed Three-Dimensional Isentropic Initial Analyses and Varied Vertical Model Resolution (R. Petersen, L. Uccellini - GSFC and K. Brill - GSC)

RESEARCH OBJECTIVES:

a) Simulate the development of mesoscale frontal features influencing rapid cyclogenesis.

b) Use results from regional, high-resolution isentropic objective analyses as initial conditions for a mesoscale numerical model.

c) Use the improved model simulations to diagnose more thoroughly the evolution of the scale-interactive dynamic and thermodynamic process responsible for the development of severe convective and winter storms.

SIGNIFICANT ACCOMPLISHMENTS:

a) An isentropic analysis was succesfully inserted directly in σ-domain of the MASS model using an historical data set. A variational procedure was developed to further meld data sets along lateral boundaries of θ analysis domain with first guess fields.

b) Thirty-six-hourly forecasts of downward potential vorticity transport prior to the Presidents' Day cyclone obtained from the 24-level model were compared with 32-level model simulations using both standard isobaric analyses and high-resolution isentropic analyses as initial conditions.

c) The isentropically initialized simulations produced much more realistic model simulations of the downward vorticity transport than the model simulations using the isobaric data sets, both with respect to the magnitudes of the potential vorticity maximum within the front and the downward extent of the stratospheric extrusion. The net effect was to produce a more realistic cyclone (in terms of depth and position).

d) The 24-level, isentropically initialized simulations showed little change from its 32-level counterpart. But, this simulation was superior to both the 24- and 32-level isobaric initializations, indicating that the use of isentropic analyses could be important in reducing the number of levels needed to properly simulate jet streak circulation patterns.

CURRENT RESEARCH:

Perform additional numerical experiments using the lateral melding procedure. Expand testing by initializing with raob data from later time periods, when jet streak/potential vorticity structure are more well defined, and apply model simulations to the rapid cyclone development phase (12Z/19 February through 00Z/20 February).

FUTURE PLANS:

a) Generalize isentropic analysis procedure to eliminate dependence on prespecified cross-sectional paths. This will involve a variational procedure to merge analyses of observed data values and observed data gradients. Airway surface data will also be included in three-dimensional isentropic analyses to better define surface structures.

b) Begin preparation for GALE project scheduled for 1986. This will include further model sensitivity tests to better understand the interaction of the downward potential vorticity transport with the surface cyclone. Formulations of a four-dimensional analysis procedure assimilate various forms of satellite data (both retrievals and radiances) into analyses of pre-convective and cyclone environments.

JOURNAL PUBLICATIONS:

Petersen, R. A., 1985: Detailed three-dimensional isentropic analysis using an objective cross-sectional approach. Mon. Wea. Rev., 113. (Accepted.)

CONFERENCE PUBLICATIONS:

Petersen, R. A., J. J. Tuccillo, K. F. Brill, and L. W. Uccellini, 1985: The sensitivity of a mesoscale forecast model to detailed three-dimensional isentropic initial analyses and varied vertical model resolution. Preprints, 7th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Montreal, Quebec, Canada. (In press.)

4.15 Model Sensitivity Studies of Major East Coast Storms (J. Zack, M. Kaplan, V. Wong, and G. Coats - SASC)

RESEARCH OBJECTIVES:

The general goal is to improve the simulations of East Coast cyclones and their associated precipitation patterns. Specific objectives include: 1) an identification of the important physical processes which determine the evolution and morphology of the East Coast cyclone and its distribution of precipitation; 2) an assessment of the sensitivity of the mesoscale numerical model to the manner in which these physical processes are parameterized; 3) an identification of the critical areas in which the model physics must be further developed in order to significantly improve the simulations; and 4) an estimation of the limits placed upon the simulations by the current availability of data and the implications of further remotely sensed data sets.

SIGNIFICANT ACCOMPLISHMENTS:

a) Incipient phases of coastal storm development show a wide range of sensitivities to the release of latent heat.

b) The manner in which latent heat release is partitioned between subgrid- and grid-scale processes can have a large impact on the simulations of East Coast cyclogenesis.

c) The sensitivity of latent heat release increases rapidly with a decrease in grid size.

d) Significant amounts of latent heat release occur within the coastal front zone and tend to strengthen and deepen the coastal front circulation.

e) Over a 24-h period, the evaporation of moisture from the Atlantic Ocean represents an important moisture source for precipitation over the Piedmont and Appalachian Mountain regions.

f) Anomalies in the sea surface temperature may exert a modest influence on the low-level temperatures, but generally have little effect on the deepening rates of coastal cyclones during a 24-h period.

CURRENT RESEARCH:

Current projects include: 1) the execution of a series of MASS model meso-α scale simulations of the 10 February 1983, Presidents' Day, 5 April 1982, 5 December 1982, 8 March 1984, and 28 March 1984 East Coast cyclones in which grid- and subgrid-scale latent heat release schemes and PBL parameters are varied; 2) the identification of the strengths and weaknesses of the simulations through the verification of precipitation and other dynamic variables produced by these simulations with standard 12 h rawinsonde data and hourly surface and precipitation data; 3) the dynamical analysis of the simulated physical processes, including phenomena such as coastal frontogenesis, cold air damming, mesoscale precipitation areas, and the coupling of upper-level and lower-level jet streaks; and 4) the analysis of the performance within the East Coast cyclone environment of several schemes for the parameterization of subgrid moist convection.

FUTURE PLANS:

Future plans include: 1) the continued development of the MASS meso-α and meso-β scale models with emphasis on the implementation of a medium-resolution PBL parameterization and a more comprehensive set of moist physics; 2) an extension of the model sensitivity experiments and dynamical analyses to a broader spectrum of cases; 3) nested-grid meso-β scale simulations and dynamical analyses of the pre-cyclogenetic environment on a selected subset of these cases; and 4) preliminary simulations and dynamical analyses of the cases selected for the GALE field experiment.

JOURNAL PUBLICATIONS [see listing for Section 4.10]

CONFERENCE PUBLICATIONS:

Zack, J. W., V. C. Wong, M. L. Kaplan, and G. D. Coats, 1984: A model-based investigation of the role of boundary layer fluxes and deep convective processes in the precipitation distribution of East Coast cyclones. Preprints, 10th Conf. Weather Forecasting and Analysis, Amer. Meteor. Soc., Clearwater Beach, FL, 588-595.

4.16 Justification and Plan for Participation in GALE (L. Uccellini, P. Kocin - GSFC, and M. Kaplan - SASC)

RESEARCH OBJECTIVES:

The overall objective of this effort is to continue our research into the study of East Coast storms using conventional and satellite data and numerical simulations archived during the Genesis of Atlantic Lows Experiment (GALE). Specific objectives include 1) the study of scale interactions and the interaction between dynamic and diabatic processes that influence the storms using actual data in concert with detailed mesoscale model experiments and 2) the assessment of TOMS ozone data for the study of stratospheric-tropospheric exchange prior to and during cyclogenesis.

SIGNIFICANT ACCOMPLISHMENTS:

a) We have completed a mesoscale numerical forecast (using the MASS model) of a cold season convective outbreak during a case of secondary East Coast cyclogenesis. The model correctly forecast the timing and location of secondary cyclogenesis, the potential for convection and an enhancement of precipitation amounts, and was an excellent indicator of the rain-snow line in a situation where empirical rules would have been erroneous. The study demonstrates that mesoscale models can simulate dynamical interactions and diabatic processes for a wintertime convective event and that they can possibly provide more useful weather forecasts than available from current operational models.

b) The first two parts of our detailed analysis of the Presidents' Day cyclone have been completed. Part I presents a synoptic overview and a thorough diagnosis of a subtropical jet that appears to become unbalanced during the pre-cyclogenetic period. The increasing upper-level divergence associated with this jet was an important factor in the development of heavy snowfall along the coast. Part II deals with a tropopause fold associated with a polar jet upstream and prior to the rapid cyclogenesis. Evidence is presented which shows that the stratospheric air mass extruded downward by the folding processes is nearly collocated with the cyclone during its rapid development phase.

Both of the above studies point to the rapid changes that occur within a 12 h time frame (model simulations show important changes occur with 6 h), indicating that data sets with enhanced temporal resolution will be needed to continue research in this area.

CURRENT RESEARCH:

a) Continuing our analysis of the Presidents' Day storm using numerical simulations to diagnose the interactions of diabatic and dynamic processes.

b) Preparing for the GALE experiment.

FUTURE PLANS:

Take an active part in GALE by 1) participating in the operations center during the Intensive Observing Period (IOP), 2) providing an initial assessment of the data for each case, 3) conducting real-time model simulations during GALE and providing an initial assessment of the strengths and weaknesses of the model forecasts, and 4) conducting detailed diagnostic studies on selected GALE cases.

JOURNAL PUBLICATIONS:

Uccellini, L. W., K. F. Brill, and P. J. Kocin, 1983: Diagnostic applications of mesoscale-limited area models for the study of severe storms. Collection of Lecture Notes on Mesoscale Models, (Y. Sasaki, Ed.), Coop. Inst. Meso. Meteor. Studies, University of Oklahoma, 209-238.

Uccellini, L. W., 1984: Comments on "Comparative diagnostic case study of East Coast secondary cyclogenesis under weak versus strong synoptic scale forcing." Mon. Wea. Rev., 112, 2540-2541.

Uccellini, L. W., P. J. Kocin, R. A. Petersen, C. H. Wash, and K. F. Brill, 1984: The Presidents' Day cyclone of 18-19 February 1979: Synoptic overview and analysis of the subtropical jet streak influencing the pre-cyclogenetic period. Mon. Wea. Rev., 112, 31-55.

Kocin, P. J., L. W. Uccellini, J. W. Zack, and M. L. Kaplan, 1985: A mesoscale numerical forecast of an intense convective snowburst along the East Coast. Bull. Amer. Meteor. Soc. (November issue.)

Uccellini, L. W., D. Keyser, K. F. Brill, and C. H. Wash, 1985: The Presidents' Day cyclone of 18-19 February 1979: Influence of upstream trough amplification and associated tropopause folding on rapid cyclogenesis. Mon. Wea. Rev., 113, 962-988.

TECHNICAL PUBLICATIONS:

Uccellini, L. W., P. J. Kocin, and C. H. Wash, 1981: The Presidents' Day cyclone 17-19 February 1979: An analysis of jet streak interactions prior to cyclogenesis. NASA TM 82077, 59 pp.

Kocin, P. J., L. W. Uccellini, J. W. Zack, and M. L. Kaplan, 1984: Recent examples of mesoscale numerical forecasts of severe weather events along the East Coast. NASA TM 86172, 57 pp.

CONFERENCE PUBLICATIONS:

Uccellini, L. W., R. A. Petersen, P. J. Kocin, M. L. Kaplan, J. W. Zack, and V. C. Wong, 1983: Mesoscale numerical simulations of the Presidents' Day cyclone: Impact of sensible and latent heating on the precyclogenetic

environment. Preprints, 6th Conf. Numerical Weather Prediction, Amer. Meteor. Soc., Omaha, NE, 45-52.

Uccellini, L. W., D. Keyser, C. H. Wash, and K. F. Brill, 1984: The Presidents' Day cyclone of 18-19 February 1979: Influence of a tropopause fold on rapid cyclogenesis. Preprints, 10th Conf. Weather Forecasting and Analysis, Amer. Meteor. Soc., Clearwater Beach, FL, 614-622.

4.17 GEneral Meteorological PAcKage (GEMPAK) (M. desJardins, R. Petersen - GSFC, M. Vilardo, I. Graffman, and M. Goodman - RDS)

RESEARCH OBJECTIVES:

The objective of this task is to develop an interactive meteorological processing system which can process the many types of data (satellite soundings, radiosondes, surface, model output) used by the Severe Storms Branch in their research activities. A graphics system (GEMPLT) is an integral part of GEMPAK. A secondary objective is to deliver GEMPAK/GEMPLT to universities which have access to VAX hardware and to continue an exchange of software to continually upgrade systems at the universities and at GSFC.

SIGNIFICANT ACCOMPLISHMENTS:

a) Delivered the GEMPAK version 3 system. This includes revised data structures, improved use of the Transportable Applications Executive (TAE), and extensions to GEMPLT to include a grid navigation system.

b) Completed user and programmer guides for GEMPAK and GEMPLT. System and intervals guides will be completed in FY85.

c) Delivered a preliminary version of GEMPAK3 to the Naval Postgraduate School and at the University of Illinois. An earlier version of GEMPAK was installed at the Colorado State University and at Yale. An operational version of GEMPAK3 will be delivered to these schools in FY85. Other schools requesting GEMPAK include North Carolina State University, James Madison University, and the University of Utah.

d) Worked with the UNIDATA working group on hardware and software systems. GEMPAK has been tentatively accepted for use by UNIDATA.

CURRENT RESEARCH:

Extend the diagnostic computation capabilities of GEMPAK3 for the Severe Storms Branch.

FUTURE PLANS:

Future GEMPAK work is uncertain. At present budget levels, we plan to only:

1) maintain the GEneral Meteorological PAcKage (GEMPAK3) software and the associated graphics software (GEMPLT) currently operational on the VAX 11/780 and MicroVAX systems supporting the Severe Storms Branch; and

2) maintain and distribute documentation for GEMPAK3 and GEMPLT.

CONFERENCE PUBLICATIONS:

desJardins, M. L., and R. A. Petersen, 1983: GEMPAK, an interactive meteorological display and analysis system. Preprints, 9th Conf. Aerospace and Aeronautical Meteorology, Amer. Meteor. Soc., Omaha, NE, 55-59.

desJardins, M. L., and R. A. Petersen, 1985: GEMPAK: A meteorological system for research and education. Preprints, 1st Intl. Conf. Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, Amer. Meteor. Soc., Los Angeles, CA, 313-319.

Vilardo, J. M., M. L. desJardins, and G. C. Chatters, 1985: GEMPLT: An interactive meteorological graphics system. Preprints, 1st Intl. Conf. Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, Amer. Meteor. Soc., Los Angeles, CA, 134-138.

5. APPENDICES

5.1 Appendix A

5.1.1 Refereed Publications (including theses and books)

Adler, R. F., and R. A. Mack, 1984: Thunderstorm cloud height-rainfall rate relations for use with satellite rainfall estimation techniques. *J. Clim. Appl. Meteor.*, *23*, 280-296.

Adler, R. F., and R. A. Mack, 1985: Thunderstorm cloud top dynamics as inferred from satellite observations and a cloud top parcel model. *J. Atmos. Sci.* (Submitted.)

Adler, R. F., M. J. Markus, and D. D. Fenn, 1985: Detection of severe midwest thunderstorms using geosynchronous satellite data. *Mon. Wea. Rev.*, *113*, 769-781.

Brill, K. F., L. W. Uccellini, R. P. Burkhart, T. T. Warner, and R. A. Anthes, 1985: Numerical simulations of a transverse indirect circulation and low-level jet in the exit region of an upper-level jet. *J. Atmos. Sci.*, *42*, 1306-1320.

Chesters, D., L. W. Uccellini, and A. Mostek, 1982: VISSR Atmospheric Sounder (VAS) simulation experiment for a severe storm environment. *Mon. Wea. Rev.*, *110*, 198-216.

Chesters, D., L. W. Uccellini, and W. D. Robinson, 1983: Low-level water vapor fields from the VISSR Atmospheric Sounder (VAS) split window channels. *J. Clim. Appl. Meteor.*, *22*, 725-743.

Chesters, D., A. Mostek, and D. A. Keyser, 1985: VAS sounding images of atmospheric stability parameters. *J. Clim. Appl. Meteor.* (Submitted.)

Cram, J. M., and M. L. Kaplan, 1985: Variational assimilation of VAS data into a mesoscale model: Assimilation method and sensitivity experiments. *Mon. Wea. Rev.* (Accepted.)

Frank, W. M., and E. B. Rodgers, 1984: Kinematic analysis of Hurricane Frederic (1979) using satellite, aircraft and rawinsonde data. Final Report on NASA Grant NAG5-102.

Gal-Chen, T., 1983: Initialization of mesoscale models: The possible impact of remotely sensed data. *Mesoscale Meteorology, Theories, Observations, and Models*, D. K. Lilly and T. Gal-Chen, Eds., Reidel, 157-171.

Gal-Chen, T., B. D. Schmidt, and L. W. Uccellini, 1985: Simulation experiments for testing the assimilation of geostationary satellite temperature retrievals into a numerical prediction model. *Mon. Wea. Rev.*, *113*. (Accepted.)

Hasler, A. F., 1985: Stereo measurements. Silver Anniversary Book on Weather Satellites, Section VII-4, NOAA (invited). (In press.)

Hasler, A. F., and K. R. Morris, 1985: Hurricane structure and dynamics from stereoscopic and infrared satellite observations and radar data. J. Clim. Appl. Meteor. (In press.)

Hasler, A. F., H. Pierce, and J. Dodge, 1985: Meteorological data fields "in perspective." Bull. Amer. Meteor. Soc., 66, 795-801.

Heymsfield, G. M., and S. Schotz, 1985: Structure and evolution of a severe Oklahoma squall line. Mon. Wea. Rev., 113. (In press.)

Hsie, E.-Y., R. A. Anthes, and D. Keyser, 1984: Numerical simulation of frontogenesis in a moist atmosphere. J. Atmos. Sci., 41, 2581-2594.

Hunter, H., E. B. Rodgers, and W. Shenk, 1984: An objective method for forecasting tropical cyclone motion using Nimbus and NOAA-2 infrared measurements. J. Clim. Appl. Meteor., 23, 668-678.

Johnson, D. R., and L. W. Uccellini, 1983: A comparison of methods for computing the sigma-coordinate pressure gradient force for flow over sloped terrain in a hybrid theta-sigma model. Mon. Wea. Rev., 111, 870-886.

Kaplan, M. L., J. W. Zack, V. C. Wong, and J. J. Tuccillo, 1982: Initial results from a mesoscale atmospheric simulation system and comparisons with an AVE-SESAME I data set. Mon. Wea. Rev., 110, 1564-1590.

Kaplan, M. L., V. C. Wong, and G. D. Coats, 1984: The interactive role of subsynoptic scale jet streak and planetary boundary layer adjustments in organizing an isolated convective complex. Mon. Wea. Rev., 112, 2212-2238.

Kessler, R. C., D. Eppel, R. A. Pielke, and J. McQueen, 1984: A numerical study of a large sandbar upon sea breeze development. Arch. Met. Geoph. Biokl. (In press.)

Keyser, D., and R. A. Anthes, 1982: The influence of planetary boundary layer physics on frontal structure in the Hoskins-Bretherton horizontal shear model. J. Atmos. Sci., 39, 1783-1802.

Keyser, D., and R. A. Anthes, 1982: An alternative expression for the Eady wave growth rate. J. Atmos. Sci., 39, 1877-1881.

Keyser, D., and T. N. Carlson, 1984: Transverse ageostrophic circulations associated with elevated mixed layers. Mon. Wea. Rev., 112, 2465-2478.

Keyser, D., 1985: Atmospheric fronts: An observational perspective. Mesoscale Meteorology and Forecasting, P. S. Ray, Ed., Amer. Meteor. Soc., Chapt. 10. (Accepted.)

Keyser, D., and M. J. Pecnick, 1985a: A two-dimensional primitive equation model of frontogenesis forced by confluence and horizontal shear. J. Atmos. Sci., 42. (In press.)

Keyser, D., and M. J. Pecnick, 1985b: Diagnosis of ageostrophic circulations in a two-dimensional primitive equation model of frontogenesis. J. Atmos. Sci., 42. (In press.)

Koch, S. E., M. desJardins, and P. J. Kocin, 1983: An interactive Barnes objective map analysis scheme for use with satellite and conventional data. J. Clim. Appl. Meteor., 22, 1487-1503.

Koch, S. E., 1984: The role of an apparent mesoscale frontogenetical circulation in squall line initiation. Mon. Wea. Rev., 112, 2090-2111.

Koch, S. E., 1985: Ability of a regional scale model to predict the genesis of intense mesoscale convective systems. Mon. Wea. Rev. (November issue.)

Koch, S. E., W. C. Skillman, P. J. Kocin, P. J. Wetzel, K. F. Brill, D. A. Keyser, and M. C. McCumber, 1985: Synoptic scale forecast skill and systematic errors in the MASS 2.0 model. Mon. Wea. Rev. (November issue.)

Kocin, P. J., 1983: An analysis of the "Blizzard of '88." Bull. Amer. Meteor. Soc., 64, 1258-1272.

Kocin, P. J., and L. W. Uccellini, 1985: A survey of major East Coast snowstorms. Meteor. Monogr. (Accepted.)

Kocin, P. J., L. W. Uccellini, J. W. Zack, and M. L. Kaplan, 1985: A mesoscale numerical forecast of an intense convective snowburst along the East Coast. Bull. Amer. Meteor. Soc. (November issue.)

Lakhtakia, M. N., and T. T. Warner, 1985: A real-data numerical simulation of a severe local-storm environment: The SESAME-IV case. (In preparation.)

Lanicci, J. M., T. N. Carlson, and T. T. Warner, 1985: Sensitivity of the severe-storm environment to soil moisture distribution: Some numerical experiments from AVE-SESAME IV. (In preparation.)

Lee, T. H., D. Chesters, and A. Mostek, 1983: The impact of conventional surface data upon VAS regression retrievals in the lower troposphere. J. Clim. Appl. Meteor., 22, 1853-1874.

Mack, R. A., A. F. Hasler, and R. F. Adler, 1983: Thunderstorm cloud top observations using satellite stereoscopy. Mon. Wea. Rev., 111, 1949-1964.

Mahrer, Y., and M. Segal, 1985: On the effect of islands geometry and size on inducing sea breeze circulation. Mon. Wea. Rev. (In press.)

McQueen, J. T., 1985: A numerical and climatological investigation of deep convective cloudiness patterns in south Florida. M.S. Thesis, Department of Atmospheric Science, Colorado State University, Fort Collins, CO, 155 pp.

Michaels, P. J., 1985: Anomalies of mid-tropospheric heights and persistent thunderstorm patterns over Florida. J. Clim., 5. (In press.)

Montgomery, H. E., and L. W. Uccellini, Eds., 1985: VAS Demonstration Description, Summary and Final Report, NASA Special Pub. (In press.)

Mostek, A., L. W. Uccellini, R. A. Petersen, and D. Chesters, 1985: Assessment of VAS soundings in the analysis of a pre-convective environment. Mon. Wea. Rev. (Conditionally accepted.)

Negri, A. J., R. F. Adler, and P. J. Wetzel, 1984: Satellite rain estimation: An analysis of the Griffith-Woodley technique. J. Clim. Appl. Meteor., 23, 102-116.

Peslen, C. A., S. E. Koch, and L. W. Uccellini, 1985: The effect of the arbitrary level assignment of satellite cloud motion wind vectors on wind analyses for a pre-thunderstorm environment. J. Clim. Appl. Meteor. (Accepted.)

Petersen, R. A., L. W. Uccellini, D. Chesters, and A. Mostek, 1983: The use of VAS satellite data in weather analysis, prediction and diagnosis. Nat. Wea. Digest, 8, 12-23.

Petersen, R. A., L. W. Uccellini, A. Mostek, and D. A. Keyser, 1984: Delineating mid- and low-level water vapor patterns in a pre-convective environment using VAS moisture channels. Mon. Wea. Rev., 112, 2178-2198.

Petersen, R. A., 1985: Detailed three-dimensional isentropic analysis using an objective cross-sectional approach. Mon. Wea. Rev., 113. (Accepted.)

Pielke, R. A., and M. Segal, 1985: Mesoscale circulations forced by differential terrain heating. Mesoscale Meteorology and Forecasting, P. Ray, Ed., Amer. Meteor. Soc.

Robinson, W. D., D. Chesters, and L. W. Uccellini, 1985: Optimized retrievals of high resolution precipitable water fields from combinations of VAS satellite and conventional surface observations. J. Geophys. Res. (Submitted.)

Rodgers, E. B., R. A. Mack, and A. F. Hasler, 1983: A satellite stereoscopic technique to estimate tropical cyclone intensity. Mon. Wea. Rev., 111, 1599-1610.

Salmon, E. M., and T. T. Warner, 1985: The impact of the diagnostic initialization of divergence on short-term precipitation forecasts provided by a mesoscale model. (In preparation.)

Schlesinger, R. E., L. W. Uccellini, and D. R. Johnson, 1983: On the effects of the Asselin time filter upon numerical solution to the linearized shallow-water wave equations. Mon. Wea. Rev., 111, 455-467.

Schlesinger, R. E., 1984: Mature thunderstorm cloud-top structure and dynamics: A three-dimensional numerical simulation study. J. Atmos. Sci., 41, 1551-1570.

Schlesinger, R. E., 1984: Effects of the pressure perturbation field in numerical models of unidirectionally sheared thunderstorm convection: Two versus three dimensions. J. Atmos. Sci., 41, 1571-1587.

Schlesinger, R. E., 1985: Effects of upstream-biased third-order space correction terms on multidimensional Crowley advection schemes. Mon. Wea. Rev., 113. (Accepted.)

Segal, M., and R. A. Pielke, 1985: On the effect of water temperature and synoptic flows on the development of surface flows over narrow-elongated water bodies. J. Geophys. Res. (In press.)

Segal, M., J. F. W. Purdom, R. A. Pielke, and Y. Mahrer, 1985: Evaluation of stratiform cloud shading effects on the generation and modification of mesoscale circulations. Mon. Wea. Rev. (Submitted.)

Simpson, J., B. R. Morton, M. C. McCumber, and R. S. Penc, 1986: Observations and mechanisms for GATE waterspouts. J. Atmos. Sci. (Accepted.)

Soong, S.-T., and W.-K. Tao, 1984: A numerical study of the vertical transport of momentum in a tropical rainband. J. Atmos. Sci., 41, 1049-1061.

Soong, S.-T., and W.-K. Tao, 1985: The statistical properties of a cloud ensemble: A numerical study. (In preparation.)

Spencer, R. W., W. S. Olson, W. Rongzhang, D. W. Martin, J. A. Weinman, and D. A. Santek, 1983a: Heavy thunderstorms observed over land by the Nimbus-7 Scanning Multichannel Microwave Radiometer. J. Clim. Appl. Meteor., 22, 1041-1046.

Spencer, R. W., D. W. Martin, B. B. Hinton, and J. A. Weinman, 1983b: Satellite microwave radiances correlated with radar rain rates over land. Nature, 304, 141-143.

Spencer, R. W., B. B. Hinton, and W. S. Olson, 1983c: Nimbus-7 37 GHz radiances correlated with radar rain rates over the Gulf of Mexico. J. Clim. Appl. Meteor., 22, 2095-2099.

Spencer, R. W., 1984: Satellite passive microwave rain rate measurement over croplands during spring, summer, and fall. J. Clim. Appl. Meteor., 23, 1553-1562.

Spencer, R. W., 1985: An improved satellite passive 37 GHz method for measuring oceanic rainfall. J. Clim. Appl. Meteor. (Accepted.)

Spencer, R. W., and D. A. Santek, 1985: Measuring the global distribution of intense convection over land with passive microwave radiometry. (Accepted.)

Spinhirne, J. D., M. Z. Hansen, and J. Simpson, 1983: The structure and phase of cloud tops as observed by polarization lidar. J. Appl. Meteor., 22, 1319.

Steranka, J., E. B. Rodgers, and R. C. Gentry, 1984: Diurnal variation of Atlantic Ocean tropical cyclone cloud distribution inferred from geostationary satellite infrared measurements. Mon. Wea. Rev., 112, 2338-2344.

Steranka, J., E. B. Rodgers, and R. C. Gentry, 1985: The influence of satellite measured convective burst upon tropical cyclone intensification. (In preparation.)

Stobie, J., F. Einaudi, and L. W. Uccellini, 1983: A case study of gravity wave-convective storm interactions: May 9, 1979. J. Atmos. Sci., 40, 2804-2830.

Tao, W.-K., and J. Simpson, 1984: Cloud interactions and merging: Numerical simulations. J. Atmos. Sci., 41, 2901-2917.

Tao, W.-K., and S.-T., Soong, 1985: A study of the response of deep tropical clouds to mesoscale processes: Three-dimensional numerical experiments. J. Atmos. Sci. (Submitted.)

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5.2 Appendix B: Severe Storms Branch and Research Support Staff

5.2.1 Storm Scale Group

*f) Dr. R. Adler
g) Mr. R. Blackmer
f) Dr. S. Chou
g) Dr. L. Chen
g) Mr. J. Firestone
u) Dr. W. Frank
g) Mr. M. Franzblau
u) Dr. C. Gentry
u) Dr. W. Gray
f) Dr. A. Hasler
g) Ms. I. Hakkarinen
f) Dr. G. Heymsfield
g) Ms. B. Houser
g) Mr. J. Ku
g) Ms. J. Liu
g) Mr. R. Mack
g) Mr. M. Markus
g) Mr. R. Morris
f) Mr. A. Negri
m) Dr. E. Nunez
r) Mr. R. Penc
g) Mr. T. Piper
f) Mr. E. Rodgers
u) Dr. R. Schlesinger
g) Mr. S. Schotz
u) Dr. R. Spencer
g) Mr. J. Stout
U) Dr. G. Szejwach
m) Dr. S. Ulanski
f) Dr. P. Wetzel

5.2.2 Mesoscale Analysis and Modeling Group

*f) Dr. L. Uccellini
s) Mr. R. Aune
g) Mr. K. Brill
s) Ms. J. Cram
s) Dr. J. Chang
f) Ms. M. desJardins
g) Mr. R. Golus
r) Mr. I. Graffman
r) Mr. M. Goodman
g) Mr. J. Homan
s) Dr. M. Kaplan
g) Mr. D. A. Keyser
f) Dr. D. Keyser
f) Dr. S. Koch
f) Mr. P. Kocin
r) Mr. D. Larko
s) Mr. J. McQueen
g) Mr. A. Mostek
g) Mr. M. Pecnick
f) Ms. C. Peslen
f) Dr. R. Petersen
u) Dr. R. Pielke
g) Mr. W. Robinson
g) Mr. B. Schmidt
m) Dr. F. Sechrist
s) Mr. J. Tuccillo
r) Mr. M. Vilardo
u) Dr. T. Warner
s) Dr. V. Wong
s) Dr. J. Zack
g) Mr. R. Woodward
U) Dr. E. Yeh

5.2.3 Other Research, Administrative, and Support Staff

*f) Dr. J. Simpson
g) Dr. J. Chen
f) Mr. L. Dubach
g) Mr. L. Long
f) Dr. M. McCumber
f) Ms. C. McEachern
g) Mr. R. Pierce
g) Ms. C. Sawyer
f) Mr. W. Skillman
n) Dr. W. Tao
g) Mr. J. Taylor
f) Ms. K. Wilson
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g - Contractor (GSC)
m - Summer Faculty
n - National Research Council RRA
s - Contractor (SASC)
r - Contractor (RDS)
u - University and Other Grantees
U - USRA

5.3 Appendix C: Glossary and Acronyms: This glossary includes entries from previous annual reports as well as the current report. This is done in order to increase its utility as a general reference.

AC	Active Convection
AIRPAK	AOIPS AIRcraft Software PAcKage
AMMS	Advanced Microwave Moisture Sounder
AMS	American Meteorological Society
AMSU	Advanced Microwave Sounding Unit
AMTEX	Air Mass Transformation EXperiment
AOIPS	Atmospheric and Oceanographic Information Processing System
API	Antecedent Precipitation Index
ARC	Ames Research Center, Sunnyvale, CA (NASA)
AVE	Atmospheric Variability Experiment
AVHRR	Advanced Very High-Resolution Radiometer
BAMS	Bulletin of the AMS
Barnes Scheme	An objective analysis scheme used to produce analyses of irregularly spaced data
CAPPI	Constant Altitude PPI Radar Display
Cb	Cumulonimbus Cloud
CCOPE	Cooperative COnvective Precipitation Experiment (Inter-agency project; 1981)
CDC-7600	Control Data Corporation Computer Model 7600
CDMP	Convective Dynamics and Microphysics Project (NOAA sponsored, south Florida; 1983)
CDO	Central Dense Overcast
CIMMS	Cooperative Institute for Mesoscale Meteorological Studies
CISK	Conditional Instability of the Second Kind

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CMM	CIMMS Mesoscale Model
CPU	Central Processing Unit
CLS	Cloud Lidar System
COSPAR	COmmittee on SPAce Research
CRAY-1	Large CDC computer named for its builder, S. Cray
CSI	Critical Success Index
CSU	Colorado State University
CTS	Cloud Top Scanner
CYBER 205	Large computer model produced by CDC, named by using a contraction of the word "cybernetics"
DEC	Digital Equipment Corporation
Doppler Radar	Radar which provides additional information on velocity of target images
EMEX	Equatorial Mesoscale EXperiment
EOS	Earth Observing System
ER-2	Super U-2 reconnaissance aircraft
ERL	NOAA Environmental Research Laboratory, Boulder, CO
ESMR	Electrically Scanning Microwave Radiometer
FAA	Federal Aviation Administration
FACE	Florida Area Cumulus Experiment
FAR	False Alarm Ratio
FCT	Flux Corrected Transport
FGGE	First GARP Global Experiment
GALE	Genesis of Atlantic Lows Experiment
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment

GEMPAK	GEneral Meteorological Software PAcKage used on AOIPS for data assimilation, analysis, and display
GEMPLT	GEMPAK PLoTting Software Program
GEOS	U.S. Geodetic Earth Orbiting Satellite
GLA	Goddard Laboratory for Atmospheres (1984 on, formerly GLAS)
GLAS	Goddard Laboratory for Atmospheric Sciences (1977-1984, subsequently GLA)
GLAS-1	An empirical techique for rain estimation (modification of the GWT)
GLAS-2	A physically based rain estimation technique
GMS	Japanese Geosynchronous Meteorological Satellite
GOES	U.S. Geostationary Operational Environmental Satellite (Note that GOES-E refers to GOES-East and is not intended to refer to the pre-launch designation of GOES-5; similarly, GOES-W refers to GOES-West. The "east and west" are designations of satellite location over the longitudes approximately passing through the U.S. East and West Coast regions and have been used with several different satellites; they have been used with the same satellite when its operating location was moved.)
GSC	General Software Corporation
GSFC	NASA Goddard Space Flight Center
GWT	Griffith-Woodley Technique
HIRS	High-Resolution IR Sensor
HMMR	High-Resolution Multi-frequency Microwave Radiometer
IAT	Image Analysis Terminal
IFOV	Instantaneous Field-Of-View
IOP	Intensive Observing Period

IR	InfraRed
ISLSCP	International Satellite Land Surface Climate Program
ITCZ	InterTropical Convergence Zone
Jet Streak	An isotach maximum area located along a jet stream
JTWC	Joint Typhoon Warning Center, GU
LaRC	Langley Research Center
LEOS	Low Earth Orbiting Satellite
LFC	Level of Free Convection
LFM	Limited-Area Fine Mesh Numerical Model; a NOAA mesoscale model
LFM-II	LFM Version 2
LI	Lifted Index
Lidar	Light detection and ranging
LLJ	Low Level Jet
M&O	Maintenance and Operation
MABL	Marine Atmospheric Boundary Layer
MAODAS	Mesoscale Atmosphere/Ocean Data Analysis System
MASEX	Mesoscale Air-Sea Interaction EXperiment
MASS	Mesoscale Atmospheric Simulation System
MASS BUSS	Trade name for DEC high-speed data transfer link between disc and memory
MCC	Mesoscale Convective Complex
MCR	Multi-Spectral Cloud Radiometer
MCS	Mesoscale Convective System
METPAK	METeorological Analysis Software PAcKage for use on AOIPS
METREAL	METPAK REAL-time

MIST	MIcroburst Severe Thunderstorm Experiment
MSI	Multi-Spectral Imager
MSFC	NASA Marshall Space Flight Center
MSU	Microwave Sounding Unit
MULTDOP	MULTiple-DOPpler Radar Analysis Program, a software package designed for use on AOIPS to process multiple Doppler radar data
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NDVI	Normalized Difference Vegetation Index (a measure of the earth's greenness, i.e., chlorophyll content)
NESDIS	NOAA National Environmental Satellite Data Information Service
NESS	NOAA National Earth Satellite Service, Suitland, MD
NHSCF	NASA High-Speed Computer Facility
NHRL	National Hurricane Research Laboratory
Nimbus	A series of seven NASA meteorological research satellites
NMC	NOAA National Meteorological Center, Suitland, MD
NOAA	National Oceanic and Atmospheric Administration (U.S. Department of Commerce)
NOAA-6, 7, 8	The second, third, and fourth satellites (TIROS-N was the first satellite) of the fourth generation (previous generations were TIROS, ESSA, and NOAA 1-5) of U.S., operational, meteorological satellites
NRC	National Research Council, Washington, DC
NSSFC	NOAA National Severe Storms Forecast Center, Kansas City, MO

NSSL	NOAA National Severe Storms Laboratory, Norman, OK
ODIS	Ocean Data Information System
OSIP	Operational (Meteorological) Satellite Improvement Program
p	pressure
PAM	Portable Automated Mesonetwork
PBL	Planetary Boundary Layer
PE	Primitive Equation
POD	Probability Of Detection
PPI	Planned Position Indicator Radar
Presidents' Day	February 19, 1979, so named for the federal holiday designated to commemorate Washington's and Lincoln's birthdays
PROFS	Prototype Regional Observing and Forecast Service
PVA	Potential Vorticity Advection
PW	Precipitable Water
QE II	Queen Elizabeth II birthday (September 9, 1978, case study)
Radar	Reflection of pulsed radar frequencies from clouds or precipitation, provides imagery related to droplet size, concentration, and phase. This is often interpreted in terms of storm intensity, precipitation rate, icing potential, etc.
Radiosonde	Same as rawinsonde except no wind tracking
RADPAK	RADar PAcKage-a software package developed for use on AOIPS to process radar data
RAMS	Regional Atmospheric Modeling System
RAOB	RAdiosonde OBservation-nominally plot of radiosonde or rawinsonde data

Rawinsonde	A Radio and wind sounding, balloon-borne instrument designed to radio coded temperature, pressure, and moisture observations and to provide a tracking target to obtain wind velocities
RDS	Research and Data Systems, Incorporated
RH	Relative Humidity
RRA	NRC Resident Research Associate
RMS	Root Mean Square
SASC	Systems and Applied Sciences Corporation
SCAMS	SCAnning Microwave Spectrometer
Seasat	Ocean (Sea) Research Satellite
SESAME	Severe Environmental Storms And Mesoscale Experiment
SFOV	Sounding Field-Of-View
SI	Skill Index: One of a variety of scores which has been devised to measure skill of a meteorological prediction
SiB	Simple Biosphere (model)
SMMR	Scanning Multichannel Microwave Radiometer
SMS	U.S. (geo-) Synchronous Meteorological Satellite
SPACE	Satellite Precipitation And Cloud Experiment
SPANDAR	SPAce RaNge RaDAR (Wallops Island, VA)
SSAI	Science Systems and Applications, Incorporated
SSMI	Special Sensor Microwave Imager
SST	Sea Surface Temperature
STEP	NASA Stratosphere-Troposphere Exchange Program
STJ	SubTropical Jet

STORM	STorm-Scale Operational and Research Meteorology
TAE	Transportable Applications Executive
TASS	Terminal Area Simulation System
TIROS-N	Television and InfraRed Observation Satellite, Model N (part of the NOAA operational satellite series-between NOAA-5 and NOAA-6)
TOMS	Total Ozone Mapping Spectrometer
TOVS	TIROS Operational Vertical Sounder
ULJ	Upper-Level Jet
UNIBUS	Trade name for DEC high-speed data transfer link between memory and image terminals
USRA	Universities Space Research Administration
UW	University of Wisconsin
"V" Notch	A characteristic "V" pattern in the IR temperature field downwind from the storm
V_{MAX}	Wind Velocity MAXimum
VAP	VAS Applications Data Processor System
VAS	VISSR Atmospheric Sounder
VAX	DEC Computer Model Name
VIS	VISible
VISSR	Visible Infrared Spin-Scan Radiometer
VP	VAS Processor
VRR	Volumetric Rain Rate
WB-57	Weather Observing/Research, modified USAF Bomber Model 57
WP-3D	Weather modified Model P-3D aircraft
WSR-57	U.S. Weather Service Radar Model 57

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16. Abstract

This report is a review of research accomplishments of the NASA/GSFC Severe Storms Branch for the 12-month period beginning in April 1984. It also briefly notes future plans. NASA's Mesoscale Atmospheric Processes Research Program is a nationwide program of integrated studies with the goal of achieving improved understanding of the basic behavior of the atmosphere through the use of remotely sensed data and space technology. The four main elements of the program consist of special observations and analysis of mesoscale systems, the development of quantitative algorithms to use remotely sensed observations, the development of new observing systems, and numerical modeling. The NASA/GSFC Severe Storms Branch objectives are improvement of our understanding, diagnosis, and prediction of a wide range of atmospheric storms, which includes severe thunderstorms, tornadoes, flash floods, tropical cyclones, and winter snowstorms (with the combined use of space observations, radar, conventional data, models, and other tools). By-products of the research often shed light upon various aspects of local weather, such as fog, sea breezes, air pollution, showers, and other products of non-severe cumulus cloud clusters. Conversely, the small part of the program devoted to boundary layer processes, gust front interactions, and soil moisture detection from satellites has contributed insights into storm growth and behavior.

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