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NASA/MSFC FY-82 Atmospheric Processes Research Review



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*Summary of a program review held at
Huntsville, Alabama
October 19-21, 1982*

NASA



NASA Conference Publication 2259

NASA/MSFC FY-82 Atmospheric Processes Research Review

*Compiled by
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Marshall Space Flight Center, Alabama*

Summary of a program review held at
Huntsville, Alabama
October 19-21, 1982

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and Space Administration
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ACKNOWLEDGMENTS

The productive inputs and comments from the participants and attendees in the Atmospheric Processes Research Review contributed very much to the success of the review. The opportunity provided for everyone to become better acquainted with the work of other investigators and to see how the research relates to the overall objective of NASA's Atmospheric Processes Research Program was an important aspect of the review. Appreciation is expressed to all those who participated in the review. The organizers trust that participation will provide each with a better frame of reference from which to proceed with the next year's research activities.

PREFACE

Each year NASA supports research in various disciplinary program areas. The coordination and exchange of information among those sponsored by NASA to conduct research studies are important elements of each program. The Office of Space Science and Applications and the Office of Aeronautics and Space Technology, via Announcements of Opportunity (AO), Application Notices (AN), etc., invites interested investigators throughout the country to communicate their research ideas within NASA and in institutions. The proposals in the Atmospheric Processes Research area selected and assigned to the NASA Marshall Space Flight Center's (MSFC's) Atmospheric Sciences Division for technical monitorship, together with the research efforts included in the FY-82 MSFC Research and Technology Operating Plan (RTOP), are the source of principal focus for the NASA/MSFC FY-82 Atmospheric Processes Research Review.

The principal purpose of the review and summary report is to provide those having major research activities sponsored by NASA on atmospheric research and assigned to MSFC's Atmospheric Sciences Division an opportunity to present their accomplishments and future plans. In addition, the review provides NASA Headquarters and MSFC Research Managers with a current status report plus suggestions for future research to use in developing the program. The principal managers involved are Dr. Shelby Tilford, Mr. John Theon and Dr. James Dodge, NASA Environmental Observation Division, Office of Space Science and Applications; Mr. Allan Tobiason, NASA, Aeronautics Systems Division, Office of Aeronautics and Space Technology; and Dr. William W. Vaughan, MSFC Atmospheric Sciences Division. Dr. Robert Turner serves as the coordinator for the research review.

Seven general areas of NASA's Atmospheric Research Program were included in the review: Upper Atmospheric and Coupling; Aviation Safety-Environmental Hazards; Doppler Lidar Application; Severe Storms Satellite Data Studies; Lightning, Global Weather - Flight Experiments and Global Weather Satellite Data Studies. The final titles of the individual papers may vary from the planned agenda depending on the particular emphasis of the principal investigator. The technical aspects of the research efforts are stressed and the individual presentations developed to provide the rationale for recommendations on the coming year's research. The agenda for the review is included as an Appendix to this report.

The organizers endeavored to make this a review of the major aspects of the sponsored research activities relative to the NASA program aims. The review was planned to permit the maximum exchange of information among the program participants insofar as practical; and further develop a research team spirit to the benefit of all concerned. To provide for a follow-up by the various program participants and other interested persons, each

investigator was requested to prepare a brief narrative outline on his research project. The investigators' unedited outlines are assembled in this report.

It was recognized that the scopes of individual research efforts comprise a wide range. Some are very modest or have been under way for only a short period of time, whereas others involve several years of activity. However, the opportunity to learn what each investigator is doing and to develop the team relationship necessary for a meaningful research program were considered most important. It is toward this goal that this summary report has been developed.

Recipients of this report on the NASA/MSFC FY82 Atmospheric Processes Research Review are encouraged to communicate directly with the respective principal investigators regarding scientific and technical matters or questions they might have on the research efforts. Any recommendations or suggestions concerning the program will be welcomed.



William W. Vaughan, Chief
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SESSION I

UPPER ATMOSPHERE AND COUPLING

The subjects covered in this session are a very heterogeneous mixture; however, they all share a common theme - significant accomplishments.

The solar terrestrial coupling subject contains a very plausible mechanism that can be evaluated using existing data. It is the only mechanism identified to date that is readily verifiable.

The hardware for the Atmospheric Emissions Photographic Imager (AEPI) has been developed and delivered to KSC where it is now being integrated into the Spacelab I flight hardware.

The ionospheric Doppler sounder array has been automated so that the data is digitized, analyzed and stored in digital format on magnetic tape cassettes. This has solved a long standing problem of researchers in this area of ionospheric research.

Robert Smith



NASA/MSFC Research Abstract

31 Aug 82.

1. Title: Solar Variability and Stationary Planetary Wave Behavior

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3. Significant Accomplishments During FY-82:

Early theoretical research into the origin and behavior of externally forced, planetary scale atmospheric waves established the fact that these vertically propagating, horizontally stationary waves are particularly sensitive to changes in the stratospheric and mesospheric zonal wind fields. In particular, the initial mathematical descriptions of these waves (Charney and Drazin, 1961) indicated that they would be reflected off critical layers in the stratosphere and mesosphere where the zonal winds exceed about 90 m/s. Approximately a decade later, the theory of vertically trapped planetary waves was expanded by the introduction of the concept of global atmospheric waveguides which steer the propagation of the non-evanescent wave modes (Matsuno, 1970). Recent work under NASA and Aspen Institute sponsorship has concentrated on identifying the locations, vertical structure, and properties of the planetary waveguides for quasi-stationary planetary waves 1 through 3 using a COSPAR-like reference atmosphere for the zonal winds.

Initial significant results indicate that during the winter, the wave guide for planetary wave (p.w.) 1 effectively couples the troposphere to the thermosphere at latitudes between 50 and 70N. The wave guides for planetary waves 2 and 3 are far more complex, being primarily confined to a narrow channel just north of the critical wind line where the stratospheric zonal winds

reverse in the lower latitudes. Inspection of the waveguide maps (positive index of refraction squared) reveal that p.w. 1 has a relatively low index of refraction over the atmospheric region bounded by 50-70N and 60-80 km altitude. Additionally, it is over this region where the wave has its maximum amplitude. Consequently, p.w. 1 is especially sensitive to external influences which are capable of reversing the sign of the index of refraction squared, thereby trapping the wave. In particular, recently developed models of atmospheric perturbations caused by the auroral electrojet (Luhmann, 1979) suggest that the gravity waves generated by the rapid commencement of the electrojet interact with the region immediately above the stratopause (50 km) to create conditions conducive to the temporary trapping of p.w. 1. The nature of the interaction necessarily leads to resonant trapping through observable increases in the zonal wind speed throughout the mid- and high-latitude stratosphere and mesosphere.

The effect of resonantly trapping planetary wave 1 is to increase its amplitude in a predictable way throughout the atmospheric waveguide. In support of the proposed mechanism, observations of planetary waveforms at 500 mb during 1979 indicate that p.w. 1 rapidly and clearly became the dominant planetary wave when resonant trapping was presumably initiated by the mechanism described.

4. Current Focus of Research:

Ongoing research is currently being directed at refining the tropospheric observational evidence and expanding the data base to other years for which NMC octagonal grid fields exist.

5. Plans for FY-83:

Since the proposed solar-terrestrial interaction is expressed in the form of a very simple model mechanism, numerous additional tests of the model are possible. Specifically, data from the meteorological rocket network (MRN) needs to be examined to check for observational consistency. Additionally, it will be instructive to verify NMC 12-72 hour forecasts to determine the impact which the proposed mechanism has on operational meteorological forecasts.

6. Recommendations for New Research:

The ongoing research strongly suggests the need for additional sensors to continuously monitor the upper atmosphere and near earth space environment.

Specifically:

a. Since the properties of the solar wind are known to be linked to the strength and commencement of the auroral electrojet, there is a clear need to improve our understanding of both the solar wind and electrojet physics. Although NASA's ISEE-3 satellite was an exceptionally good vehicle for accomplishing this, its utility to perform the mission will be totally lost when it is sent through the earth's magnetotail in the fall of 1982.

b. Because the behavior of the quasi-stationary planetary waves is dominated by the fine spatial structure of the global zonal winds between the surface and about 100 km altitude, new initiatives need to be proposed to continuously monitor stratospheric and mesospheric winds. The remote sensing technology to passively measure these winds from spacecraft with sufficient accuracy (5 m/s), spatial resolution (5 km vertical, 150 sq km horizontal), and timeliness has been recently developed. Such an instrument would be a logical payload for NASA's planned Solar Terrestrial Observatory (STO).

c. Finally, since the proposed mechanism is possibly related to the 22 year solar magnetic cycle, it is plausible that wintertime drought, particularly that caused by tropospheric blocks (Rex, 1950, Brezowsky et al., 1951), is linked to resonant planetary wave trapping of p.w. 1. Additional consideration of this possibility is warranted.

7. Publications since June 81:

Solar Variability and Force Planetary Wave Behavior to be published in the Proceedings of the Second International Symposium on Solar Terrestrial Influences on Weather and Climate, 2-6 Aug 82, Boulder, CO.

8. References:

Brezowsky, H., H. Flohn, and P. Hess, Some Remarks on the Climatology of Blocking Action, *Tellus*, 3, 191, 1951.

Charney, J. G., and P. G. Drazin, Propagation of Planetary-Scale Disturbances from the Lower into the Upper Atmosphere, *J. Geophys. Res.*, 66, 83, 1961.

Matsuno, T., Vertical Propagation of Stationary Planetary Waves in the Winter Northern Hemisphere, *J. Atmos. Sci.*, 27, 871, 1970.

Luhmann, J. G., Atmospheric Pressure and Velocity Fluctuations Near the Auroral Electrojet, *J. Geophys. Res.*, 85, 1749, 1980.

Rex, D. F., Blocking Action in the Middle Troposphere and its Effect on Regional Climate, *Tellus*, 2, 275, 1950).

TITLE: ATMOSPHERIC EMISSIONS PHOTOMETRIC IMAGER ON SPACELAB

RESEARCH INVESTIGATORS:

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SIGNIFICANT ACCOMPLISHMENTS FY-82

In FY82, the fabrication of AEPI flight system for Spacelab 1 was completed. The system was environmentally tested including vibration, thermal vac, off-gasing, out-gasing, and EMI. The system software was completed and two crew training sessions were conducted with the flight system.

The system was delivered to KSC in May, 1982 for integration into the spacelab. The four module mounted components have been installed in the rack and the detector/pointing assembly has been installed on the pallet completing mechanical integration.

The experiment activity for Spacelab 1 is well cast. AEPI is scheduled for approximately 30-10 minute experiment opportunities over the 7 day mission. Approximately 1/2 of those involve particle beam experiments with the 2 particle instruments on the spacecraft. The targets of opportunity will most likely be limited to our scheduled opportunity times because of mission complexity. We have structured the experiment operation for quick response when opportunities arise. A great deal of orbiter attitude and timeline analysis has been performed.

CURRENT FOCUS OF RESEARCH WORK:

Integrate the experiment electrically and functionally with the spacecraft systems and other experiments. Work timeline studies, POCC (payload operations control center) simulations, crew training, test and crew procedures, and real time data system for optimum mission performance.

We are studying replacement imagers for reflight which include two stage image intensifiers coupled to solid state area arrays rather than the outdated vidicon being used in the Spacelab 1 instrument. Several candidate combinations are promising. A breadboard CID system is being assembled for ground use and testing. Remote detector applications are proving feasible. This is ideal since the mass carried by pointing systems can be made very small and easier to accomodate than past systems.

PLANS FOR FY-83:

Work Spacelab 1 integration, crew training, mission planning, and POCC systems.

Plans and software for post mission analysis of data will be performed. Image analysis software and hardware will be accomplished.

Continued development of solid state imager as applied to atmospheric sensing.

RECOMMENDATIONS FOR NEW RESEARCH:

Study and develop methods to cool image intensified solid state arrays for spacelab environments.

PUBLICATIONS:

None

MODIFICATION OF THE IONOSPHERIC DOPPLER SYSTEM

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The goals of the research are: (1) to determine the feasibility of collecting the ionospheric doppler data in a form permitting real time digitalization and near real time mathematical manipulation of the data; (2) to identify methods for assessing in near real time the quality of the data; and (3) to identify techniques and programs, compatible with the capabilities of a small desk-top computer, for reducing the data.

In the original ionospheric doppler system, the transmitters operate continuously except for brief interruptions every 30 minutes to permit transmission of station identification call letters. To permit identification of the transmitting station in the continuously collected ionospheric doppler data stream, the operating frequencies of the transmitters at a given base frequency differ slightly from each other; with one being set at the base frequency, one at 1 Hz above the base frequency, and the third at 2 Hz above the base frequency. When the received signal is then heterodyned with a signal at the base frequency the output signal consists of three distinct components; with the first being the signal, about a 0 mean, of the doppler shift of the signal transmitted at the base frequency by the motion of the ionosphere in the region of reflection; the second a signal about the 1 Hz mean, and the third a signal about the 2 Hz mean. The output from the receiver is recorded at slow speed on magnetic tape. The frequency content is subsequently recovered by playing back the tape at greatly increased speed and processing the output signal through a spectrum analyser. Reduction and analysis of the data are not possible in real time with this system.

Relatively recent improvements in frequency meters make possible the measurement of frequency with a precision of about 1 part in 10^8 of signals stable over a 1-second interval. The technique presently being investigated uses such a frequency meter.

The transmissions from the three stations are separated in time, rather than frequency, from each other so that no two stations transmit simultaneously at the same frequency. The time of occurrence and duration of transmission at each station is controlled by a local clock which derives its base frequency from the highly stable crystal controlled oscillator of the middle frequency (4759000 Hz) transmitter. The clock can be set, against the time signal from WWV, with an accuracy of ± 1 ms.

The tunable heterodyne receivers have been replaced by narrow-band, fixed frequency, R F amplifiers. Outputs from the amplifiers are switched sequentially to the frequency meter which is gated on for 1 second. The measured output of the frequency meter is recorded on magnetic discs for permanent storage. Switching of the receivers, activation of the frequency meter, and formatting and storage of the data are accomplished by a small, programmable, desk-top controller/ computer. Measurements of the signal at a given frequency from a given station are made at 10-second intervals. Timing of the operations is controlled by the computer clock on a program interrupt basis. Execution of these operations requires less than 10 percent of the operating time. Effective use of the disc storage capacity dictates that the data be held in the machine temporarily and stored in 7 minute-long records. The time of occurrence of the first reading in the record and a code identifying the transmitter are recorded at the beginning of each record.

A measured frequency that deviates from the transmitter frequency by more than 3 Hz is identified as a bad datum. If in a given stream of data the total number of bad measurements does not exceed some threshold value and if the bad data do not occur in sequences longer than some threshold value, it is possible to reduce and analyze the data without loss of confidence in the results. We are currently testing the effects of the threshold values on the validity of the subsequent reduction and analysis operations.

We are also testing methods for assessing the stationarity of the data, for filtering, and for extracting information on the periods and amplitudes of the doppler frequencies and the velocities of the forcing wave disturbances in the ionosphere. Accepted techniques for accomplishing all of these tasks already exist. The challenge currently lies in adapting the standard techniques for execution on the controller/computer which is a limited capability machine.

TITLE: The Effects of Solar Flares on the Accuracy of Numerical Weather Prediction Techniques

RESEARCH INVESTIGATORS: R. E. Smith
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SIGNIFICANT ACCOMPLISHMENT FY-82:

Preliminary results based on analysis of 500 mb data only show no statistically significant correlation between prediction inaccuracies and short-term variations in solar activity such as flares, X-ray bursts, etc. Inaccuracies in initialization techniques, input data, and prediction algorithms all combine to produce prediction inaccuracies which are of a greater magnitude than errors that could be attributed to the effects of short term variations in solar activity.

CURRENT FOCUS OF RESEARCH:

Analysis activities up to the present have considered the effects on a hemispherical basis. It is possible that this procedure has masked some small effect on a regional basis.

PLANS FOR FY83:

Available data will be re-examined to see whether or not there are preferred locations where effects of solar flares can be identified. Then analysis will be started on the 300 mb data to see if a solar signal is evident at this higher altitude.

ACOUSTIC AND GRAVITY WAVES IN THE NEUTRAL ATMOSPHERE AND
THE IONOSPHERE, GENERATED BY SEVERE STORMS

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The generation of infrasound (of frequency of about 1 Hz) in association with the collapse of the charged region in a lightning discharge, has been confirmed. Simultaneous measurements of electric-field changes and audible thunder were made. The highly directional nature of the infrasound signal was also confirmed.

Experimental and theoretical work on gravity waves from severe storms is continuing. So far, our studies indicate that gravity waves are generated when severe thunderstorms penetrate the tropopause.

High amplitude gravity waves at ionospheric levels were detected on January 12, 1982, during the outbreak of severe cold weather over the east coast. The waves had a period of about 10 minutes (see Fig.1) and a speed of about 185 meters/sec. The source of the waves was identified as a cold upper air low seen on the 500mb charts. Preliminary analysis indicates that geostrophic adjustment associated with the dissipation of this upper air low may be the generating mechanism for the waves.

Ionospheric Doppler-sounder measurements were made in association with the passage of the Dynamic Explorer Satellite over our area. Satellite measurements of neutral, electron and ion density fluctuations will be compared with the Doppler-sounder data. For FY-83, we plan to continue the study of infrasonic thunder signals to understand their relationship to the type of electric discharge and nature of the charged region. We plan to continue the experimental and theoretical work on the generation of gravity waves by thunderstorms. Detection and analysis of infrasonic signals from thunder at ionospheric levels will be another objective. Such studies may indicate ways of studying thunderstorms from space with the help of ionospheric perturbations generated by acoustic and gravity waves from these storms.

We also plan to conduct data analysis and interpretation to compare the Dynamic Explorer data with our ionospheric data. This project will be carried out in collaboration with NASA GSFC, Greenbelt, M D and Polytechnic Institute of New York, Farmingdale, N Y.

Recommendation for future research will be the coordination of our ground-based ionospheric measurements with appropriate satellite measurements. Such coordination will be especially beneficial for the WISP (Waves in Space Plasmas) program

Publications:

Balachandran, N.K., Acoustic and electric signals from lightning;
Submitted, J. Geophys. Res.

Gedzelman, S.D., Short-period atmospheric gravity waves: A study
of their statistical properties and source
mechanisms; Submitted, Mon. Wea. Rev.

TIME →→

10:00 EST

Jan. 12, 1982

←←5 min→→

DOPPLER SHIFT

±2 Hz

13

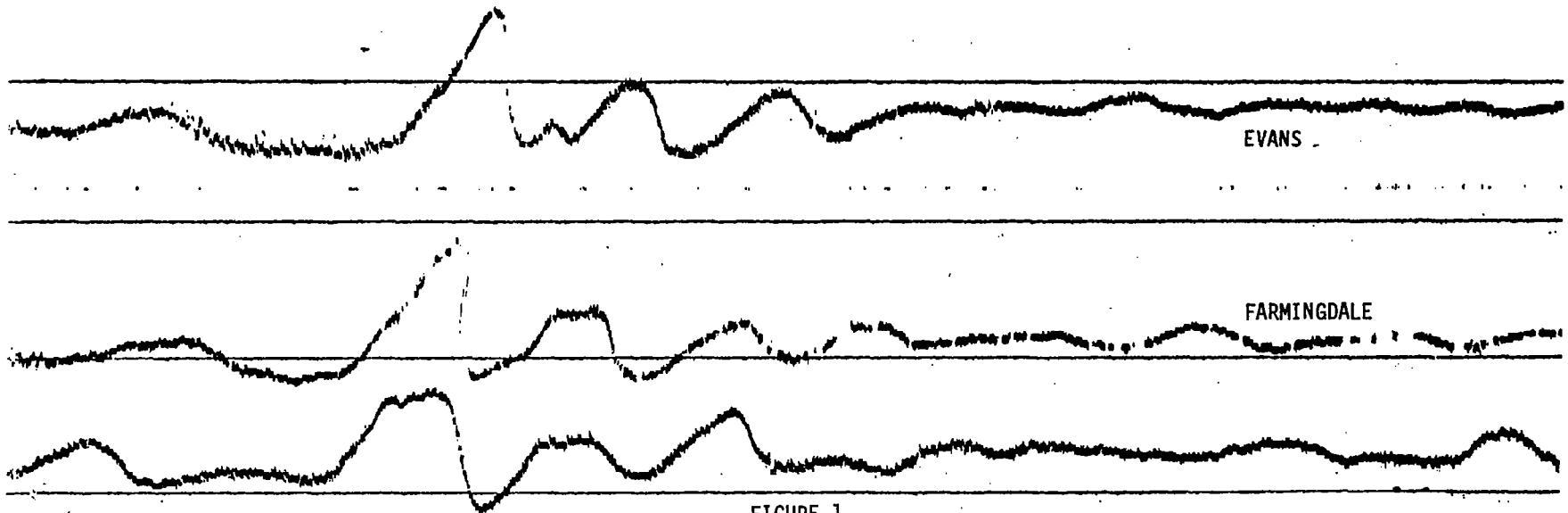


FIGURE 1

NEWBURGH



SESSION II

AVIATION SAFETY – ENVIRONMENTAL HAZARDS

In this section are some brief write-ups concerning meteorological effects on safe and efficient operations of aeronautical systems. This program is a responsibility of the Aeronautical Systems Division of the Office of Aeronautical and Space Technology. These write-ups are concerned with wind gust gradients, the dynamics of thunderstorms, clear air turbulence, fog dispersal, ice/frost on aeronautical surfaces, and wake flow about buildings. The efforts presented are being conducted both inhouse and under contract. Additional information can be obtained from the Session Chairman.

Dennis Camp

TITLE: B-57B Gust Gradient Program

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SIGNIFICANT ACCOMPLISHMENTS DURING FY82:

The B-57B aircraft collected flight data during the Joint Airport Weather Studies (JAWS) Project, from July 6-July 22 in the Denver area. NCAR support for these flights included triple Doppler radar, the Portable Automated Mesonet (PAM), the Multiple Aircraft Positioning System (MAPS) data, etc. In the course of the Gust Gradient Program, tornadoes/funnel clouds, hail, and microbursts were sighted. On two days (July 14 and July 15) the B-57B encountered severe turbulence.

During the JAWS Project the B-57B was directed to areas of suspected outflow from the JAWS operations van at CP-2, where one of the Doppler radars was located as well as the operational control point for JAWS.

CURRENT FOCUS OF RESEARCH WORK:

The B-57B Gust Gradient Program is a joint effort involving MSFC, Langley Research Center (LaRC), Dryden Flight Research Facility (DFRF) and the Ames Research Center (ARC). Marshall's role is data analysis, LaRC instrumented the plane and converts the raw data into engineering units, DFRF is in charge of aircraft operations and ARC serves in an advisory role as well as doing some investigative work on an IR radiometer.

The long range objective of the Gust Gradient Program is to provide detailed information to aircraft designers on turbulent patchiness and spatial variability of turbulence. This information is also to be provided to flight simulator and training personnel. The detailed structure of turbulence, in particular the spanwise variation of turbulent gusts in the planetary boundary layer, is to be measured by the B-57B which is instrumented with velocity, temperature, and pressure probes on each wingtip and at the nose. Currently, many

flight simulations are based on the assumption that the aircraft is small relative to turbulence length scales. If the gust gradients are generated for use in simulations, some assumptions are made which become questionable in the boundary layer. See for example reference 1. The assumption of a small aircraft is obviously questionable for wide bodied aircraft. At JAWS the B-57B flew approach and departures at Stapleton International Airport, Buckley Air National Guard Base, Jefferson County Airport, and simulated approach and departures over open fields. All of these places are in the Denver, Colorado area. In addition, measurements at constant low altitudes of 50-1000 m were made. In addition to the fundamental gust gradient flight requirements, inter-comparison flights were made with the University of Wyoming's Beechcraft King Air and a HS 125 aircraft operated by the UK Royal Aircraft Establishment.

The data from these flights are being processed at the present time. Data analysis will include statistical and spectral analyses, and correlations with meteorological phenomena as indicated on Doppler radar, PAM, etc.

PLANS FOR FY83:

In the coming year, the data gust gradient collected during the JAWS project will be analyzed. In addition, depending on funding, it is hoped that data from additional sites will be collected. These sites include but are not restricted to DFRF, Norman (NSSL), MSFC, LaRC, and KSC.

RECOMMENDATIONS FOR FUTURE RESEARCH:

The B-57B is a rugged and stiff aircraft ideally suited for the investigation of microbursts, and severe wind environments. The B-57B should be used to obtain a more complete picture of turbulent structure in the vicinity of thunderstorms. In the near future, plans call for the installation of a humidity sensor, a field mill for atmospheric electricity measurements, and other instruments. We hope that funding will be made available for B-57B participation in field programs studying severe storms.

1. Tatom, F. B., et al. Simulation of Atmospheric Turbulent Gusts and Gust Gradients, Journal of Aircraft, Vol. 19, Number 4, April 1982, 264-271.

TITLE:

The Joint Airport Weather Studies (JAWS) Project

Conducted by: The National Center for Atmospheric Research
The University of Chicago

Sponsored by: The National Science Foundation
The National Aeronautics and Space Administration
The National Oceanic and Atmospheric Administration
The Federal Aviation Administration (pending)

Technical Support: The Federal Aviation Administration

RESEARCH INVESTIGATOR(S):

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FY-82 ACCOMPLISHMENTS:

The Joint Airport Weather Studies (JAWS) Project was originally conceived in April 1980, as an outgrowth of the evolution of three scientific investigations: The Northern Illinois Meteorological Research on Downbursts (NIMROD) by Dr. Theodore Fujita; aircraft performance Doppler radar studies of low-level wind shear by Dr. John McCarthy; and operational uses of Doppler radar with emphasis on display development by Mr. James Wilson.

Fujita, McCarthy and Wilson developed a concept to address highly focused objectives in JAWS, concentrating on the evolution of the microburst. The microburst is a meso-alpha scale (400 m to 4 km) downburst that usually has pure divergent airflow associated with it near the surface. A downburst is defined as a meso-beta scale (4 to 40 km) downdraft which causes damaging winds on or near the surface. Expected maximum horizontal wind speeds in a microburst are 50 to 75 m/s, with temporal scales of 2 to 10 min for ground damage and 2 to 20 min for aviation hazards. The low-level wind shear associated with the microburst has been implicated as a cause of several major aviation accidents. A host of related applied and technology transfer objectives has been developed for JAWS, including aircraft performance in wind shear conditions, optional detection and warning of wind shear, and several fundamental Doppler radar objectives related to the next generation radar program (NEXRAD).

Early in the evolution of JAWS, a close relationship with NOAA's Prototype Regional Observing and Forecasting Service (PROFS) program was established. Technology transfer goals vital to PROFS were found to be identical to those for JAWS. From these shared goals, an agreement was reached between JAWS and PROFS for joint use of the NCAR 10-cm Doppler radar (CP-2) with full funding by PROFS.

A combined meeting of the sponsoring agencies and investigating scientists was held 17 November 1981 to provide the research community with an updated overview of the systems to be tested during JAWS, to present operational strategies, and to coordinate the research needs of each sponsoring agency and others interested in basic studies.

From input gathered from participants, we produced a detailed JAWS Field Operations Plan 1982. Developing in parallel, arrangements were made to set up the field project, including three Doppler radars, two LIDARS, 27 Portable Automated Mesonet (PAM) stations, and coordination of six research aircraft to be flown during the summer field project from 15 May to 15 August 1982.

CURRENT FOCUS OF RESEARCH WORK:

The principal objective of JAWS is additional basic knowledge of microbursts and their environment to help scientists understand what causes them and how they can be detected and predicted. In addition, JAWS has its applied research side. The program will: (1) determine the effects of low-level wind shear on aircraft performance; (2) test and evaluate wind-shear detection and warning systems; and (3) extend the usefulness of Doppler radars for detecting conditions of which pilots and the public need to be warned.

The basic questions JAWS will pursue are: (1) Why don't microbursts occur in all thunderstorms? (2) What physical mechanisms are responsible for generating microbursts? (3) Can downburst-inducing thunderstorms be distinguished from other types on Doppler radar and satellite measurements? (4) Why do dangerous microbursts sometimes occur in association with clouds much smaller than thunderstorms? (5) Is there a particular region within the cloud in which the downburst originates? (6) Is there an interrelationship among overshooting cloud tops, subsequent downdrafts, sinking tops, and microbursts?

A particularly relevant JAWS/NASA focus addresses thunderstorm turbulence characterization, with both Doppler radar and aircraft sensing perspectives. NCAR Doppler radar data will be used to support the NASA B-57B Gust Gradient effort to identify both longitudinal and internal gust components of turbulence and wind shear.

PLANS FOR FY-83:

The JAWS Project will obtain wind-shear characterization data in four dimensions (x, y, z, and t), with an improved resolution previously unavailable. These data can be used to provide air carriers with improved wind shear profiles, to be used in advanced manned flight simulators for training and proficiency needs. A second use of these data will extend the proof of wind-shear detection system concept of the airspeed, groundspeed procedure with more adverse shear cases than in previously tested "worst case" conditions. The data sets are expected to provide severe wind-shear cases in fine resolution. Profiles used in previous wind-shear characterizations have been inferred from accident flight data recorders, from conceptual models, and from meteorological towers. JAWS will provide the first high-resolution Doppler radar data collected for the specific hazard intended.

JAWS will produce a report that will evaluate five low-level wind-shear detection and warning systems: (1) on-site pulsed microwave Doppler and computer simulation; (2) area-wide Doppler radar applications; (3) low-level wind-shear alert system; (4) pressure jump alert system; (5) airborne airspeed and groundspeed procedure.

JAWS plans to conduct a real-time test of the ability of an airport-located Doppler radar to measure wind shear along approach and departure flight paths and to process these data in real time in a computer to provide a quantitative estimation of potential aircraft approach deterioration. This procedure provides wind shear hazard potential, without aircraft entering the hazard region.

In addition, JAWS will be collecting high-resolution Doppler radar airflow and turbulence data in the thunderstorm boundary layer, which can provide a complete descriptive context for the gust gradient program, using NASA's B-57B aircraft.

RECOMMENDATIONS FOR NEW RESEARCH:

Although it is premature at this stage to recommend new research as an outgrowth of JAWS analyses not yet begun, new NASA research objectives that should be addressed focus around manual flight simulation theory and practice in wind shear conditions. It appears that current training simulators do an inadequate job of responding to wind shear gust input, possibly overdamping the long period phugoid mode response, since the microburst signal is likely to excite this mode in a manner critical to jet transport safety.

We recommend a thorough investigation of:

- (1) Research and training simulator frequency response to wind shear input visuals.
- (2) A careful study of simulator equations of motion with regard to wind shear.
- (3) Extensive communication with simulator technology experts regarding the findings of (1) and (2).

RECENT PUBLICATIONS -- JOHN MCCARTHY

"The Evolution of an Oklahoma Dryline Part I: Meso- and Subsynoptic-Scale Analysis," J. Atmos. Sci., 39, February 1982, 225-236 (by S. E. Koch and J. McCarthy).

"The Evolution of an Oklahoma Dryline Part II: Boundary-Layer Forcing of Mesoconvective Systems," J. Atmos. Sci., 39, February 1982, 237-257 (by S. E. Koch and J. McCarthy).

"Simulation of Phugoid Excitation Due to Hazardous Wind Shear " (by W. Frost, B. S. Turkel, and J. McCarthy), AIAA 20th Aerospace Sciences Meeting, Jan. 11-14, 1982, Orlando, Florida. Published by The American Institute of Aeronautics and Astronautics, New York, N Y.

"Numerical and Flight Simulator Test of the Flight Deterioration Concept " (by J. McCarthy and V. Norviel), NASA Contractor Report 3500, NASA, Washington, D.C., 31 pp.

"The Joint Airport Weather Studies Project (JAWS) " (by J. McCarthy, J. Wilson, and T. Fujita), Bull. Amer. Meteor. Soc., 63, 15-22.

"The Joint Airport Weather Studies Project (JAWS) " (by J. McCarthy, J. Wilson, and T. Fujita), 20th Conference on Radar Meteorology, Nov. 30-Dec. 3, 1981, Boston, Mass. Published by the American Meteorological Society, Boston, Mass., 762-768.

"An Airport Wind Shear Detection and Warning System Using Doppler Radar - A Feasibility Study " (with E. Block and K. Elmore), NASA Contractor Report CR-3379, Jan. 1981, Washington, D. C., 86 pp.

"Aircraft Sensor Quality in SESAME 1979: Results of Tower Fly-bys and Aircraft Intercomparison " (by D. E. Ziegler and J. McCarthy), Bull. Amer. Meteor. Soc., 62, 403-411, (March 1981).

Chapter of Book entitled "Thunderstorms: A Social, Scientific and Technological Documentary " (edited by Edwin Kessler), chapter title: "Instruments and Techniques for Thunderstorm Observaton and Analysis: Observations from Instrumented Aircraft," to be published in 1982 by Government Printing Office.

"The Joint Airport Weather Studies (JAWS) Project," AMS Proceedings of the Int. Conf. on Aviation Weather System, Montreal, Quebec, Canada, 4-6 May 1981, in press.

TITLE: Clear Air Turbulence Detection and Prediction Using a Diagnostic Richardson Number Tendency

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SIGNIFICANT ACCOMPLISHMENTS THROUGH FY-82:

The original Diagnostic Richardson number Tendency (DRT) formulations of Oard (1974) and Roach (1971) have been extended and the results subjected to statistical evaluation. A "risk-of-encounter" index, C was defined which takes into account the energetics of turbulent shear layers in determining CAT intensity and the propagating nature of turbulence at jet stream levels. Using a data base of ten days during the British Central Forecast Office 1976 Turbulence Survey the mean of C at points of pilot-documented turbulence encounters, was significantly greater than that of the background sample.

CURRENT FOCUS OF RESEARCH:

The current focus is concentrated in software testing and streamlining, surveying possible data-sets to be used and laying the conceptual groundwork for improvements in the current DRT formulation.

The computing will be performed on the UDRI VAX 11-780 rather than the WPAFB CDC-7600 system in earlier work. Software changes necessary to do this as well as general code and output streamlining are being made. Several possible data-sets are being considered for use as case studies. These include the United Incident of 3 April 1980, the SESAME/AVE experiment of Spring

1979, and the Kennedy-Shapiro April, 1978 experimental aircraft field study. These studies were subsequent to the 1976 survey and the data may have certain advantages over the British survey. Recent literature on jet-stream energetics is being studied. It is hoped that the DRT formulation can be improved to be more flexible in its application and more sensitive to potential CAT development.

PLANS FOR FY-83:

- Generalization of the vertical shear tendency.
- Incorporation of significant terrain effects.
- Improved vertical interpolation of the horizontal wind velocity and 1000 mb temperature.
- Establish the relationship between observed and DRT CAT intensities.
- Investigation of the temporal behavior of CAT regions.
- Determine the effect of including supplemental RW ascent data.

RECOMMENDATIONS FOR NEW RESEARCH:

- Model fuel consumption penalties resulting from flying in turbulent conditions.
- Coordinated real-time testing of DRT system using standard data acquisition systems against actual PIREPS of turbulence.
- Incorporate DRT CAT probability time/space distributions into flight path optimization software.

PUBLICATIONS SINCE JUNE 1981:

Keller, J., 1981: Prediction and monitoring of CAT: an evaluation of the applicability of the Rawinsonde system. J. Appl. Meteor., 20(6), 686-692.

Keller, J. and P. A. Haines, 1982: Detection of CAT using a diagnostic Richardson number tendency formulation. J. Aircraft, to be published in NOV/DEC issue.

TITLE: COMPUTER SIMULATION OF AIRCRAFT NOCTURNAL ICE/FROST
FORMATION AND IT'S EFFECT ON AIRCRAFT TAKEOFF PERFORMANCE

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SIGNIFICANT ACCOMPLISHMENTS FY-82:

The computer program for predicting and forecasting the nocturnal ice/frost formation on an aircraft wing was completed and delivered. In addition, the analysis of the takeoff performance of the aircraft with frost covered wings was completed. Several features incorporated into the model include variable radiation cooling with view factors, forced and natural convection on the wing section, and frost density and thickness growth calculations responsive to environmental changes and geometry.

The results of the prediction mode of frost growth show fairly good comparison with the experimental data on an exposed inclined plate set out overnight.

The results of the forecasting mode of ice/frost growth, which forecasts the environmental conditions from 5 P.M. to 6 A.M., shows that an air temperature slightly above freezing and a 100% humidity produced about 1 mm. thick frost under clear skies at 6 A.M. Differences in the wind or the surface emissivity did not have a strong effect on the frost thickness. The forecasting mode assumes constant wind, absolute humidity, and cloud cover throughout the night. However, the air temperature is decreased throughout the night to allow for the evening radiative cooling.

Studies on the aerodynamic penalties of roughened wing section has demonstrated a roughness height of 1 mm. will produce about 30% maximum lift loss for a specified aircraft and wing type. As a result the takeoff safety margin becomes dangerously low and in some cases none whatsoever. Further studies have shown the aircraft can retain the original safety margin by reducing maximum gross weight by the same percentage as the maximum lift loss and slightly reducing the aircraft's takeoff angle of attack. But a more rational alternative is frost prevention by covering the aircraft in a hangar, or with a plastic, cancel the flight for the next morning, wait for the sun to dissipate the frost, or clear the frost off. More specific results are being documented in a final report to NASA/MSFC.

CURRENT FOCUS OF RESEARCH WORK:

No further modeling work is being done and presently the final reports are being shortened for professional publication purposes. A very small effort is being applied to presenting a paper on, "A Proposed Simple and Safe Aircraft Takeoff or Landing Procedure with Wing Roughness or Protuberances" at the AIAA proceedings in Reno, Nevada, January 1983. This paper is an outgrowth of this research.

PLANS FOR FY-83: None.

RECOMMENDATIONS FOR NEW RESEARCH:

- (1) A model validation program should be pursued. An aircraft can be located next to a meteorological station out on an open field when nocturnal frost is expected and measurements done. This should serve to validate the predictive and the forecasting mode of the nocturnal ice/frost formation model.
- (2) The model of rime frost due to freezing rain or fog should be adapted from current research on the ice/frost formation on the external tank of the space shuttle.
- (3) Start a program to test the takeoff modification procedure proposed for a roughened wing. This program can be done in three phases. The first phase, put a specific roughened wing section at takeoff configuration in a wind tunnel and determine the relative maximum lift loss. In the second phase, do a takeoff modification procedure with an aircraft of the same specific roughened wing section to test the concept of maximum gross weight reduction with original safety margin. Lastly exposed the same aircraft to nocturnal frost and make estimates of the wing roughness. Then takeoff with the modified takeoff procedures due to wing roughness.

LIST OF PUBLICATIONS PREPARED SINCE JUNE 1981:

Dietenberger, M. A. "A Frost Formation Model and Its Validation Under Various Experimental Conditions," Final Report, January 1982, NASA/MSFC under Contract NAS8-33369, UDR-TR-82-77.

Dietenberger, M. A. "Generalized Correlation of the Water Frost Thermal Conductivity," accepted by International Journal of Heat and Mass Transfer.

Title: Charged Particle Fog Dispersal Program

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Accomplishments FY82:

A charged particle generator was designed, fabricated, and tested. The generator, as initially designed, functioned well and provided approximately 20 microamps current. Tests of the variation of the current in the jet as a function of liquid water flow rate, height above the nozzle exit plane, corona needle and attractor position, and plenum pressure were made. The optimum liquid water flow rate for the system was found to be between 4 to 7 cc/min. The current output along the centerline of the jet decayed exponentially to roughly 3 microamps at 3 ft above the nozzle. The 3 microamp current output was fairly uniform over a wide horizontal plane at that level. Optimum performance was obtained with the corona needle approximately one inch downstream from the throat of the nozzle with both the upper and lower attractors connected in the circuit.

A number of deficiencies in the system were identified during the initial testing.

1. The physical meaning of the jet current measured with the grounded needle probe arrangement was not completely clear. Whether it measured total current or some fraction, or alternately, if it represented a corona discharge, was not known.
2. The liquid water flow rate continually dropped off with depletion of the water supply in the tank and a more steady water supply was needed to assure longer periods of operation.
3. The voltage across the corona needle and attractor was not measured and could not be correlated with current output.

4. The water droplet size and the mechanism of droplet formation in the nozzle (i.e., condensation in the nozzle throat versus upstream atomization) could not be determined.

Modifications to correct deficiencies #1 through #3 were made in the second stage of testing. Deficiency #4 has yet to be resolved. A collecting pipe arrangement, which would capture the entire jet flow and bleed the charge in the jet to ground through an ammeter, was designed to provide a measure of the total current. It was found, however, that in all cases, even with variation of the measurement with height, the current output with the pipe collector was essentially identical to that with the needle arrangement. Thus, it was concluded that the magnitude of approximately 20 microamps at the nozzle exit decaying exponentially to 3 microamps at 3 to 5 ft represents a meaningful measure of the current output from the system. Also, a high voltage probe was used to measure the electric field distribution of the jet. These measurements indicated that the electric field along the centerline of the jet had a peak value on the order of 6,000 to 8,000 volts. The peak value occurred approximately 2 to 3 in from the nozzle exit.

The high-voltage probe was also inserted into the corona power supply circuit to measure the voltage drop between the corona needle and attractor. The current output of the jet was found to vary almost linearly with the voltage.

To assure a steady liquid water flow rate, a positive displacement pump rather than the original bleed air pressurized system was installed. This system was found to work extremely well, and a very steady flow rate of liquid water was achieved.

Based on the experience gained through testing of the system, it is believed that a charged particle generator which will provide a steady current output on a routine operational basis can be designed. The output from the unit of roughly 20 microamps is consistent with simple analysis and with reported results from similar systems.

Plans for FY83:

During FY83, a field test utilizing a number of charged particle generators to investigate the capability of charged particles to disperse fog will be planned. Joint participation in the program will be solicited to not only investigate the capabilities of the charged particle technique in dispersing fog but also to study its capability for dispersing battlefield obscurants such as smoke. The plan will call for a very well instrumented field site where visibility, both in the seeded area and also in controlled areas both upstream and downstream, can be measured. Actual improved visibility as contrasted to dissipation of the fog by natural causes will thus be distinguished.

Plans to measure both the natural as well as the induced electric field distribution and the condensation nuclei condensation prior to and

after the fog are being made. Of course, droplet size and distribution will be measured and the potential to measure charges on the droplet studied. It is hoped to carry out these measurements both with ground-based and airborne instrumentation. The experiment will be designed to demonstrate the effectiveness of charged particle techniques for dispersing fog and also to provide scientific knowledge relative to the electric field in the atmosphere and the microphysics of fog formation and decay.

Publications:

"Fog Dispersion," by L. S. Christensen and W. Frost, NASA CR 3255, 1980.

"Charged Particle Concepts for Fog Dispersal," by W. Frost, F. G. Collins, and D. Koepf, NASA CR 3440, 1981.

"Design of Prototype Charged Particle Fog Dispersal Unit," by F. G. Collins, W. Frost, and P. A. Kessel, NASA CR 3481, 1981.

"Preliminary Test Results of Electrical Charged Particle Generator for Application to Fog Dispersal," by W. Frost, Final report for Contract NAS8-33541, 1982.

"Test Results of Modified Electrical Charged Particle Generator for Application to Fog Dispersal," by K. H. Huang and W. Frost, Final report for Contract NAS8-34729, 1982.

Title: WAKES FROM BUILDINGS AND NATURAL OBSTACLES

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Significant Accomplishments in FY-82:

Experiments have been carried out in a small wind tunnel in which atmospheric flow around buildings was simulated. Arrays of one, two, three and four model buildings were tested, and wake profiles of velocity and turbulence were measured. The data indicate the effect of the buildings on the wind environment encountered by aircraft during landing or takeoff operations. It was possible to use the results to locate the boundaries of the air regions affected by the obstacles and to recommend preferred arrangements of buildings to maximize flight safety.

A total of 16 patterns of single or multiple building models were studied in FY-82. In some cases all three velocity components were measured in the wakes, and in others only the longitudinal component was measured. In the former case, measurements were made on the centerline behind the array and at off-centerline positions as well. In the latter case only U (longitudinal mean velocity) and u' (longitudinal turbulence fluctuation) were measured on the centerline. Surface flow around each of the 16 arrays was observed through the oil-film technique. Table 1 lists the patterns studied and the measurements associated with each. The aluminum models used were block-shaped, of height H and were of square cross section.

Prior to FY-82 flow in the wake behind two laterally spaced, long buildings had been initiated. The first measurements were reported by Schofield, Barber and Logan (Journal of Fluids Engineering, Vol. 103, 1981) and did not include flow visualization and off-centerline or three-component measurements. The hot-wire method of Acrivlellis (Disa No. 23, 1978) was adopted and utilized to obtain U , V and W , the three components of mean velocity, and \overline{uv} , \overline{uw} and \overline{vw} , the three components of Reynolds shear stress. This method was then used in FY-82, along with the five-hole-pressure-probe and the single-cylinder, hot-film probe methods, to obtain the quantities listed in Table 1.

Centerline velocity data were plotted on Clauser Charts to determine skin friction coefficient C_f . Extrapolation to zero value of C_f curves led to the location of reattachment points behind models. In the gap region a dip in C_f curves was noted. The clear definition of the reattachment line for the region near the ends of buildings was observed in photographs of surface streamlines. The variation of this pattern with building length and multiple-building array was also noted. Flow visualization combined with three-dimensional probe measurements indicate that a vortical motion arises near the ends of buildings. Surface fluid flows towards the backside of the building from the end region, whereas flow at higher levels occurs towards the ends of the buildings. Crossflow velocities W associated with these motions can amount to 10 percent of the longitudinal velocity U . Comparable magnitudes of updraft or downdraft velocities V were also observed.

Table 1 Building Arrays

No. Models	Arrangement	Model Length	Model Spacing	Measurements Velocity	Turbulence	Flow Visualization
1	Single	3H	∞	U	u'	yes
1	Single	6H	∞	U, V, W	u'	yes
1	Single	9H	∞	U	u'	yes
1	Single	∞	∞	U, V, W	u', \overline{uv} , \overline{uw} , \overline{vw}	yes
2	Tandem	3H	2H	U	u'	yes
2	Tandem	6H	2H	U	u'	yes
2	Tandem	6H	3H	U	u'	yes
2	Tandem	6H	6H	U, V, W	u'	yes
2	Tandem	6H	9H	U	u'	yes
4	Two-row Tandem	6H	6H lateral 3H longitudinal	U	u'	yes
4	Two-row Tandem	6H	6H lateral 6H longitudinal	U	u'	yes
4	Two-row Tandem	6H	6H lateral 9H longitudinal	U	u'	yes
2	Side by Side	∞	1H lateral	U, V, W	u', \overline{uv} , \overline{uw} , \overline{vw} ,	yes
2	Side by Side	∞	5H lateral	U, V, W	u', \overline{uv} , \overline{uw} , \overline{vw} ,	yes
3	Triangular Array	2-∞	6H lateral	U	u'	yes
		1-6H	3H longitudinal			
3	Triangular Array	2-∞	6H lateral	U	u'	yes
		1-6H	6H longitudinal			
0	Undisturbed	-	-	U, V, W	u', \overline{uv} , \overline{uw} , \overline{vw} ,	no

Models were glued to the wind tunnel floor with their major axes perpendicular to the main flow direction.

The region of disturbed velocity and turbulence profile, which could affect the flight path of aircraft, was identified through analysis of the available data for the configurations of Table 1. For example, the upper boundary of the region of high-than-normal shear behind single buildings can be estimated with

$$\frac{\delta_i}{H} = 1.75 \left(\frac{x}{H} \right)^{.3228}$$

where δ_i is the height of the upper boundary of the region and x is the distance downstream of the building. Lateral growth rate of the disturbed region follows roughly the same law but could not be given clear definition from the available data.

Wakes produced by the configurations of Table 1 were compared as to the extent of the disturbed region, the intensity of the turbulence, the height of the intensely turbulent region and the magnitude of the velocity gradient. Unfavorable wake conditions were observed in the case of the three-building array, whereas the tandem array with low spacing represents an improved condition over a single building wake.

Current Focus of Research Work:

The present work has as its goal the definition of the region of the atmosphere affected by the presence of one or more buildings in the vicinity of airports. The effect of buildings on vertical velocity gradients, lateral variation of longitudinal velocity, updrafts or downdrafts and turbulence is determined experimentally through the use of wind tunnels and surface-mounted models. The optimum geometry corresponding to minimum wind disturbance is sought.

Plans for FY-83:

The work described above is to be continued with more off-centerline, three-component measurements being made. Lateral spreading rates are to be clarified. Only the most interesting patterns and modifications are to be considered, i.e., those producing or minimizing hazardous flying conditions.

Recommendations for New Research:

The effect of building orientation to the wind should be studied. For multiple-building arrangements, different wind orientations and different model heights within the same array should be considered.

List of Publications prepared since June 1981:

Lin, S.H., "Wind Tunnel Measurements of Three-dimensional Wakes of Buildings," M.S. Thesis, Arizona State University, May 1982.

Logan, E. and Lin, S.H., "Wind Tunnel Measurements of Three-dimensional Wakes of Buildings," NASA CR-3565, Marshall Space Flight Center, June 1982.

Logan, E. and Lin, S.H., "Wakes from Arrays of Buildings," Final Report, Marshall Space Flight Center, August 1982.

SESSION III

DOPPLER LIDAR APPLICATION

The Doppler Lidar provides a method of measuring winds in the cloud-free part of the atmosphere. The apparatus can be mounted on ground-based, airborne, or space-borne platforms. The papers presented here report the results of ground-based experiments, airborne experiments with a scanning Lidar system, and atmospheric backscatter studies that are needed to plan for the space-borne Doppler Lidar system.

Dan Fitzjarrald

TITLE: Airborne Doppler Lidar System Science Activities

RESEARCH INVESTIGATOR: D. E. Fitzjarrald
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SIGNIFICANT ACCOMPLISHMENTS FY82:

1. Preparation of 1981 Flight Data: The research data that was obtained during the 1981 flight program has been provided to the research investigators (seven outside NASA, one USRA visiting scientist). Algorithms for calculating the vector velocity, divergence, and other products that were developed by Robert Lee/Lassen Research were implemented by Boeing Computer Services on the NASA/MSFC Univac computer. Some difficulties were encountered in the implementation of these computer programs and some additional problems that required coordination with Lassen Research were found in the data sets. The delivery of the data to research scientists was later than we had anticipated, but because of delays in getting the research contracts signed, the data was made available to them not long after they were able to start work. A meeting with the researchers was held on May 26, 1982 to acquaint them with the data that is being provided and to discuss some of the limitations and errors of the system and the 1981 data. Based on preliminary looks at the flight data the research investigators are quite enthusiastic, and we expect that the analysis of these unique data will result in significant scientific results.

2. Planning for 1983/1984 Flight Program: An atmospheric science workshop was held May 27-28, 1982 to involve a larger portion of the research community in the preliminary planning for the next flight series. The response was good, with 18 scientists attending the workshop and a number of others sending ideas for potential experiments. Each participant presented an idea for the use of the ADLS system, and the discussion was lively and informative for all concerned. New experiments were presented (many based on preliminary analysis of the 1981 data) spring/summer weather events that we had already identified as likely research targets for the instrument, specifically: severe storms, cumulus entrainment, boundary layer flows, and flow about complex terrain. Several very promising possibilities were suggested in fall/winter events that had not been previously considered. With such enthusiasm by atmospheric scientists representing a wide variety of interests, it is expected that the new series of flight experiments will be very profitable.

CURRENT FOCUS OF RESEARCH WORK:

Work continues in the analysis of the 1981 flight data, both for its scientific interest and for instrument improvement for the next flight series. As the research investigators begin to use the flight data, it is necessary to work with them to assure that the data are correctly used. Improvement of the data processing procedures and algorithms is an on-going process, and the goal is to get the most out of the data that were obtained. The analysis of the 1981 data is also helping to provide inputs to the improvements that are currently being made in the instrument system, both in the hardware (INS system) and the software control (timing and control system).

PLANS FOR FY83:

Analysis of the 1981 flight data will continue through FY83, as will the improvement of the data processing techniques. Planning for the next flight experiments will continue, and specific research proposals will be obtained from those who have indicated their interest. Instrument development and improvement will be supported, as it has an effect on the scientific activities. Specific flight plans will be prepared and coordinated with the NASA Ames Flight Facility. Activities of the on-board scientists will be organized and coordinated.

RECOMMENDATIONS FOR NEW RESEARCH:

The results of the flight planning workshop indicate that a two-part flight program would be desired in order to obtain the maximum scientific results. A portion of this flight program would necessarily occur in FY84. Analysis of the data obtained during the new flight program will occur in FY84 and FY85. Based on the results so far, there is reason to believe that the atmospheric science community would be interested in additional research programs using this instrument system.

LIST OF PUBLICATIONS SINCE JUNE 1981:

Airborne Doppler Lidar Wind Field Measurements, Bilbro, J. W., Fichtl, G. H., Fitzjarrald, D. E., and Krause, H. G. (submitted to Bul. Amer. Met. Soc., 1982).

TITLE - Airborne Doppler Lidar Project

Research Investigators - C.A. DiMarzio
M.C. Krause
Raytheon Company
Sudbury, MA 01776
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Significant FY'82 Accomplishments

After the 1981 flight test program, the system was installed in the van for ground-based measurements. Prior to these measurements, it was re-furbished by cleaning and aligning some of the optical elements. Preparations were made for ground-based measurements to:

1. Perform meteorological experiments,
2. Perform engineering experiments to support the ground-based meteorological studies, and
3. Perform engineering experiments to assist in data evaluation of the 1981 flight tests and in preparation for later flight tests.

The system was then deployed to Denver's Stapelton Airport for participation in the joint airport weather studies (JAWS) program.

An engineering data analysis program was undertaken to evaluate the accuracy of the measurements made during the 1981 flights and to identify changes in data collection techniques to improve the accuracy in subsequent flights.

Current Focus of Research Work

At present, meteorological experiments are being performed at JAWS with engineering experiments being performed as time permits.

The emphasis in data analysis is on comparing LIDAR-derived winds with ground truth to establish the magnitude and causes of errors in the LIDAR wind fields.

Plans for FY'83

The ground tests will continue at NASA's Marshall Space Flight Center, with completion of the engineering tests and a set of meteorological experiments.

The data analysis task will continue with emphasis gradually shifting to improvement of the system for future flights. Better alignment and data collection techniques will be established. Modification of the system will be performed to accomplish the goals dictated by this analysis.

Recommendations for New Research

Investigation of alternate frequencies of operation may result in significant enhancement of range capabilities of CO₂ lidars. The development of a compact, sealed, moderate-energy transmitter, along with this investigation, is also recommended.

Publications Prepared in FY'82

Improved Airborne Lidar, presented at 11th ILRC, Madison, Wisconsin, June 23, 1982.

TITLE: Doppler Lidar Participation in JAWS Experiment

RESEARCH INVESTIGATORS: D. E. Fitzjarrald, Atmospheric Sciences Division
G. D. Emmitt, Atmospheric Sciences Division
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SIGNIFICANT ACCOMPLISHMENTS FY82:

The Doppler lidar system was installed in the MSFC van, and tested at MSFC. It was then packed and shipped to Colorado, arriving at the NCAR JAWS CP4 radar site at Denver airport on July 8. By July 15 the system was operating and collecting data in conjunction with three Doppler radars and one other Doppler lidar. The MSFC lidar was co-located with the CP4 radar and was 15 km from the NOAA/ERL lidar so that the data could be compared with the radar data and dual Doppler velocities could be calculated with data from both lidars. A number of different dual lidar runs were made so that a variety of different atmospheric conditions were included.

CURRENT FOCUS OF RESEARCH WORK:

Preliminary analysis of the data obtained during the JAWS experiment using both the MSFC graphics in the lidar van and the NCAR color radar displays (RDSS system) indicates that the lidar data that was obtained is of good quality. The data should yield some very interesting scientific results. The current work is in preliminary processing, cleaning up bad data, and inventory of events and supporting data.

PLANS FOR FY83:

Analysis of the JAWS data will be completed. The NCAR dual Doppler radar computer programs will be used to calculate wind velocities from the two lidars that were in operation. This will be the first time such data have been obtained, and the results should be complementary to the dual Doppler radar data that were obtained at the same time.

RECOMMENDATIONS FOR NEW RESEARCH:

Based on the results of this summer's data, it may be of interest to propose further dual Doppler lidar experiments using ground-based systems. Such a proposal will depend on the outcome of analysis of the JAWS data, however.

NO PUBLICATIONS HAVE YET BEEN PREPARED

TITLE: Groundbased Research Using the NASA/MSFC Doppler Lidar Systems

INVESTIGATOR: *G. D. Emmitt, Atmospheric Sciences Division, 453-2570
*D. Fitzjarrald, Atmospheric Sciences Division, 453-3104
*G. H. Fichtl, Atmospheric Sciences Division, 453-0875
*J. W. Bilbro, Electronics and Control Laboratory, 453-1597

SIGNIFICANT ACCOMPLISHMENTS, FY-82:

Following a successful 1981 airborne research season, a series of groundbased engineering and scientific experiments were designed for the 1982 period. During the first portion of the period, a new computer controlled hemispherical scanner was installed, existing software updated, and new software developed to permit realtime velocity profile display, glide slope shear detection/prediction, and dual doppler lidar observations. Details of the proposed groundbased studies are available in a planning document entitled, "MSFC Doppler Lidar Experiments and Operations Plans for 1982/1983 Groundbased Research."

In general, several engineering development have been/are examined which will enable proposed scientific experiments to be conducted.

1) Rapid Hemispherical Conical Scanning (HEMISCAN).

By rapidly scanning (15-30°/sec) the lidar at elevations ranging from 1-90°, a complete mass budget for a hemisphere volume can be obtained. Deviations of the net mass flow from zero provide some estimation of the usefulness of any attempts to quantify horizontal divergence and vertical speeds for selected horizontal planes. This approach will produce a unique and hopefully more instructive description of the subcloud interaction of convective scale phenomena within 25-300 km² areas.

2) Mirror Aided Doppler (MAD) Lidar.

An advantage that lidar has over radar is the use of conventional optics to deflect the beam and to direct the returned signal to the receiver without any intermediate amplification. Using a mirror located 2-4 km from the Doppler Lidar Van to produce simulated dual doppler lidar has been judged feasible, the mirror has been prepared and permission to mount the mirror on an existing structure on Redstone Arsenal has been obtained. Initially the mirror will be positioned so that the direct lidar beam and the indirect beam (through the mirror) will focus upon a common volume containing a conventional tri-vane anemometer. With this arrangement, a two-dimensional wind vector can be estimated and verified. In the future a scanning mirror would allow a horizontal velocity field to be described (much like the airborne system product). Such a capability would enable a more definitive description of meso α phenomena than is presently possible with tower mounted anemometer or instrumental aircraft.

*Marshall Space Flight Center, Alabama 35812

3) Variable Pulse Delay.

By varying the delay in the interrogation of the returning pulses, a "scanning" of the pulse train can be effected. The engineering of this capability has been examined and judged feasible without much difficulty. The plan is to see if higher spacial resolution of the wind field is possible. Initial calculations suggest that significant wind features could be resolved to within 50 meters rather than the current 330 meters.

CURRENT FOCUS OF RESEARCH WORK:

The current focus of the research is the demonstration of ground-based operations capability at NASA/MSFC. With the system just returned from the JAWS experiment in Colorado, we are in the process of reinstallation. Computer simulations of the HEMISCAN, MAD lidar and Variable Pulse Delay are continuing in an effort to optimize the lidar operations. For example, one of the questions being addressed is what are the optimum elevation angles between 1-90° for the HEMISCAN. The complete hemispherical scan should be completed as quickly as possible so that stationarity of the wind field can be evoked.

PLANS FOR FY-83:

After the groundbase HEMISCAN and MAD lidar operations are demonstrated, a program of correlating wind fields with satellite observed clouds will begin. The study will begin with MSFC based operations. However, it may become desirable to use the system in conjunction with other field programs where supplementary and complementary measurements are being taken. The focus of this work will be the precloud mass/moisture convergence fields as useful precursors to cumulus convection.

PUBLICATIONS:

Emmitt, G. D., Bilbro, J. W., Fichtl, G. H., and Fitzjarrald, D., 1982: MSFC Doppler Lidar Experiments and Operations Plans for 1982/1983 Ground-Based Research, May 1982.

Determination of Atmospheric
Backscatter at 10.6 μm

W. D. Jones

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Significant Accomplishments FY-82

- o Calibration of instrument in both volume (integrated path) backscatter and in single particle mode, using wire wheel and glass microbottom targets.
- o Incorporation of Dicke-switched mode into instrument and generation of appropriate software to record and utilize this data.
- o June-July, 1982 data flights - 20 total
 - o California
 - o Montana
 - o Colorado (in conjunction with JAWS)
 - o Pacific Ocean
 - o Puerto Rico
 - o Jamaica
 - o Dominican Republic
 - o Two transcontinental flights
- o Algorithm development to invert single particle data to volume or integrated path backscatter values

Current Focus of Research Work

- o Post-flight calibration of instrument
- o Analysis of data from June-July data flights, and correlate with meteorological data

Plans for FY-83

- o Set up 9.11 μm laser heterodyne system to make laboratory measurements of scattering at CO_2 isotope laser wavelength
- o Continue data collection in ground-based configuration

Publications Since June 1981

- o "Design and Calibration of a Coherent Lidar for Measurement of Atmospheric Backscatter," W. D. Jones, J. W. Bilbro, et al, 25th SPIE Conference, San Diego, CA, August 25-26, 1981.

- o "Coherent Focal Volume Mapping of a Continuous Wave CO₂ Doppler Lidar,"
W. D. Jones, L. Z. Kennedy, J. W. Bilbro, H. B. Jeffreys, May 1982,
submitted for publication in Applied Optics.

TITLE: ATMOSPHERIC BACKSCATTER MODEL DEVELOPMENT FOR CO₂ WAVELENGTHS

RESEARCH INVESTIGATORS: A. Deepak - Principal Investigator
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SIGNIFICANT ACCOMPLISHMENTS IN FY82:

Investigations have been made into the problems of modeling atmospheric backscatter from aerosols, in the lowest 20 km of the atmosphere, at CO₂ wavelengths. Different methods of calculating the aerosol backscattering function, both from measured aerosol characteristics and from optical measurements made at other wavelengths, have been examined in detail and limits placed on the accuracy of these methods. The effects of changing atmospheric humidity and temperature on the backscatter have been analyzed and related to the real atmosphere. The backscatter from aerosols at CO₂ wavelengths has been modeled, its variation with height and geographic location examined and limits placed on the magnitude of the backscattering function, β_{CO_2} . (The modeled values are shown in Fig. 1.) The most significant conclusions that have been drawn from this study are as follows.

1. The qualitative behavior of β_{CO_2} can be modeled, including the variation with height and major geographic features.
2. Accurate calculation of β_{CO_2} requires an accurate knowledge of the particle size distribution to a particle radius of at least 1 μm , for stratospheric aerosols, and at least 5 μm for tropospheric aerosols.
3. Particles with radii greater than 0.5 μm are responsible for 50% to 95% of the scattering from tropospheric aerosols.
4. β_{CO_2} decreases from about $10^{-6} \text{ m}^{-1} \text{ sr}^{-1}$ at the Earth's surface to $10^{-11} \text{ m}^{-1} \text{ sr}^{-1}$ in the stratosphere. A minimum value of $10^{-11} \text{ m}^{-1} \text{ sr}^{-1}$ is also observed in the free troposphere over the remote ocean.
5. The variation of β_{CO_2} with wavelength between 9 μm and 11 μm is not significant, except for water soluble aerosols.
6. β_{CO_2} is not strongly dependent upon relative humidity, except for very high values well above the point of deliquescence for the water soluble component.
7. The major information gap is in the composition and size distribution of particles with radii greater than 1 μm , particularly above an altitude of 7 km.

CURRENT FOCUS OF RESEARCH WORK:

Work on NAS8-34427 is complete. Present work is focussed on development plans for FY83.

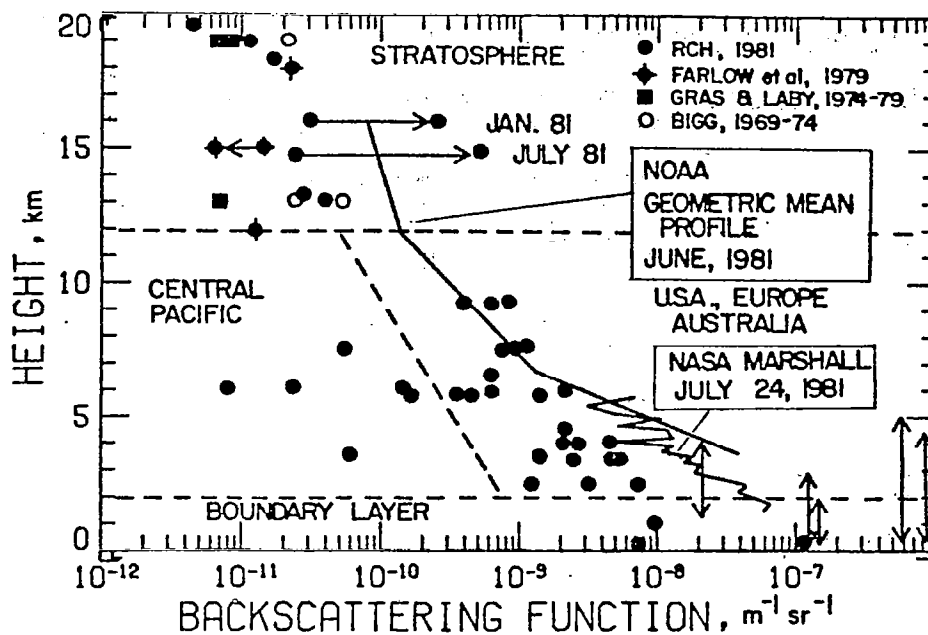


Figure 1. Modeled backscattering functions as a function of altitude for a large number of particle size distributions. Also shown are two curves for experimental determined values of β_{CO_2} (Bilbro, J.M., 1981, private communication; Post, M.J., Hall, F.F., Richter, R.A. and Lawrence, T.R., Aerosol backscattering profiles at $\lambda = 10.6 \mu\text{m}$, submitted to Applied Optics, 1982).

PLANS FOR FY83:

To continue work on the modeling of atmospheric aerosol backscatter at CO_2 wavelengths. The emphasis of this work will be on

1. Improvements in the modeling techniques used.
2. Theoretical analysis to improve our understanding of the physical and dynamical processes controlling naturally occurring aerosol size distributions.
3. Detailed studies of selected aerosol data sets, with a view to improving our modeling of β_{CO_2} values over the remoter regions of the globe.

RECOMMENDATION FOR NEW RESEARCH:

Simultaneous measurements of aerosol size distributions, using conventional particle sensors, and β_{CO_2} , using CO_2 lidar. This should be accompanied by appropriate data analysis and comparison of modeled β_{CO_2} values, based on particle sensor measurements, with the measured values obtained with the lidar. The measurements should be made under as large a variety of conditions as possible. The objective of these measurements would be

1. To provide an exhaustive test for the present modeling techniques used to estimate β_{CO_2} .

2. To resolve ambiguities and uncertainties that exist in our present knowledge of aerosol size distributions.

PUBLICATIONS:

Yue, G.K., G.S. Kent and A. Deepak, "The Modeling of Growth and Evaporation Effects on the Extinction Coefficients and Backscattering Functions of Common Hygroscopic Aerosols," presented at a workshop entitled "Hygroscopic Aerosols in the Planetary Boundary Layer" held in Vail, CO, April 13-15, 1982.

Kent, G.S., G.K. Yue, U. Farrukh and A. Deepak, "Modeling Atmospheric Backscatter at CO₂ Wavelengths. Part I: Backscatter Variations, Modeling Techniques and Associated Errors," invited paper presented at the Global Large Aerosol Workshop, NOAA, Boulder, CO, June 7-9, 1982.

Yue, G.K., G.S. Kent, U. Farrukh and A. Deepak, "Modeling Atmospheric Backscatter at CO₂ Wavelengths. Part II: Effects of changes in wavelength and ambient conditions," presented at the Global Large Aerosol Workshop, NOAA, Boulder, CO, June 7-9, 1982.

Kent, G.S., G.K. Yue, U.O. Farrukh and A. Deepak, "The modeling of atmospheric aerosol backscattering at CO₂ wavelengths," Eleventh International Lidar Radar Conference, Madison, Wisconsin, June 21-25, 1982. Conference Abstracts pp. 219-222.

Deepak, A., G.S. Kent and G.K. Yue, "Atmospheric Backscatter and Model Development for CO₂ Wavelengths," Draft Final Report (Submitted July 1982--to be published as a NASA Contractor Report) on NASA Contract NAS8-34427 with NASA Marshall Space Flight Center.

TITLE: Impact of Mesoscale and Convective Scale Phenomena on the Proposed Global Lidar Wind Measurements from Space System Concept

RESEARCHERS:

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SIGNIFICANT ACCOMPLISHMENTS FY-82:

A computer simulation model was developed to study the importance of atmospheric phenomena having length scales of 10 m - 100 km in obtaining global (≈ 500 km) wind estimates using conical lidar scanning from low earth orbit. A primary concern is the specification of the required number of laser shots to achieve desired accuracy. This number changes depending upon the distribution of atmospheric turbulent energy. While wind speed estimates are enhanced by greater sample density, laser lifetime is reduced. Optimization of the satellite-borne lidar operations may require onboard evaluation of shot density requirements. Specification of these variable densities will initially be based upon simulation studies such as the one presently in progress.

CURRENT FOCUS OF RESEARCH:

Presently, the simulation model is designed to incorporate lidar scanning parameters, wind fields at any desired resolution, and cloud cover patterns. The study approach is currently based upon two principles:

1. Although a wind estimate has been requested for a volume of $(100,000 \text{ km}^3)$, the lidar beam sample volume is small (0.3 km^3) and the anticipated shot density is low (1 per 2000 km^3). Therefore, sub-global wind features must be carefully considered.
2. Winds, aerosol distributions and cloud cover must be considered as correlated phenomena and not evaluated in isolation.

In addition to examining the effects of mesoscale horizontal wind gradients and convective scale vertical velocity features, the present effort is to identify case studies (perhaps taken from AVE/VAS data set) that will demonstrate the importance of the correlative approach to the feasibility studies for satellite lidar wind measurements.

3

PLANS FOR FY-83:

Under consideration is a plan to expand the computer simulation studies to include lidar performance, platform design and data processing requirements. Formal proposal presentation is pending.

RECOMMENDATIONS FOR NEW RESEARCH:

Some of the conclusions based upon the computer simulation studies will be verifiable using currently available data sets. Other conclusions will require new measurements for substantiation. Presently, an airborne conical scanning lidar capability would be necessary and appropriate to verify desk studies such as those regarding aerosol distribution over oceanic and polar regions, downward SNR estimates, and influence of clouds and mesoscale phenomena.

PREPARED PAPERS:

Emmitt, G. D., "Conical Lidar Scanning from LEO - The Effects of Meso β and Convective Scale Atmospheric Phenomena," 11th International Laser Radar Conference, Madison, Wisconsin, 1982.

TITLE: Severe Storm Boundary Layer Outflows as Observed by NASA/MSFC
Airborne Doppler Lidar

INVESTIGATOR: G. D. Emmitt
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SIGNIFICANT ACCOMPLISHMENTS, FY-82:

On 21 and 23 July, 1981, during participation in the CCOPE, the NASA Airborne Doppler Lidar was making observations up and downwind of several thunderstorm systems. Flight level on both days was 1500' AGL. Much effort to date has been in the processing, editing, and display of the 2-D wind fields. Concurrently, satellite (GOES, VIS, IR and VAS), radar (WS-57), rawinsonde (AVE-CCOPE), surface network (PROBE), and aircraft data have been obtained and prepared for a correlative study of storm outflow interactions and inflow organization.

In preparation for detailed case studies, an evaluation of the accuracy and usefulness of the lidar winds is being made. Presently, the coherence in the wind field descriptors is very encouraging. However, convergence, vorticity, and deformation calculations must be done with great care using smoothed data. The degree of smoothing desired is still being studied.

CURRENT FOCUS OF RESEARCH WORK:

The current effort is focused upon the overlaying (navigation) of satellite, radar, surface network, and aircraft data to optimize the correlative study on the 1-2 km scale. Rapid scan GOES data is being acquired to obtain cloud tracked winds for comparison with the lidar winds. The surface network and aircraft temperature/moisture measurements are being used when possible to provide the basis for thermodynamic explanation of the kinematic features described by the lidar winds. The radar data are being used to locate precipitation/wind field interactions.

PLANS FOR FY-83:

Following the CCOPE case studies, attention will be shifted to other CCOPE data, JAWS data, and MSFC ground-based research.

RECOMMENDATIONS FOR NEW RESEARCH:

The spatial resolution of the lidar wind fields exceeds the capability of available temperature and moisture remote measurement systems. This is a serious problem for storm dynamics research. An effort should be made to acquire the necessary temperature/moisture measurement capabilities.

TITLE: EVALUATION OF DATA OBTAINED FROM ATMOSPHERIC LASER DOPPLER VELOCIMETER

RESEARCH INVESTIGATOR INVOLVED: Dr. James W. Telford
Director, Air Motions Laboratory
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SIGNIFICANT ACCOMPLISHMENTS FY-82:

The time frame of FY-82 has been devoted mostly to planning and preliminary surveys of the data, because of a problem in the real time data due to the inertial velocity time discrepancies. The development of initial software to produce air motion velocities free of aircraft motion components, is now nearly complete, so that the data will become available for scientific data analysis.

The other data analysis task has been to provide interpolated values into different coordinate systems so that the data displays are easier to understand and discuss.

CURRENT FOCUS OF RESEARCH WORK:

The current focus will be to look over the processed data and seek out meteorological points of interest which warrant further analysis.

PLANS FOR FY-83:

The plan is to extract information about entrainment and evaporation of cloud from the observations near cloud tops, which were collected during the CCOPE operation in 1981.

Since we believe this data is essentially a record of the mixed cloud and entrained dry air, after evaporation has occurred, it should provide additional insight into how the process works; how much former cloud material remains above the inversion, whether the remnant cloud material is filled with nuclei of similar concentrations to subcloud air, etc.

RECOMMENDATIONS FOR NEW RESEARCH:

Clearly some more carefully made measurements will be needed soon.

LIST OF PUBLICATIONS PREPARED SINCE JUNE 1981:

We can reasonably expect to publish something after we receive the data.

TITLE: An Inertial Velocity Reference for the NASA/MSFC Airborne Doppler Lidar

RESEARCH INVESTIGATOR INVOLVED: Dr. James W. Telford
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SIGNIFICANT ACCOMPLISHMENTS FY-82:

This contract is to build a customized inertial navigation system for providing the three components of aircraft velocity (and three angular components) to support the lidar doppler velocimeter system.

The Air Force has released some Litton LN15S gyro stabilized platform units which are of high performance, and under Air Force maintenance schedules. This will provide the reference system.

The control and navigation loop will be implemented on the Intel 86/300A computer system which has just been released with high level software operating systems, and Fortran. The present software is multitasked and multiprocessor, which is ideal for this application where the housekeeping for the platform operation must be sustained continuously. This allows other tasks to run on a noninterference basis without having to write time division priorities into our custom software. The use of a second processor makes the interfacing of the platform much more straightforward.

Because the microprocessor, an Intel 8086/8087 combination, is so fast, and because the software is so powerful, elaborate calibration procedures can be easily devised and implemented in effective time frames, to allow rather sophisticated calibration procedures to maintain the best quality platform performance.

Once we have a solid reliable basic system, then a very high range of choices are available for upgrading the device, with special tasks related to platform performance, or other meteorological functions such as processing variables for plotter output in real time, etc.

An inertial platform is necessary for all measuring systems which measure air motion from an aircraft, because every airborne device measures the air motion relative to the airframe in which it is mounted. Since our interest is in air motion measured relative to the earth, three precise components of the velocity are necessary. The need for precision is because the aircraft motion must be cancelled by subtraction, by combining two separate measurements where the useful component is often less than 10% of the spurious aircraft velocity. One degree in angular error is an unacceptable error; because this is about 1/60 of the aircraft speed and is thus a few meters per second.

Inertial platforms balance like a pendulum in a uniform gravitational field the same as the local field, with a bob on a string of length equal to the earth's radius. This has an 84 minute period so the platform velocity errors, generated during a turn, say, oscillate at this period. Errors due to gyroscope drift, and accelerometer errors, both act in this way. Once they occur they can only be removed by comparing the platform position to a measured position of higher accuracy and computing correction terms.

Another approach is to calibrate the drift of the gyroscope, and the accelerometer errors, as functions of the acceleration, and then correct the measured values accordingly. The advantage of a customized system like this, with easy programming and excess compute capability, is that such procedures can be built in as field updates, after the basic system is operating, if it is found better performance is needed. Such service from a platform manufacturer is prohibitively expensive.

Furthermore, the platform data output can be customized to fit the remaining data devices which form part of the velocity measuring system.

CURRENT FOCUS OF RESEARCH WORK:

At present we are settling design options primarily in regard to the need for uninterruptable power for the platform system from about an hour before flight to shutdown after the flight. This is a more expensive problem than anticipated, but must be accomplished carefully to create a viable system. Platform interfacing appears to be meeting our more optimistic expectations, however, except that more money will need to be put into purchased parts and less into construction.

The software effort has begun with a platform cluster simulator so we can write software before the hardware is delivered.

PLANS FOR FY-83:

This includes most of the tasks yet to be accomplished on this project. The prototype card carrying the differential drivers and the syncros to digital converters and their interfacing to the computer buss, or the CPU card, are to be built. The noninterruptable power supply and the cables will be built.

Simultaneously, the software system will be configured and tested. This includes a Fortran platform navigation simulator on the simplest form, and the initial upgrades, such as the figure of the earth. Gyroscope bias loops will need to be written at this stage, and probably accelerometer calibration procedures.

A good deal of effort will also go towards efficacious displays to facilitate operator control and monitoring of platform performance. Graphical displays such as aircraft track will probably be needed also.

RECOMMENDATIONS FOR NEW RESEARCH:

The continued effort should be aimed at implementing the superior performance this gyro stabilized platform unit should be capable of realizing. This includes more detailed calibration to establish instrument orthogonality, and accelerometer sensitivities and perhaps position updating.

LIST OF PUBLICATIONS PREPARED SINCE JUNE 1981:

There will not be any technical publications until the device is completed.

TITLE: ANALYZE NASA/MSFC AIRBORNE DOPPLER LIDAR RESULTS FROM THE SAN GORGONIO PASS EXPERIMENTS

RESEARCH INVESTIGATORS INVOLVED:

Dr. William C. Cliff and Dr. David S. Renne
Battelle Pacific Northwest Laboratories
Battelle Boulevard
Richland, Washington 99352
Phone (509) 375-2024

SIGNIFICANT ACCOMPLISHMENTS FY-82:

A preliminary investigation of three low level flight paths near the mouth of San Gorgonio Pass revealed an interesting flow pattern over Palm Springs. In Figure 1, the horizontal velocity vectors at about 460 m (1500 ft) above grade level are seen to follow the topographic relief lines with no recirculation patterns in the lee of the mountain.

Information such as this is not only important from an atmospheric phenomena point of view but a knowledge of the wind patterns and strengths should also be important to city and commercial planners.

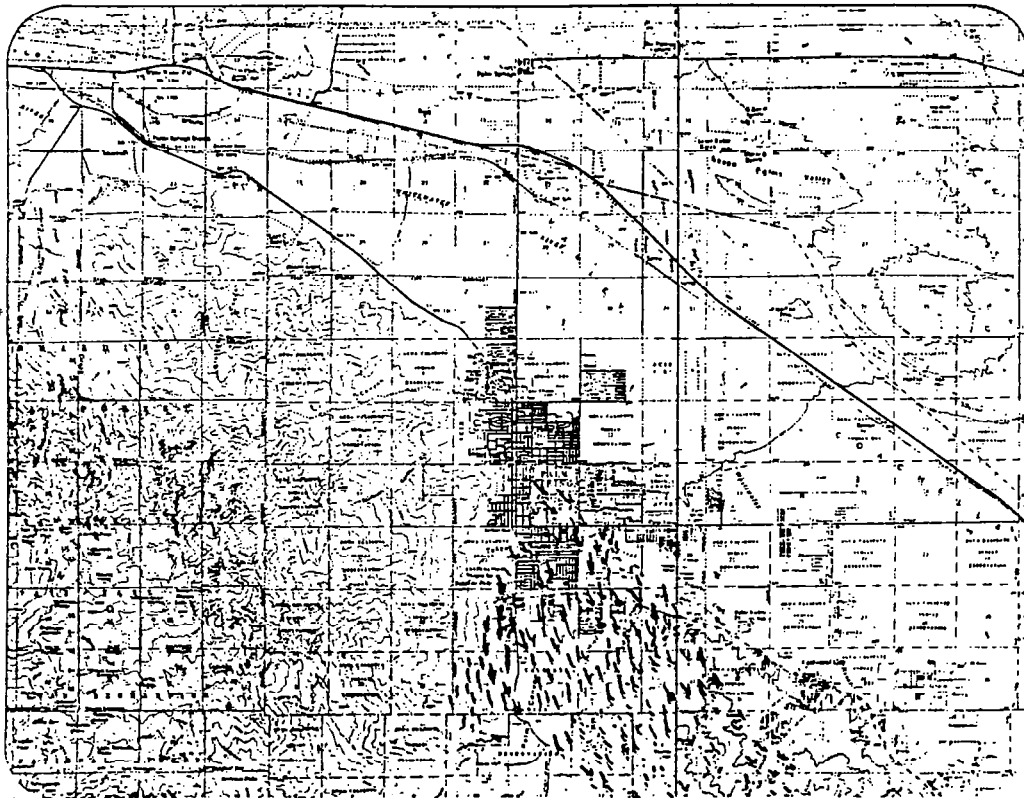


FIGURE 1. Horizontal Component of Atmospheric Velocity About 1500 ft Above the Palm Springs Valley Floor (Taken during High Wind Condition in San Gorgonio Pass.)

The length of the vectors in Figure 1 are proportional to the magnitude of the horizontal velocity. The longest vectors represent a 10 m/s (22 mph) wind.

Figure 2 shows the convergence of the atmospheric flow discharging from San Gorgonio Pass and the general circulation flow behind the San Jacinto mountains. The large vectors represent about a 10 m/s (22 mph) horizontal wind. The smaller vectors show the spreading of the pass flow into the valley region.

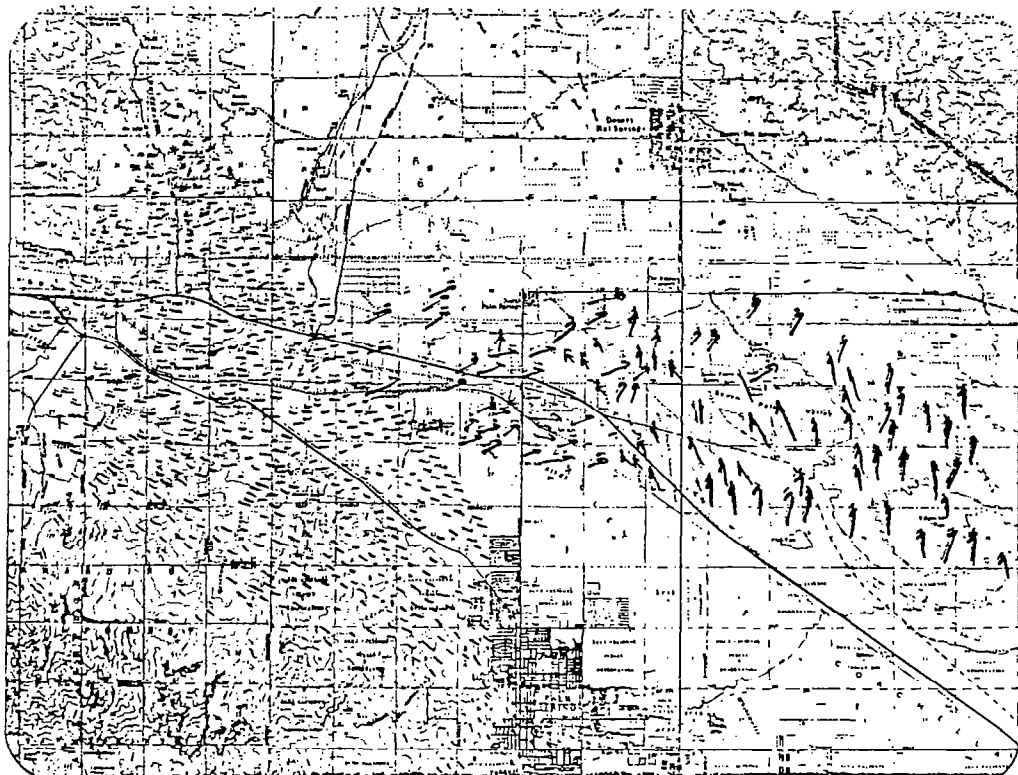


FIGURE 2. Convergence of San Gorgonio Pass flow with General Circulation Flow Associated with Regional Synoptic Conditions

CURRENT FOCUS OF RESEARCH WORK AND PLANS FOR FY-83:

Analyze the NASA Doppler Lidar data and compare where possible with ground truth data. Use the NASA Doppler Lidar data to determine the vertical and horizontal extent of the accelerated flow issuing from San Gorgonio Pass.

RECOMMENDATIONS FOR NEW RESEARCH:

Use the NASA Doppler Lidar System to investigate Strouhal/Reynolds number relations at Reynolds number of 10^8 to 10^{11} . The Strouhal/Reynolds number

test could be performed behind a large rod shaped structure such as table mountain or behind an isolated mountain on an island capped by an inversion layer. Characterization of near surface flow patterns in regions of potential hazardous aerosol releases would also be extremely useful in the development and verification of numerical diffusion models as well as for normal safety analysis of release of hazardous materials.

LIST OF PUBLICATIONS PREPARED SINCE JUNE 1981:

None.

Evaluation of Airborne Doppler Wind Measurements

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FY 82: Accomplishments

During the summer of 1981, several CV990 flights were conducted in the Central Valley of California during which Doppler lidar data were recorded. The flights were of two types, the first being in the vicinity of a 1560 foot tower with a recording anemometer at the top and the second type being a closed flight path along the perimeter of the southern part of the Central Valley.

The first type of lidar data will be compared with the in situ data recorded at the top of the tower. As we have not obtained the flight data as of this writing, we are not able to report any results other than to say that both the lidar and in situ data have been recorded and await comparative analysis.

The second type of data will be used to analyse the properties of the lidar measured wind field and to document the flow patterns over and near the mountainous regions which surround the valley. In preparation for the analyses to be made using the lidar data, the hourly surface observations for observing stations within and close to the area of study have been obtained and detailed surface maps for the flight hours are being prepared. The major objective -- in addition to the assessment of the utility of the lidar determined wind fields to studies of mesoscale flows -- is to attempt to map a coherent picture of the air flow to and within the Central Valley. The focus will be to use the surface and airborne observations, plus the tower data, to attempt a comprehensive description of the marine air intrusion into the Central Valley and to identify critical locations at which greater observational detail is required to obtain such a description.

FY 83

The major plans for FY 83 are to complete the analyses described above and to design a follow-on field observing program which will concentrate on critical locations identified in this analysis. It is proposed that the CV990 be used to circumnavigate the Sierra Nevada mountains to obtain a comprehensive map of the afternoon air flow up the western slopes from the Central Valley and over the crest.

Publications

No publications have been prepared as yet under this project.

TITLE: Severe Storms Lidar Signal Processing

RESEARCH INVESTIGATOR: R. W. Lee
Lassen Research
Manton, CA 96059
(916) 474-3966

FY-82 ACCOMPLISHMENTS:

Engineering analysis of the data obtained during the FY-81 flight program is nearly complete. Horizontal windfield components measured by the coherent Doppler lidar system were significantly contaminated by various errors introduced by aircraft dynamics. The major portion of these errors has been traced to certain time lags between aircraft attitude measurements and the application of these measurements to correction for aircraft motion. Algorithms have been designed and tested to compensate for these errors. The accuracy of the windfield estimates after correction is limited primarily by errors in the INS estimates of aircraft motion.

The editing and smoothing algorithms developed in FY-81 have been applied to this data, and the parameters have been optimized.

PLANS FOR FY-83:

- 1) An adaptive algorithm will be developed and tested to improve the internal consistency of the windfield estimates beyond the limits imposed by the INS system.
- 2) Navigation and data-acquisition procedures will be developed which will enhance the accuracy obtainable on future flights.
- 3) Algorithms will be developed for the automatic recognition and parameterization of convective structures in the boundary layer.

RECOMMENDATIONS FOR FUTURE RESEARCH:

Alternative scanning techniques offering increased navigational and velocity accuracy should be investigated.

TITLE: Aerosol Assessment Study

INVESTIGATOR: David A. Bowdle
Universities Space Research Association
Atmospheric Sciences Division
Marshall Space Flight Center, Alabama 35812
Phone: (205) 453-1557 or FTS 872-1557

SIGNIFICANT ACCOMPLISHMENTS, FY-82:

1. Completed review of NASA-sponsored aerosol research programs.
2. Evaluated each aerosol research task for contribution to global aerosol data base to be used in establishing design criteria for satellite-based CO₂ Doppler lidar wind measurement system.
3. Completed review of atmospheric aerosol models used in preliminary feasibility studies for satellite Doppler lidar system.
4. Developed preliminary aerosol model concept to guide data base screening, field program planning/evaluation, and model formulation for future aerosol research programs in support of satellite Doppler lidar system.
5. Attended Global Large Aerosol Workshop (June 7-9, 1982, Boulder, Colorado, Joint NOAA/NASA/USAF sponsorship).

CURRENT FOCUS OF RESEARCH WORK:

Identify and prioritize spatial/temporal domains in the atmosphere which are most critical to the development of a global aerosol data base of the scope and quality needed to generate criteria for the satellite Doppler system.

PLANS FOR FY-83:

1. Identify optimum balance of literature reviews, theoretical studies, laboratory measurements, and atmospheric aerosol measurements for obtaining the required data base.
2. Identify optimum complement of aerosol sensors, aerosol measurement platforms, and field program sites for future field measurement programs.

RECOMMENDATIONS FOR FUTURE RESEARCH:

Provide for the performance of the literature reviews, theoretical studies, and laboratory/field measurement programs identified in the ongoing aerosol assessment study.

OUTLINE OF RESEARCH ACTIVITIES

Analysis of Lidar, Radar, and Satellite Measurements on Severe Thunderstorms and their Environments

Research Investigators:

Dr. Howard B. Bluestein	National Severe Storms Laboratory
Dr. Richard J. Doviak	1313 Halley Circle
Mr. Robert Rabin	Norman, OK 73069
Dr. A. Sundara-Rajan	
Dr. Dusan Zrnich	

A. Significant Accomplishments FY'82:

In spite of the fact that we are only two months into the project, we have made significant progress which can be reported at the Research Review in September '82. There are three areas of investigation:

1. Prestorm and storm data
Dr. Bluestein, Project Leader
2. Planetary boundary layer
Dr. A. Sundara-Rajan, Project Leader
3. Doppler radar/lidar intercomparisons
Dr. Zrnich, Project Leader

Accomplishments are:

1. First intercomparisons of Doppler lidar and dual Doppler radar derived wind fields
2. Paper presenting results of Joint NASA/NSSL experiment was presented at a URSI meeting.

B. Current Focus of Research Work:

1. Prestorm and storm data

Studies of surface and upper air charts have been made in order to determine the conditions producing the thunderstorms of June 30 on which we have data from both the CV990 airborne Doppler lidar and NSSL's Doppler radar. Although some of the thunderstorms generated damaging winds, and even one small gust-front tornado, they occurred in an environment characterized by weak, disorganized winds aloft, and an absence of marked potential instability.

The Doppler lidar and radar at Page Airfield were simultaneously collecting data on a gust front, and we are now in the process of editing radar data and expecting the lidar data for intercomparison of data fields.

2. Planetary boundary layer

The computation of the surface stress and heat flux values based on the analysis of NSSL-KTVY tower data for June 29, 1981, and July 1, 1981, (the first and third day of the CV990 experiments) has been completed. June 29, 1982, data from NSSL's two Doppler radars and its 500 meter tall tower seem to be excellent for the study of the structure of the convective PBL and comparison of data obtained from NASA's airborne Doppler lidar. The analysis of dual Doppler wind data for the vertical profiles of mean wind and the variances of longitudinal and lateral wind velocity fluctuations is under way.

The lidar data tapes have not arrived yet; we hope to have them within a fortnight.

3. Doppler lidar/radar intercomparison

A program that computes azimuth and range between two points (given their longitude and latitude) has been put on the Boulder CDC-750 computer. The program will be used to locate the CV-990 with respect to the Norman Doppler radar. Azimuth and ranges for the circular part of the flight 8 were obtained. Comparison will be made between the winds obtained by the three instruments--Doppler lidar, Doppler radar, and the onboard wind measuring equipment. Presently we have projected the winds measured from the aircraft on the radar radials and are in the process of estimating Doppler winds. We anticipate to have the Doppler radar and lidar winds in about a month at which time we shall make a comparison between the two.

C. Plans for FY-83:

1. Continue analysis of thunderstorm gust front of June 30th using NASA's lidar data (to be provided very shortly) and NSSL's Cimarron Doppler radar and surface data.

2. Make a thorough study of the wind field for June 29, 1982, for which we have excellent dual Doppler radar data. We plan to use lidar, tower, surface and radar data for intercomparisons.

3. Conduct a detailed comparison between spectra of turbulent velocities obtained by radar, lidar, and the tower. From dual Doppler analysis, spectra of u and v will be obtained. Furthermore, spectra of the radial velocities (single radar) will be computed. Similar analysis will be generated with lidar data; spectra will be computed from new radial velocities and from synthesized two-dimensional velocities.

D. Recommendations for New Research:

1. In order to better understand how winds organize themselves to generate thunderstorms, we suggest to study:

- a) The wind structure along a frontal zone prior to the formation of deep convection, and
 - b) the wind field in the vicinity of dryline-front intersection.
2. In order to better assess the wind shear hazards to aircraft, we propose to study the wind field along gust fronts using:
- a) NSSL's Doppler weather radar which is a prototype of the next generation radar being considered for nationwide deployment, and
 - b) NASA's lidar which should give detailed structure of wind shear values to be compared with the relatively smooth gust front winds resolved by radar.

E. List of Publications:

- 1. Doviak, R. J., R. Rabin, and A. Koscielny, "Doppler Weather Radar for Profiling and Mapping Winds in the Prestorm Environment." To be published in Jan. 1983 in IEEE Trans. Geosci. & Remote Sensing.
- 2. Zrnich, D.S., and J.W. Bilbro, "Probing of Optically Clear Air at NSSL." Presented at National Radio Sci. Meeting in Jan. 1982.



SESSION IV

SEVERE STORMS SATELLITE DATA STUDIES

Mesoscale and Severe Storms Program

Observe and study mesoscale and severe storm phenomena, from the unique perspective of space, to increase our understanding and predictive capability of these important atmospheric circulation systems.

This goal is approached through a balanced program of:

- Scientific Research
- Technology Development
- Resource Development

Strong scientific research is the centerpiece of the program and is divided into four research areas:

- 1) Remote Atmospheric Measurements
- 2) Diagnostic Case-Study Analyses
- 3) Modeling, Simulations and Predictions
- 4) Interactive Data Analysis Systems

Cooperative NASA/University scientific research is encouraged to more effectively accomplish the overall goals of the program.

Gregory Wilson

TITLE: The AVE-VAS Ground Truth Field Experiment

RESEARCH INVESTIGATOR:

James R. Scoggins
Department of Meteorology
Texas A&M University
College Station, TX 77843
713-845-7671

SIGNIFICANT ACCOMPLISHMENTS IN FY-82:

A rawinsonde sounding mesonetwork of 12 special stations was set up and operated on five days during the period February-May, 1982. Except for the first (shakedown) day, soundings were made at 3-hr intervals beginning at 1200 GMT and ending at 0600 GMT (seven times). Concurrently with these soundings, digital radar data were recorded at Texas A&M University from the 10-cm radar, and all National Weather Service teletype and facsimile data for the area were archived.

Processing of the sounding data is nearly complete. Data for four days have been provided to NASA (magnetic tapes and data reports), and data for the fifth and last day will be sent to NASA early in November.

CURRENT FOCUS OF RESEARCH WORK:

Processing the rawinsonde soundings, preparation of magnetic tapes and data reports, and development of computer programs for evaluating the VAS sounding data.

PLANS FOR FY-83:

Start comparative analysis of rawinsonde and satellite soundings.

RECOMMENDATIONS FOR NEW RESEARCH:

The accuracy and representativeness, and the value and utility of satellite soundings in synoptic and mesoscale analyses, remain to be established. Much work needs to be done in these areas so that satellite sounding data can be used effectively.

PUBLICATIONS:

Four data reports authored by Ms. Meta Sienkiewicz. These (and magnetic data tapes) are available from Dr. Robert Turner, Chief, ES84, NASA, Marshall Space Flight Center, Alabama 35812. Data for the last AVE-VAS operational day will also be available in November.

TITLE: VAS Demonstration Correlative Research

PRINCIPAL INVESTIGATORS:

Gary J. Jedlovec (USRA)
Atmospheric Sciences Division
Marshall Space Flight Center, Alabama 35812
(205) 453-3570 or FTS 872-2570

James R. Scoggins
Department of Meteorology
Texas A&M University
College Station, Texas 77843
(713) 845-6011

SIGNIFICANT ACCOMPLISHMENT:

The AVE/VAS Ground Truth Field Experiment was conducted during the spring of 1982 under NASA's Severe Storm and Weather Research program. The experiment was managed by Marshall Space Flight Center (MSFC) with field support supplied by Texas A&M University. The AVE/VAS experiment also supports the VAS demonstration conducted by NASA and managed by Goddard Space Flight Center (GSFC) and is essential to the Demonstration because it provides, via the special mesoscale rawinsonde network, the fundamental data upon which the VAS sounding data will be evaluated and verified.

MSFC's Role in the VAS Demonstration is to provide an independent evaluation of VAS sounding data produced by various retrieval techniques. The VAS derived soundings will be produced using a physical and a statistical regression method by the National Environmental Satellite Service (NESS) and GSFC, respectively. Two experiment days have been selected for evaluation by MSFC scientists and agreed upon by NESS and GSFC. The periods from 1200 GMT March 6, 1982, through 0000 GMT March 7, 1982, will be used to evaluate VAS sounding data and techniques in a stable, clear-air environment. The data from 1200 GMT April 24, 1982, through 1200 GMT April 25, 1982, will be used to evaluate how well VAS soundings represent conditions of a pre-thunderstorm environment.

VAS derived soundings produced using a physical retrieval technique for the March 6-7 case have been provided to MSFC for evaluation. A subjective analysis of base state parameters has been performed at 850, 700, 500, and 300 mb. This subjective evaluation and comparison to the ground truth rawinsonde data indicates that VAS derived data captures mesoscale features to a fair degree of accuracy. VAS derived temperatures appear best in the lower levels and capture the larger structure represented in the rawinsonde data (see attached figure). The moisture values from VAS show a fair degree of accuracy in delineating dry and moist areas but lack mesoscale detail. The VAS derived height fields tend to be the poorest of the parameters. This may be due to known radiance errors in the NESS data sets.

CURRENT FOCUS OF WORK:

Current efforts in the VAS evaluation are to produce gridded fields of both VAS derived and rawinsonde data for quantitative comparisons and statistical error assessments. This will take some time since the non-uniformity of VAS sounding data (because of the presence of cloudy areas) complicates the gridding process.

PLANS FOR FY-83:

The approach used in the evaluation of VAS sounding products will consider two broad areas of data comparison. First, RMS comparisons of basic dynamical and state parameters will be made from both paired sounding (coincident raob and satellite sounding in space and time) and gridded field analysis. Dr. Scoggins, Texas A&M University, will participate heavily in this area. Second, atmospheric structure over the AVE/VAS region will be evaluated from VAS sounding data using the ground truth rawinsonde data, satellite imagery, radar data, and surface conditions as verification. Significant effort will be used to explain differences that can be attributed to expected GMD error, VAS radiance error, retrieval error, as well as time and space sampling problems.

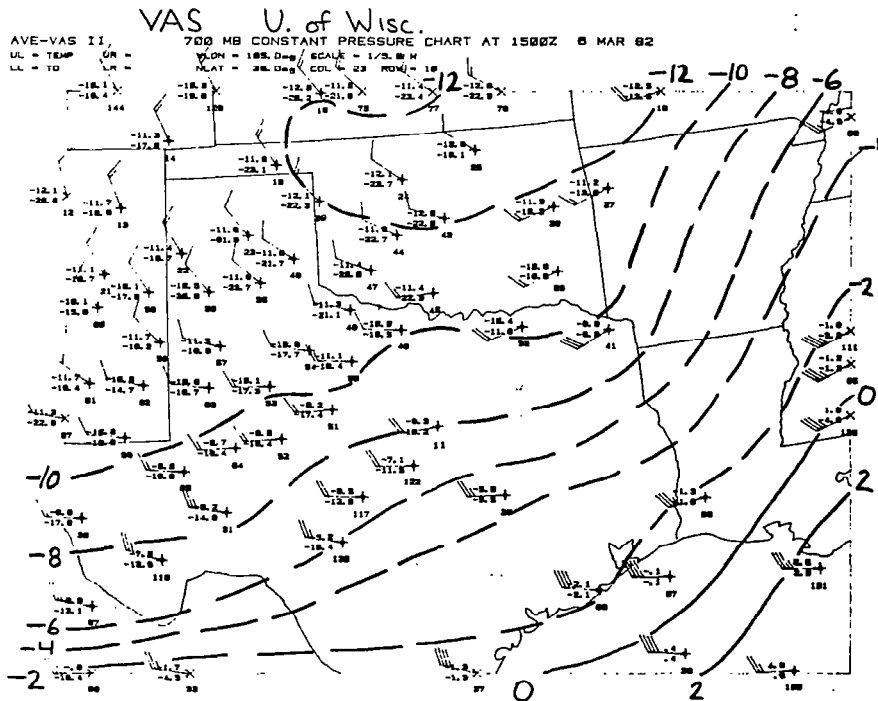
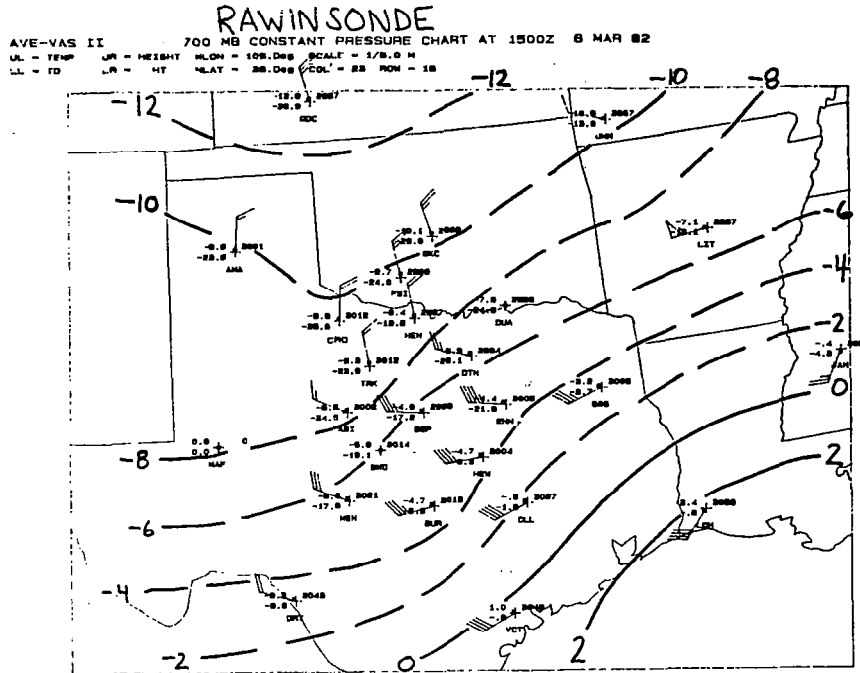
RECOMMENDATIONS FOR NEW RESEARCH:

Two major obstacles stand in the way of the operational use of VAS sounding products. First, since soundings can not be made in areas where extensive cloud cover exists, data void regions are common. Objective techniques to interpolate data to gridpoints, for the calculation of parameters useful in diagnosing severe weather events, perform poorly in data void regions and for non-uniform station spacings. Analysis techniques which use other data sources or VAS data at other times to fill in these gaps are necessary. Second, the assimilation of VAS data with rawinsonde data, so that the quality and structure inherent in each data type is preserved, is a must for meso-scale analysis and modeling work. This area has not been addressed to a large degree.

PUBLICATIONS:

Jedlovec, G. J., 1982: AVE/VAS Ground Truth Field Experiment and Preliminary Results. Abstracts from the American Geophysical Union, Spring Meeting, June 1982, Philadelphia, PA.

AVE/VAS 700 mb temperature analysis from 6 March 1982 at 1500 GMT. Ground truth rawinsonde data (top) indicate a strong northwest to southeast temperature gradient over the mesoscale network. The VAS derived temperature analysis shows a similar pattern but with a somewhat weaker gradient. VAS temperature values are generally 1° to 2° C colder than the rawinsonde values over the region.



Title: AUTOMATED MESOSCALE WINDS DETERMINED FROM GOES SATELLITE
IMAGERY AND AVE/SESAME/VAS DATA

Research Investigators: Gregory S. Wilson
Robert R. Jayroe
NASA/MSFC
Huntsville, Alabama
Telephone: (205) 453-2570

and

Bob Atkinson
General Electric
Huntsville, Alabama

Significant Accomplishments FY82:

An automated technique for timely and accurate calculations of mesoscale winds using GOES satellite imagery has been developed and tested on a selected case-study data sample (see example in Fig. 1). This technique calculates "feature" motion in sequences of images using template registration within image subscenes. Feature selection is done objectively to insure that motion calculations are height assignable and are representative of the actual wind. Comparisons have been made between the "automated" winds and those 1) measured by the AVE IV special rawinsondes, 2) calculated by single pixel tracking at MSFC and on the AOIPS system at GSFC. Overall, the comparisons have been very favorable in that wind speeds differences range between $0-4 \text{ ms}^{-1}$. In addition, the patterns and features of automatically computed cloud winds are very similar to manually-tracked cloud winds leading to consistent and dynamically meaningful divergence and vorticity distributions (see Fig.2).

The computer code for automatic cloud motions has been vectorized and configured for interactive processing and analysis on MSFC's HP-1000 F/McIDAS system in preparation for 1) comparisons on McIDAS, 2) real-time testing, and 3) incorporation of VAS data.

Current Focus of Research Work:

Diagnostic evaluation of automatically-derived mesoscale winds is continuing focusing upon the image separation time vs spatial resolution problem. Smaller template sizes (i.e., finer spatial resolution) and improved objective editing procedures are also being tested. The usefulness of automatic cloud winds in real-time predictive environments, in combination with existing surface and upper air measurements is also being examined.

Plans for FY83:

In addition to minor refinements to the system, meteorological evaluation of cloud winds will continue. A major independent comparison of McIDAS/WINDCO vectors with MSFC automatic winds is

scheduled for Fall CY82. Real-time testing at MSFC will begin in CY83 along with the development work required to include VAS imagery in the system for improved cloud height assignment and water vapor tracking. Publication of the method in the Journal of Applied Meteorology is scheduled for late Fall CY82.

Recommendations for New Research:

We recommend this method be implemented and tested in both research and operational environments to assess the usefulness of these wind estimates for numerical and short-range mesoscale analysis and prediction problems possibly using the McIDAS/CSIS computer network.

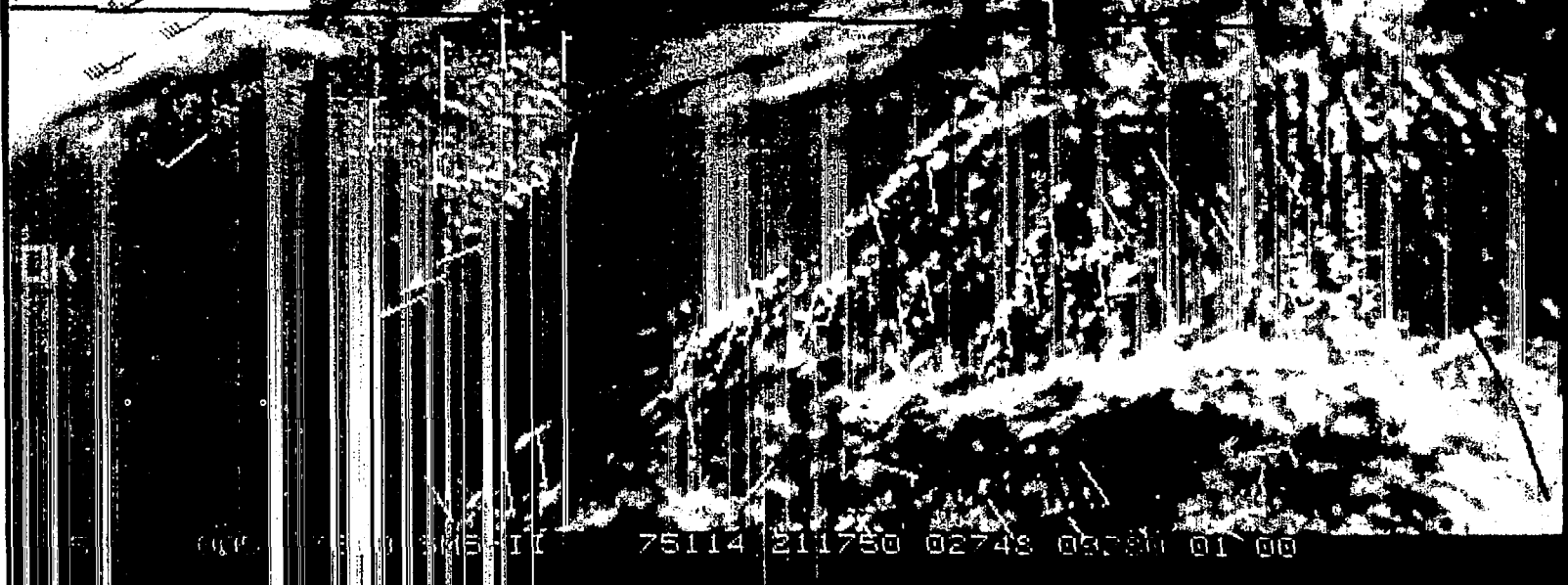
Publications:

"Automated Mesoscale Winds Determined from Satellite Imagery,"
NASA contract report (in press).

AUTOMATIC CLOUD WIND

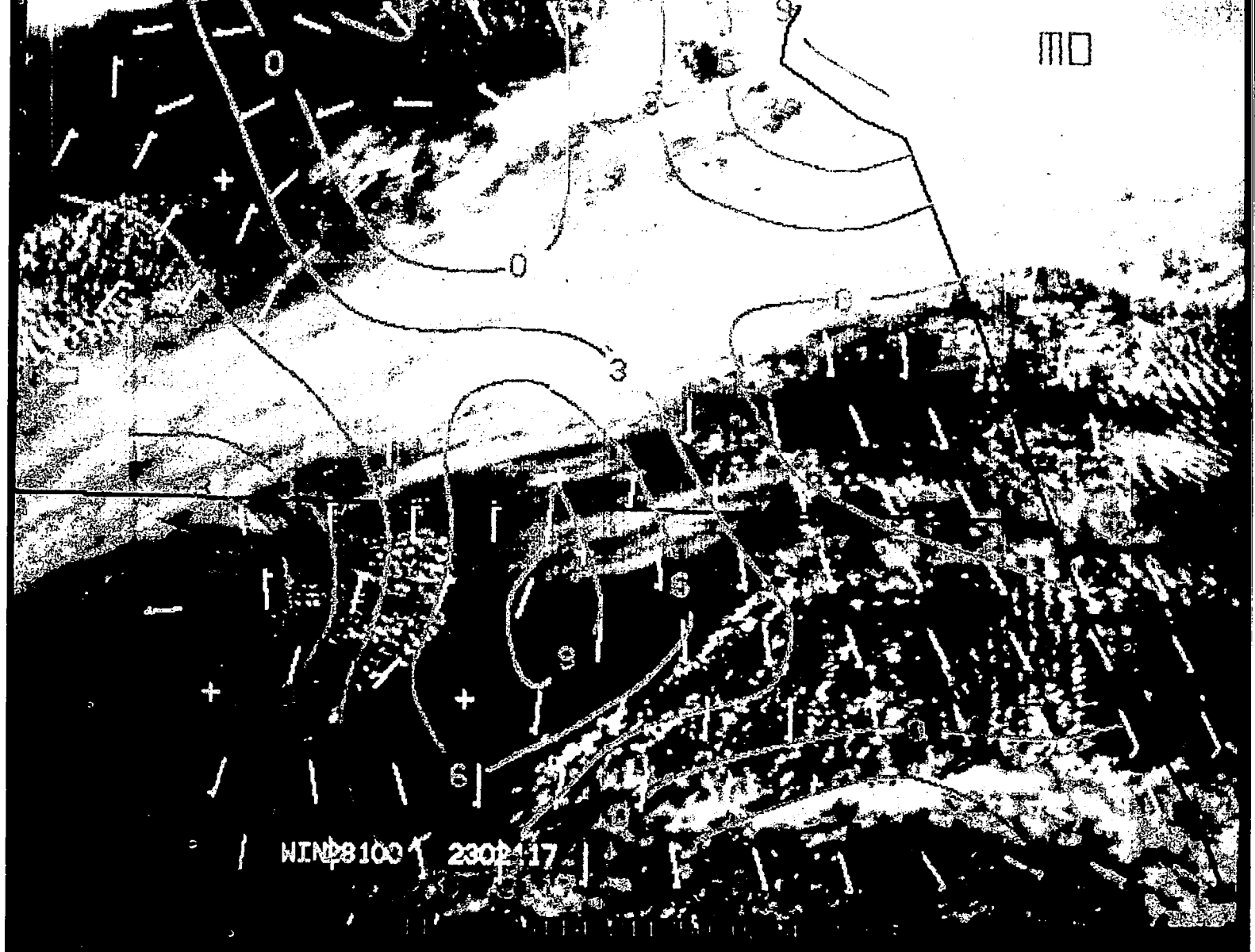
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LOW-LEVEL AUTO WINDS



Title: Mesoscale Satellite Sounding Research

Research Investigator: William L. Smith
NOAA/NESS Development Laboratory
University of Wisconsin
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Henry E. Revercomb
Space Science and Engineering Center
University of Wisconsin
Madison, Wisconsin 53706
(608)263-6758

Significant Accomplishments FY82:

During the past fiscal year emphasis has been placed on (1) refining the algorithm used for the routine retrieval of atmospheric temperature and water vapor profiles from the geostationary satellite VAS sounding data, and (2) the development of an advanced geostationary satellite sounding instrument capable of observing the important finer scale vertical temperature and moisture structures unresolved by the VAS.

(1) The VAS sounding retrieval algorithm has evolved into a procedure which utilizes an established iterative solution of the radiative transfer equation in order to provide approximation of the true profiles. Atmospheric structure deviations from the iterative result are then calculated by direct analytical solution of a system of radiative transfer perturbation equations and used to enhance the temperature and moisture solutions. The approach (a) accounts for the non-linear dependence of the temperature profile solution on the water vapor solution, (b) provides a stable solution which satisfies the radiance observations to within the measurement noise level, and (c) provides a solution which is minimally dependent upon the initial guess profile. The VAS temperature and moisture profile retrievals determined by this method have successfully captured sub-synoptic scale horizontal and temporal variations of vertically integrated temperature and moisture parameters that are used for convective storm forecasting (e.g., thermodynamic stability, total precipitable water, and thermal wind shear). On the other hand, the utility of the retrievals from VAS have been found to be severely limited by the coarse vertical resolution of the sensor. Figure 1 shows two example comparisons of VAS retrievals with two closely spaced radiosonde observations during the AVE/VAS Special Network observation day of 6 March 1982. These retrievals were obtained using (a) a "Standard Atmosphere" and (b) an "NMC 12 hour forecast" as the initial profiles for the VAS retrieval. (The operational practice is to use the NMC 12 hour forecast to construct the initial profiles for the VAS retrievals.) The comparisons are shown on a Skew-T log-p diagram in order to dramatize the differences between the retrievals and radiosondes. Since the "Standard Atmosphere" initial profile differs drastically from the radiosonde, one can see that the moisture solutions and the temperature profile solutions below the 500 mb level are indeed insensitive to the initial profile accuracy. However, above the 500 mb level the VAS retrieval accuracy becomes highly dependent upon the initial guess, indicating that the profile information content is very limited at these upper levels. Moreover the inability of VAS to resolve the important vertical temperature structure is striking.

(2) A radically improved passive vertical sounding capability concept has been developed. The concept exploits the ability of an interferometer to measure the high frequency components (high spectral resolution features) of the emission spectrum separate from the low frequency component (the broad band spectral resolution features). The fine scale vertical structure of the atmosphere is distinctly reflected in the high frequency emission line features of the spectrum rather than the broad band spectral features that are observed by VAS and other similar broad band radiometers. An optimally scanned interferometer concept (i.e., where dwell time is concentrated on the high frequency spectral component of the signal) has been developed which will enable the fine scale spectral signatures of vertical atmospheric structure to be observed with high signal to noise. The approach has been demonstrated to be an order of magnitude more efficient (e.g., in dwell time) than a conventional spectrometer approach. Furthermore, several hundred spectrally independent channels of information are obtained by a single detector thus enabling the analytical solution for the profiles to be achieved from a greatly overdetermined system of simultaneous equations (i.e., many more observation equations than unknown profile points). Simulations show that 1°C accuracy of temperature is achievable for all levels between the surface and 10 mbs from measurements using currently available interferometer technology and a 3-axis geostationary spacecraft.

Plans for FY83 and New Research:

(1) Research to optimize the VAS profile retrieval algorithm will continue. Particular emphasis will be placed on VAS profile solutions above low level extended cloud which can be combined with surface observations below the clouds to provide an approximation of the complete profile.

(2) A proposal to demonstrate from the NASA U-2 aircraft the high vertical resolution sounding capability of a high spectral resolution optimally scanned interferometer has been submitted to NASA Headquarters. It is planned to conduct the flight program and complete the data analysis during the next fiscal year, provided that NASA funds this most important sounding improvement program.

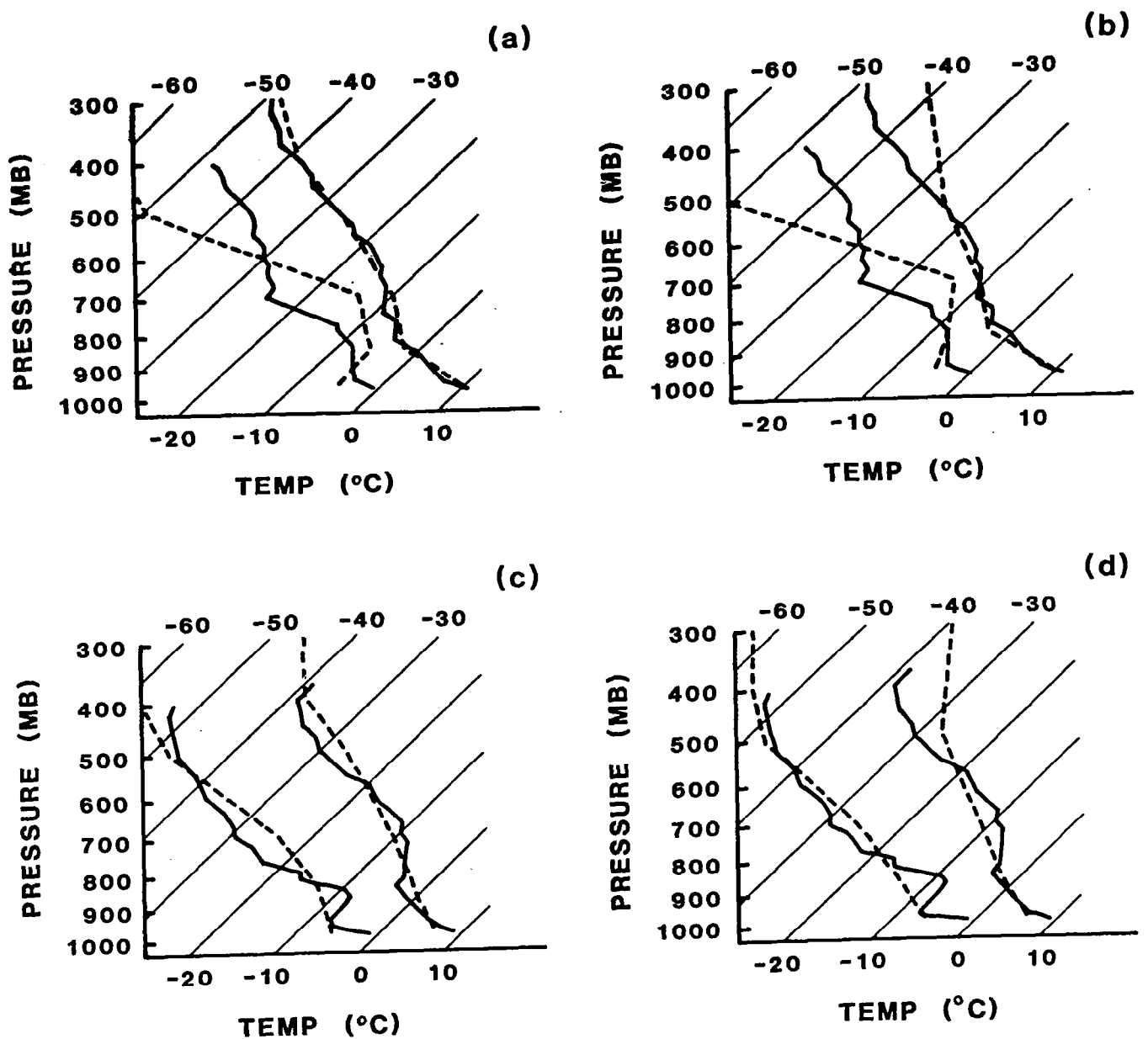


Figure 1: Comparison of VAS and AVE-VAS Special Network Radiosonde temperature and dewpoint observations at 2300 GMT on 6 March 1982 at Stations 72101 (34.5°N 98°W) and 72003 (34.0°N 96.5°W). Figures 1a and 1b (Station 72101) and Figures 1c and 1d (Station 72003) correspond to VAS retrievals using an NMC 12 hour forecast first guess (a and c) and a climatological profile first guess (b and d), respectively. The profiles are plotted on a Skew-T/Log-P diagram in order to accentuate the profile differences.

NOTE ON THE
ADVANTAGES OF THE HIGH-RESOLUTION INTERFEROMETER SOUNDER (HIS)
DESIGN FOR THE NEXT GEOS SOUNDER

The design feasibility study for HIS, completed in July 1981, provided a new and exciting option for an advanced GOES sounder. Simulations of the HIS performance show that it can provide a vast improvement over current sounders, and the instrument design is very compact and attractive.

However, apparently the value of high spectral resolution for infrared sounding is being questioned, by some people, because the simulated sounding performance of AMTS (a grating spectrometer) is not sufficiently better than that of HIRS (a filter radiometer). Two fundamental advantages of the HIS approach over any option using a filter radiometer or a grating spectrometer, which account for the superior HIS performance, are (1) the interferometer multiplex advantage allows contiguous spectral coverage (i.e. a very large number of spectral channels) and low noise, with no need for huge detector arrays, and (2) dramatic noise reduction is realizable from optimum interferogram sampling because of the concentration of high-resolution spectral structure information in localized regions of interferograms.

The Multiplex Advantage of the Interferometer Approach

The multiplex advantage refers to the noise advantage of an interferometer over any other type of instrument which looks at spectral channels sequentially. Comparing instruments with the same number of detectors (say one for simplicity), an interferometer looks at all of the energy in a broad spectral band, while a sequential instrument looks at only the energy in a narrow spectral channel. As a result, the noise advantage of the interferometer is proportional to the square root of the ratio of the total spectral band pass to the spectral resolution. While for low spectral resolution applications this basic advantage of the interferometer may be outweighed by other instrument design differences, for high resolution instruments the interferometer starts out with a very large advantage which is hard for other approaches to overcome. For the HIS $15\mu\text{m}$ CO₂ band, extending from 600 to 770 cm^{-1} , the interferometer noise advantage is a factor of $\sqrt{334}=18$. A grating spectrometer with the same transmittance and detector sensitivity as the HIS would require 334 separate detectors (and the incumbent cooler capacity) to equal the interferometer radiometric performance. A more realistic number is probably about 100 detectors, because for most interferometer designs 1/2 of the incident energy is reflected by the interferometer. However, even if a 100 detector array were used to achieve noise parity with the interferometer, contiguous spectral coverage would not be achieved. For an instrument with low detector noise such as the HIS, all of the many contiguous spectral channels contain useful independent temperature information. Figure 1 compares the HIS spectral coverage to that for AMTS.

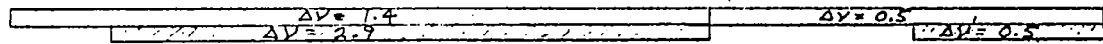
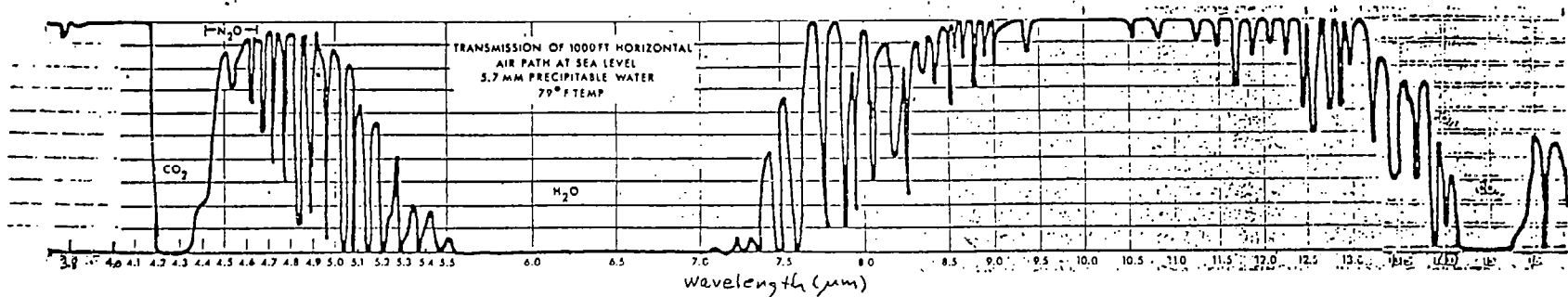
Optimum Interferogram Sampling

Optimum interferogram sampling is a method for acquiring the information needed for sounding more efficiently than is possible in the spectral domain. This approach makes use of the concentration of information on spectral line characteristics in equally spaced, narrow regions of an interferogram of the $15\mu\text{m}$ band, which results from the large number of uniformly spaced CO_2 absorption lines in this band. Since the HIS design makes measurements directly in the interferogram domain (optical path difference or delay is varied to yield measurements of the Fourier transform of the wavenumber spectrum), it is possible to concentrate dwell time in the regions containing the most high resolution information and to skip regions where the signal is small for all atmospheric temperature profiles. The design allows the interferogram to be measured over specified regions, selected to optimize the limited time available for sounding from geosynchronous orbit.

The $15\mu\text{m}$ CO_2 band is the spectral region where both the HIS and the AMTS approaches require the highest spectral resolution ($<0.5\text{ cm}^{-1}$) and which, as a result, poses the most severe performance requirements on instrument design. Therefore a technique for making efficient measurements in this region can make a big effect on overall instrument performance. The region of optical path difference covered by the HIS design (0-1.4 cm, which yields a maximum apodized spectral resolution of 0.5 cm^{-1}) contains three important regions, one near zero delay and one each near 0.6 cm and 1.3 cm. Simulations have demonstrated that the best efficiency is achieved by spending the most time sampling the larger delay regions, such that the instrument noise level is lowest in the region of largest delay. Because of this characteristic of the optimum noise distribution and because the important regions are narrow, the interferogram can be scanned much faster by optimal sampling than by equal sampling of all delays, with very little information loss. Figure 2 compares the RMS temperature errors from sounding simulations using complete interferograms with a noise level of $0.5\text{ mW/m}^2\text{sr}$ at all delays to those using interferograms sampled only in the three important regions with noise levels of 2., 1., and $0.5\text{ mW/m}^2\text{sr}$. The performance is very similar and the time required for the optimal scan by the HIS conceptual design instrument is seven times shorter.

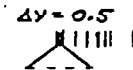
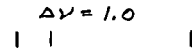
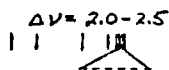
To summarize, because of the interferometer multiplex advantage, a grating spectrometer or filter radiometer require arrays of hundreds of detectors to equal the HIS noise performance, and would require even more detectors (more than are practical) to equal the contiguous spectral coverage of HIS. In addition, the optimum sampling capability of the HIS design allows the effective instrument noise to be further reduced or, equivalently, allows sampling times to be reduced by almost an order of magnitude.

Further, because of its broad spectral coverage, low noise, and flexible operation (programmable spectral resolution and noise distribution), the HIS instrument approach to high-resolution sounding can do the jobs envisioned for its competition, and more. The alternatives to HIS can not do the HIS job. This generality of the HIS approach recommends it for an aircraft demonstration of the advantages of sounding with high spectral resolution.



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HIS SPECTRAL COVERAGE (UPPER BAR = AIRCRAFT, LOWER = GEO)



AMTS SPECTRAL COVERAGE

FIGURE 1. Comparison of HIS spectral coverage for the aircraft and the GEO models to that for AMTS.

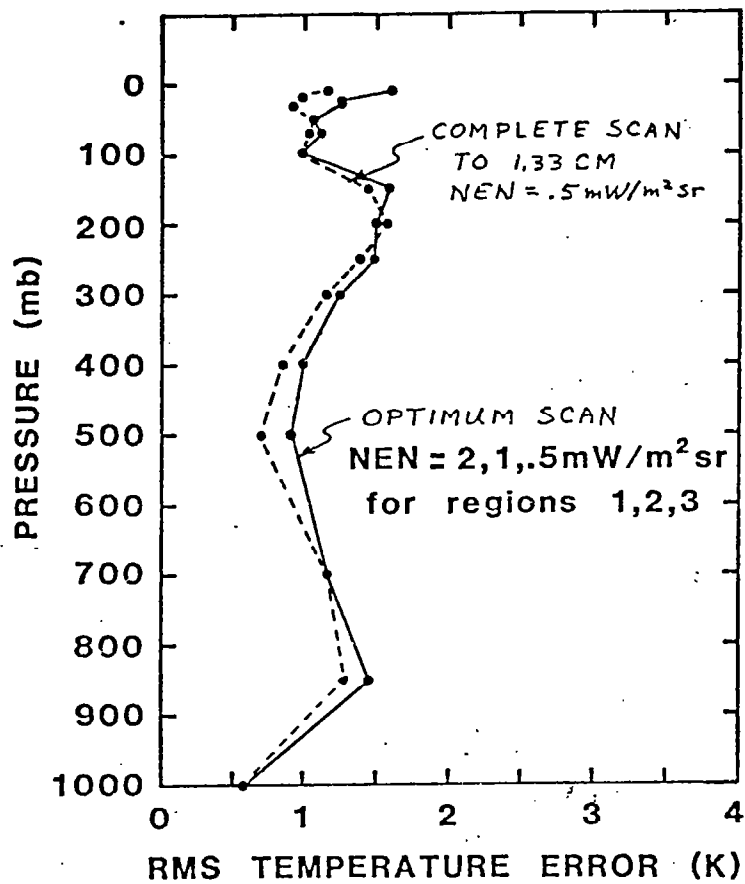


FIGURE 2. Comparison of RMS temperature errors from simulations using complete interferograms to those from partial interferograms with optimum noise distribution. The errors are nearly the same, and the optimum scan can be performed seven times faster.

OUTLINE OF RESEARCH ACTIVITIES

ANALYSIS OF SATELLITE DATA FOR SENSOR IMPROVEMENT (Detection of Severe Storms from Space)

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Significant Accomplishments for FY-82

The major subject being investigated under the current grant is to establish the relationship between (1) cloud-top features, and (2) storm characteristics on the earth. Triple Doppler observations and photography of tornadoes and their parent thunderstorms were accomplished on June 12, 1982 during the JAWS Project operation near Denver, Colorado.

Current Focus of Research Work

Computer method of obtaining stereoscopic cloud heights from GOES West and East. To develop further the NASA-Japan cooperative program of stereo photography of GMS (Japanese Geosynchronous Meteorological Satellite) and GOES West.

Plans for FY-83

- (1) To investigate cloud-top features by using high-flying Lear Jet aircraft.
- (2) To determine the tornado-thunderstorm relationship based on the June 12, 1982 data.
- (3) To obtain and analyze GMS-GOES West stereo pictures under the NASA-Japan cooperative program.

Published Papers in FY-82

- [1] Fujita, T.T. (1982)
Principle of stereoscopic height computations and their applications to stratospheric cirrus over severe thunderstorms. Journal of Meteorological Society of Japan, Vol. 60, No. 1, pp. 355-368.
- [2] Fujita, T.T. and J.C. Dodge (1982)
Applications of stereoscopic height computations from dual geosynchronous satellite data - Joint NASA-JAPAN Stereo Project - COSPAR XXIV May 1982, Ottawa, Canada, 8 pages.

- [3] Fujita, T.T. (1982)
Infrared, stereo-height, cloud-motion, and radar echo analysis of SESAME-day thunderstorms. Preprint, 12th Conference on Severe Local Storms, San Antonio, Texas, January 1982, pp.213-216.
- [4] Stiegler, D.J. and T. T. Fujita (1982)
A detailed analysis fo the San Marcos, Texas tornado induced by hurricane Allen on 10 August 1980. Preprint, 12th Conference on Severe Local Storms, San Antonio, Texas, January 1982, pp. 371-374.
- [5] Fujita, T.T. and R.M. Wakimoto (1982)
Anticyclonic tornadoes in 1980 and 1981. Preprint, 12th Conference on Severe Local Storms, San Antonio, Texas, January 1982, pp. 401-404.
- [6] Fujita, T.T. (1982 Manuscript)
Overshooting tops of severe thunderstorms revealed by Lear Jet, Satellite, and Radar Observations.

Title: Storm-Environment Interactions Determined from AVE-SESAME and Satellite Data

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Contributors: Carol Belt, Pete Browning, Matt Printy, Mark Ruminski

Significant Accomplishments FY-82

Our goal is to better understand atmospheric conditions that produce severe local storms, especially those conditions at the subsynoptic scales. In addition, we are seeking a better knowledge of how severe convective storms alter their surroundings once they are formed. As a result, we hope that better forecasts will result and that satellite technology can be used to better advantage.

During FY-82 we began investigating the AVE-SESAME V period (20-21 May 1979). Rawinsonde data at 75 km spacings and 1.5 or 3 h intervals are available over Oklahoma during a period of intense thunderstorm activity. These data are at approximately the same scale as those provided by the VAS satellite. Thus, the SESAME V data provide valuable experience for the satellite based studies that we propose for 1983-86. Thermal, kinematic, and kinetic energy parameters are being investigated. The results are fascinating in that the meso β -scale storm environment undergoes tremendous changes as the convection develops. Areas of heating, diffluence, and speed changes are observed (Fig. 1).

A second new area of investigation is the computation of boundary layer winds that are derived from TIROS-N thermal data. Variations in low level winds have been closely linked to convective outbreaks by previous studies. During FY-82, our major thrust was to conduct a thorough literature review, develop the appropriate theory, and select the period to be studied (AVE-SESAME II, 19-20 April 1979). Actual calculations have just begun. The procedure is to first compute geostrophic winds at seven levels below 1600 km AGL using thermal wind relationships. Then, the winds will be modified to conform with Ekman theory. Our approach is similar to that contained within the Air Force's Boundary Layer Model. Computed winds and derived kinematic parameters will be evaluated for usefulness as severe storm forecast aids.

Efforts to better understand the Wichita Falls Tornado Outbreak (AVE-SESAME I), 10-11 April 1979) continued. Several publications on this topic are given at the end of this report. We are now focussing on the role that latent heat released by the storms had in producing a subsynoptic scale, upper level jet maximum over the storm area. Parameterization techniques are being used to obtain the various components of diabatic heating. Figure 2 shows that heating was maximized in the storm environment. A budget of available potential energy will be prepared to further relate the wind maximum to the convection. The study involving contributions of divergent and rotational wind components to the kinetic energy balance of the AVE IV period (24-25 April 1975) has been completed. A sensitivity analysis of the various energy parameters was performed. Results showed that the divergent wind component was quite important within the storm environment (Fig. 3). This is significant since current NWP models inadequately handle the divergent component.

Current Focus of Research

Most of the efforts begun during FY-82 are two year projects that will extend into FY-83. In particular, those studies involving satellite-derived boundary layer winds, meso β -scale diagnoses, and parameterization are continuing.

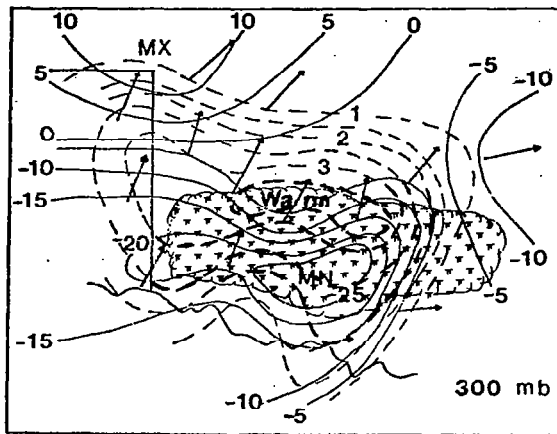


Fig. 1 300 mb isobaric surface for the 1700-2300 GMT period on 20 May 1979. Wind speed changes (solid, kt/6 h) show the formation of a wind maximum to the north of the storm area (echoes shaded at 2130 GMT) and a decrease in winds toward the south. Wind data at the stations are for 2130 GMT 20 May. Temperature changes (dashed, °C/6 h) show heating in the storm environment.

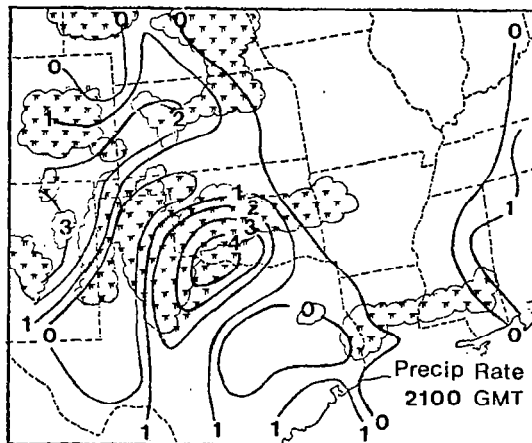


Fig. 2 Positive values of diabatic heating expressed as precipitation rate (mm/h) for 2100 GMT 10 April 1979. Values were obtained from the thermodynamic equation. Radar echoes at 2035 GMT are shaded.

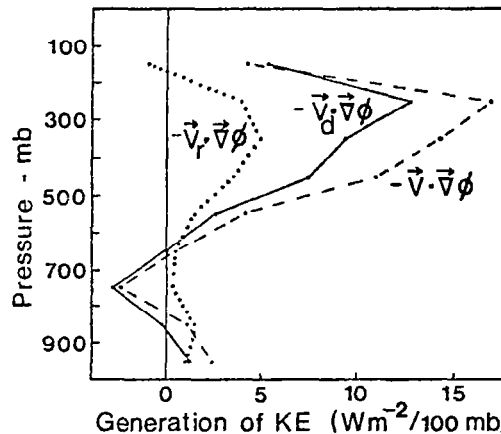


Fig. 3 Generation of kinetic energy in a limited volume enclosing the meso-scale convective complex at 0600 GMT 25 April 1975. Note the relative contributions of the divergent (\vec{v}_D) and rotational (\vec{v}_r) components in producing the large values of generation.

Plans for FY-83

Each of the above mentioned studies will be completed and the appropriate reports prepared. In addition, we hope to begin a major new effort utilizing data from the 1982 AVE/VAS Field Experiment. This research will be an extension of our previous and current efforts to better understand and forecast mesoscale phenomena. Basic thermodynamic variables obtained from the VAS will be evaluated against those from special rawinsonde networks. Winds will be obtained from the two data sources via thermal techniques. Derived parameters such as stability, moisture advection, kinetic energy, and adiabatic vertical motion also will be investigated. In each case, relationships between the variables and weather phenomena will be sought.

Recommendations for New Research

Further efforts are needed to assimilate satellite and rawinsonde data into a single set such that the advantages of each are realized. VAS sounding data appear to have excellent horizontal and temporal resolution, but poorer vertical resolution and absolute accuracy. On the other hand, the weaknesses of the satellite system generally are the strengths of the RAOB network.

Publications since June 1981

- Belt, C. L., and H. E. Fuelberg, 1982: The effects of random errors in rawinsonde data on derived kinematic quantities. Mon. Wea. Rev., 110, 91-101.
- Browning, P. A., and H. E. Fuelberg, 1982: Contributions of divergent and nondivergent winds to the kinetic energy balance of a severe storm environment. Preprints Twelfth Conf. Severe Local Storms, San Antonio, Amer. Meteor. Soc., 581-584.
- Fuelberg, H. E., and W. S. Lee, 1982: A comparison of adiabatic and kinematic vertical motions using mesoscale data. Preprints Ninth Conf. Weather Forecasting and Analysis, Seattle, Amer. Meteor. Soc., 417-423.
- Fuelberg, H. E., and G. J. Jedlovec, 1982: A subsynoptic-scale kinetic energy analysis of the Red River Valley tornado outbreak (AVE-SESAME I). Tentatively accepted by Mon. Wea. Rev.
- Jedlovec, G. J., and H. E. Fuelberg, 1981: A subsynoptic-scale kinetic energy study of the Red River Valley tornado outbreak (AVE-SESAME I). NASA CR 3456, George C. Marshall Space Flight Center, AL, 126 pp.
- Jedlovec, G. J., and H. E. Fuelberg, 1982: The analysis and kinetic energy balance of an upper-level wind maximum during intense convection. Preprints Ninth Conf. Weather Forecasting and Analysis, Seattle, Amer. Meteor. Soc., 430-434.
- Jedlovec, G. J., and H. E. Fuelberg, 1982: The kinetic energy balance of the AVE-SESAME I period. Preprints Twelfth Conf. Severe Local Storms, San Antonio, Amer. Meteor. Soc., 228-231.
- Moore, J. T., and H. E. Fuelberg, 1981: A synoptic analysis of the first AVE-SESAME '79 period. Bull. Amer. Meteor. Soc., 62, 1577-1590.

Title: Statistical Structure of Convective Periods Derived from
Satellite and Ground Based Data

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Significant Accomplishments FY-82

The statistical structure function is a relatively new variable for describing the information content of a data set, and it offers promise as a forecasting aid as well. Structure function analyses are somewhat analogous to spectral methods.

During FY-82, structure functions were computed on RAOB-derived values of geopotential height, temperatures, winds, and humidity for the Wichita Falls Tornado Outbreak period (AVE-SESAME I, 10-11 April 1979). Calculations assuming homogeneous, isotropic conditions were made at four levels in the lower and upper troposphere. Results show that subsynoptic scale features were important components of the wind and humidity fields. The activity at these smaller scales appears closely linked to the presence of convection within the area. Figure 1 shows the development of a low level jet near 1600 km wavelength that reached peak intensity near the time of the Wichita Falls Tornado Outbreak (0000-0300 GMT). In addition, computations were made using only the NWS RAOB data; i.e., the special SESAME data were removed. The special data network was found to yield an improved representation of most parameters. For example, Fig. 2 shows the inability of NWS stations to detect important mesoscale wind features that were resolved by the finer scale network. Finally, the functions were used to assess random errors contained within the data.

Current Focus of Research

Research continues on the AVE-SESAME I period. Correlation functions are being computed, and anisotropic structure calculations are underway to determine the orientations of gradients. Computations for AVE-SESAME I also are being performed using TIROS-N data. By comparing the two sets of results, we can assess the relative abilities of the two data sources to detect the important wavelengths during this convectively active period. A sensitivity study is underway to quantify variations in structure that could be due solely to input data uncertainty or to particular computational procedures. The results should allow us to firmly justify all subsequent conclusions.

Plans for FY-83

Additional AVE-SESAME cases will be studied. These will include some of the storm scale (75 km spacing) periods. In addition, we will

begin to investigate VAS sounder data from the 1982 Field Experiment. Calculations made using the sounder data will be evaluated against those from simultaneous RAOB soundings in order to assess the satellite's ability to determine short term atmospheric variability.

Recommendations for New Research

A "climatology" of structure functions should be established by performing calculations on the twice daily RAOB data for an extended period. The goal would be to isolate a "signature" in the structure profiles that would be indicative of potential severe storm development.

Publications since June 1981

Fuelberg, H. E., and P. J. Meyer, 1982: A structure function analysis of the AVE-SESAME I period. Preprints Twelfth Conf. Severe Local Storms, San Antonio, Amer. Meteor. Soc., 188-191.

Meyer, P. J., 1982: An analysis of statistical structure during the first regional-scale SESAME '79 experiment (AVE-SESAME I). Unpublished manuscript submitted to NASA and to the American Meteorological Society as an entry for the 1983 Father Macelwane Award. Copies are available from the authors on request.

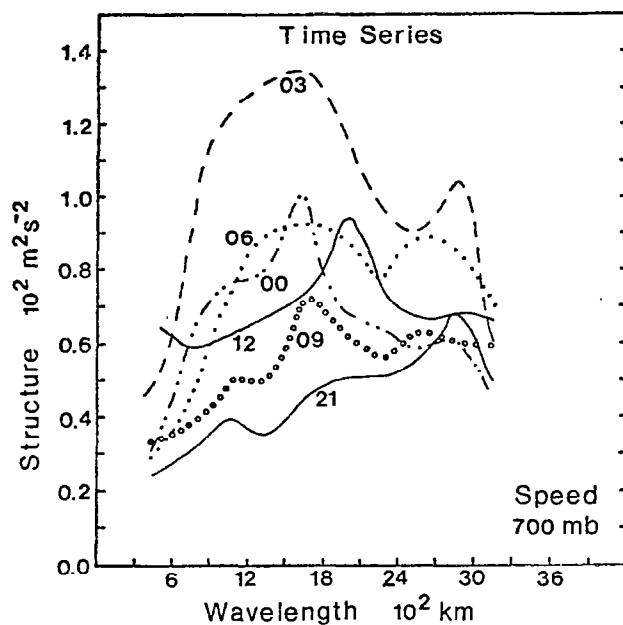


Fig. 1 Time series of wind speed structure at 700 mb based on 39 RAOB stations at 250 km intervals from AVE-SESAME I. Time ranges from 2100 GMT 10 April through 1200 GMT 11 April 1979. Note the peak near 1600 km wavelength.

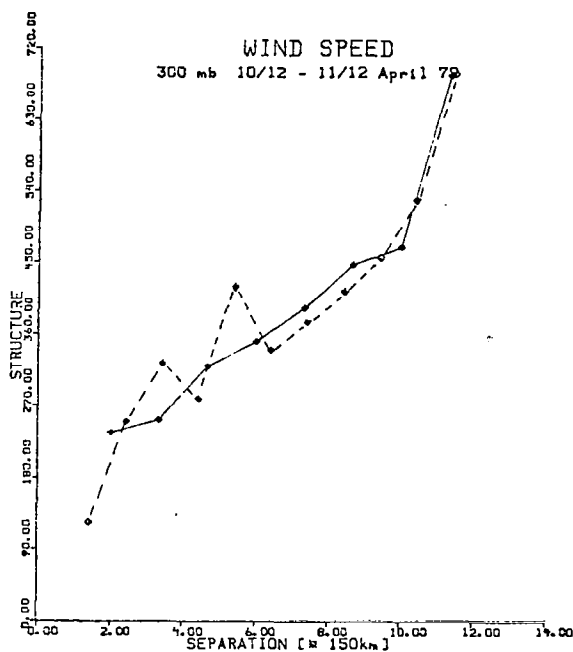


Fig. 2 Structure function of 300 mb wind speed (m^2/s^2) for the composite AVE-SESAME I period based on 39 stations (dashed) and 23 NWS only stations (solid).

TITLE: UTILIZATION OF AVE-VAS/SESAME DATA IN THE STUDY OF MASS-DERIVED WINDS AND AGEOSTROPHY IN THE MESOSCALE ENVIRONMENT

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SIGNIFICANT ACCOMPLISHMENTS FY-82

The major thrust of our research effort is to study the three-dimensional variability of the ageostrophic wind and its components within the mesoscale environment, especially prior to the onset of convection. An isentropic coordinate system is utilized to derive mass-balanced (i.e., geostrophic) and isallobaric winds from the mass geometry as well as inertial advective and tendency winds from the momentum field. VAS-derived soundings allow calculation of the former with enhanced temporal and horizontal resolution.

During FY-82 this research has concentrated on the AVE-SESAME I, Red River Valley tornado outbreak. Results indicate that:

- (1) the inertial advective wind is very active in the exit region of an upper level jet (ULJ), transporting mass from the cyclonic to the anticyclonic side of the jet,
- (2) the low level jet (LLJ) is strongly forced by the isallobaric wind and appears to be coupled with the ULJ,
- (3) low level ageostrophy helped to enhance upward vertical motion in the vicinity of a strong baroclinic zone,
- (4) the isallobaric wind tends to be more continuous in space-time than the tendency wind (for which it is an approximation),
- (5) the ratio of the isallobaric wind to the inertial advective wind increases in response to short wave trough translation through an area, and
- (6) isentropic air parcel trajectories help to depict the ageostrophic accelerations imposed upon the fluid and yield reasonable vertical motion patterns when compared to satellite imagery and radar echoes.

CURRENT FOCUS OF RESEARCH

We are nearing completion of our work with AVE-SESAME I and will soon begin constructing a time-adjusted, isentropic data set for AVE-SESAME II. Similar diagnostic, ageostrophic wind studies will be carried out to see if our conclusions from AVE-SESAME I can be made more general. In addition, we intend to run an error analysis on the ageostrophic wind components by perturbing the original u,v wind components and Montgomery stream function

fields with a random number generator using standard rawinsonde errors. This will give us confidence limits on our earlier results.

PLANS FOR FY-83

Based upon our experience with the AVE-SESAME data sets, we wish to exploit the temporal and horizontal resolution of the VAS-sounder in measuring geostrophic and isallobaric wind fields. For each VAS demonstration day selected, three isentropic data sets will be constructed; one using only the National Weather Service (NWS) regular rawinsonde network (meso alpha scale), a second using only the special meso beta scale rawinsonde network, and a third incorporating VAS-derived sounding data together with the latter data set. This will be done for both "clear" (i.e., non-convective) and "stormy" (i.e., convective) cases. In this way, we hope to test the effectiveness of the VAS data, in combination with the rawinsonde data, in a unique objective analysis scheme for mesometeorological research. It will also allow testing of the degree to which VAS data may be used to enhance the resolution of geostrophic and isallobaric winds. In addition, stability parameters and moisture convergence will be computed to compare meso alpha to meso beta scales of motion. Explicit isentropic trajectories will be run to test their sensitivity to VAS data input into the objective analysis schemes. A diagram illustrating present and future research efforts is displayed in Fig. 1. We are hopeful that such studies may extend the usefulness of the VAS-sounder to the operational forecaster community.

RECOMMENDATIONS FOR NEW RESEARCH

We wish to expand upon the geostrophic wind concept to explore other mass-balanced winds including the gradient and balance winds. Winds that deviate from these latter winds may yield more information about the three-dimensional structure of non-balanced flow than the ageostrophic wind provides. In addition, the gradient and balance winds may be computed from VAS-derived soundings. Thus, there is an opportunity here to utilize VAS-sounder data in studying mass-balanced flow and deviations from it in the mesoscale environment.

Secondly, we hope to band pass filter one of our data sets in order to examine key wavelength features and their role in enhancing ageostrophic or non-balanced flow.

PUBLICATIONS SINCE JUNE 1981

Moore, J.T. and H.E. Fuelberg, 1981: A Synoptic Analysis of the First AVE-SESAME '79 Period. Bull. Amer. Meteor. Soc., vol. 62, pp. 1577-1590.

Arnold, J.E., 1982: Characteristics of Ageostrophic Flow in the Vicinity of a Severe Weather Outbreak-AVE-SESAME I. Preprints-Twelfth Conference on Severe Local Storms, San Antonio, TX, pp. 205-208.

Moore, J.T. and M.F. Squires, 1982: Ageostrophic Winds and Vertical Motion Fields Accompanying Upper Level Jet Streak Propagation During the Red River Valley Tornado Outbreak. Preprints-Ninth Conference on Weather Forecasting and Analysis, Seattle, WA, pp. 424-429.

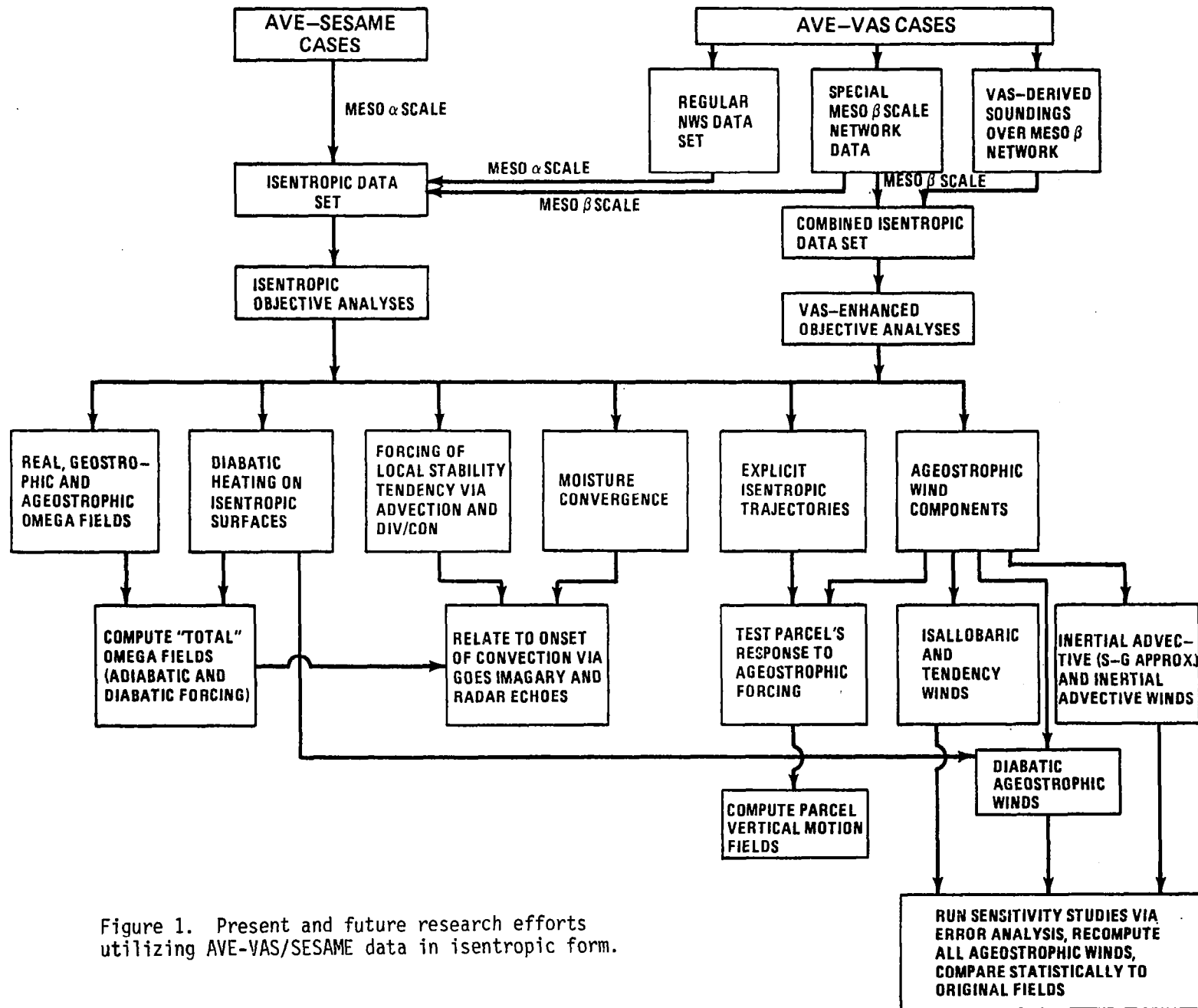


Figure 1. Present and future research efforts utilizing AVE-VAS/SESAME data in isentropic form.

Title: AN INTEGRATED SATELLITE AND SURFACE EVALUATION OF
PRECIPITATION CHARACTERISTICS

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Significant Accomplishments FY-82:

Activities during the past year have been associated with the development of a radar data base coincident with the experiment days of the 1982 AVE/VAS Ground Truth Field Experiment. During the AVE/VAS experiment, digital radar data was taken at both Texas A&M and the National Weather Service radar site located at Stephenville, Texas. The digital radar coverage encompasses the meso- β network of RAWINSONDE stations in north central Texas which supported the AVE/VAS Ground Truth Experiment during March through May of 1982. The digital radar data taken by Texas A&M University at College Station, TX consists of scans at 0.5, 2, 3.5 and 5 degrees and will be used to estimate vertically integrated liquid water changes throughout the storm's life as well as low-level accumulated rainfall based on z-r relationships. The National Weather Service radar data is taken at 0.5 degrees elevation angle and will also be used to estimate precipitation characteristics over the network. The digital radar data and the resulting liquid water and precipitation amounts will be integrated with VAS moisture information and surface based precipitation information in order to evaluate relationships between precipitation characteristics observed in the hourly data from the Climatic Data Stations and storm characteristics as observed in the VAS, VISSR, and surface radar data.

Current Focus of Research:

The present work has been directed toward the preparation of the digital radar tapes for utilization in the integrated satellite and radar study of the surface characteristics of rainfall. Computer software development has been underway in order to transform the radar data tapes into average intensities and associated rainfall accumulations for 10 km square areas within the AVE/VAS network in north Texas. The radar estimates of surface precipitation will be tuned using hourly precipitation measurements made at the surface. Objective analysis techniques are being experimented with which will allow analysis of the hourly precipitation patterns and subsequent integration of surface precipitation fields and radar patterns using the MSFC McIDAS processing.

VAS soundings are being processed via the University of Wisconsin technique in order to develop a technique to incorporate

satellite derived moisture amounts and their changes into a moisture budget field within which the precipitating echoes/cloud patterns can be inserted. The vertically integrated liquid water amounts and their changes that will be estimated from the radar data will be compared with the changes observed at the cloud top from the multispectral satellite data.

The analysis of MDR patterns during the VAS periods has been conducted in order to evaluate precipitation patterns existing at the time of the AVE/VAS experiment. These MDR fields have been compared with the National Weather Service reports of precipitation. This information is being used to isolate geographic areas and time periods of greatest interest for the satellite-radar characteristics study.

Plans for FY83:

The main portion of the data analysis will be begun early in FY83 as the rawinsonde data, the hourly rainfall data, and the research satellite soundings become available. The primary efforts during the first quarter of FY83 will be to develop an integrated radar and surface rainfall mapping as well as integrated liquid water estimates based on the Texas A&M radar system. Interactive development of atmospheric moisture convergence and water budgets will be carried out using the special network and surrounding rawinsonde stations. A similar analyses will be done with the VAS data. Cloud top characteristics including cloud top temperature patterns and area changes will be tabulated and compared with radar and surface characteristics.

Recommendations for New Research:

An increased diversity of precipitation cases over those existing in the present study should be obtained for analysis. The precipitation processes as observed using digital radar, surface networks and atmospheric characteristics sensed from space could then be made more general than is possible in the present study. The scope of the investigation into precipitation detection and measurement from space also should be expanded to include the cloud electrification process during precipitation events.

TITLE: Investigation of Mesoscale Meteorological Phenomena as Observed by Geostationary Satellite

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SIGNIFICANT ACCOMPLISHMENTS FY82:

GOES-EAST imagery plus conventional synoptic observations have been used to examine three mesoscale systems commonly observed by meteorological satellite. The McIDAS system was used but because of the brief time involved (less than two months) the analyses performed are quite cursory at best. The three systems are an arc cloud complex (ACC), mountain lee waves and air mass cloud streets parallel to the wind shear. Gravity wave activity is evident in all three cases at one time or another.

Of particular interest is the ACC which has received some attention in the literature. It has been shown that this line marks the leading edge of a mesohigh of meso- β proportions and behaves much like a cold front. It frequently interacts with other mesoscale boundaries which it encounters to produce intense convection. It can be seen in satellite imagery as a thin line of cumulus clouds except where it has enhanced or initiated deep convection.

Fig. 1 shows the ACC case that was studied by the author. Fig. 2 shows the ACC 3.5 hours earlier than in Fig. 1; it developed after several hours of storm activity in northern Texas and Oklahoma. As the arc cloud moved southward over the next 7 hours, clouds in the interior of the complex vanished, presumably due to subsidence. The southward movement of the arc was against what the general flow should have been according to the large-scale pressure field. Deep convection was maintained on the eastern flank of the arc as it moved southward but dissipated on the western flank. However, at the time of Fig. 1 new convection is just being initiated at the western flank, as can be

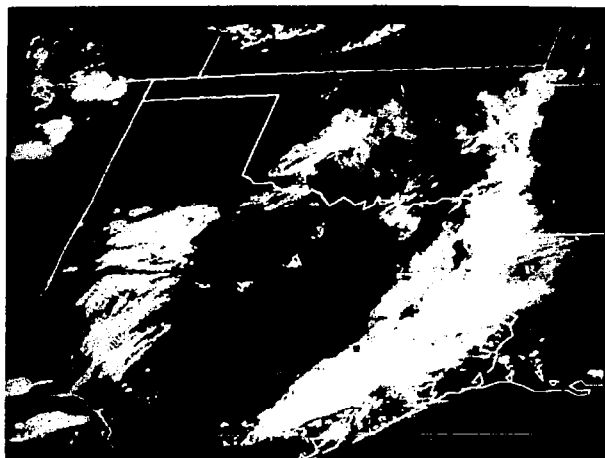


Figure 1

seen by the single cell near the New Mexico border. Intense activity developed from this point northward over far west Texas and eastern New Mexico over the next 8 hours.

CURRENT FOCUS OF RESEARCH WORK:

An analysis of the temperature and pressure fields of the ACC, based upon surface synoptic data, reveals that the cold-air center is displaced from the high-pressure center by about 200 km. Thus, the dynamics and thermodynamics of the ACC must be somewhat different than that classically associated with solitary convective cells. The recent literature is being reviewed to determine if studies have been made of this situation or if other related studies may give some clues to help develop an hypothesis for the ACC dynamics.

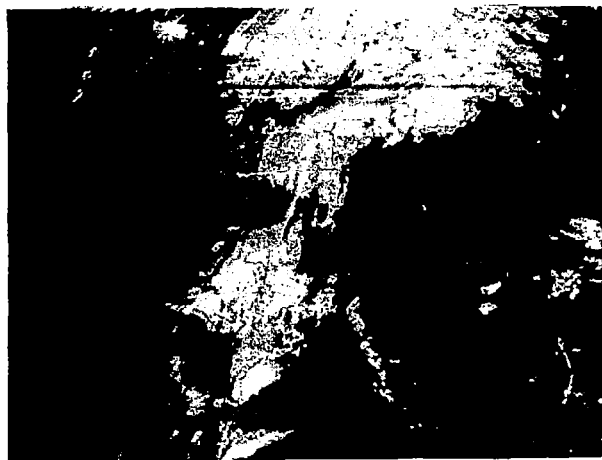


Figure 2

PLANS FOR FY83:

The analysis of the ACC discussed here will be continued, bringing to bear all conventional synoptic data that are available. A theory for the ACC dynamics will be developed. The PI intends to submit a proposal for this research to the OSA Severe Storms and Local Weather Program.

RECOMMENDATIONS FOR NEW RESEARCH:

The ACC appears to be a very important phenomenon for the development of extended periods of intense convection over extensive areas. There appears to be a CISK-like situation in its maintenance. The difficulty in developing a theory for its dynamics is that conventional upper-air observations within the ACC generally are not available. Radar observations are not greatly useful here because by the time the arc cloud becomes well-defined in the satellite imagery, apparent subsidence is clearing out the interior of the arc ring.

It is recommended that VAS observations be utilized to help establish the moisture and temperature fields in the vicinity of the ACC. The height fields of the pressure surfaces could be used to establish geostrophic wind fields from which advective fields could be established as well as the vorticity field. Estimates of vertical motion could be obtained using the adiabatic method. A number of ACC cases should be studied to determine systematic conditions.

PUBLICATIONS SINCE JUNE 1981:

None

APPLICATION OF THE AVE-SESAME DATA SETS
TO MESOSCALE STUDIES

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Contributors: Brian Auvine, H. Michael Goodman, Raymond Lord, David Santek

Scope of Research:

To investigate the quantitative application of GOES data, complemented by conventional data, in the investigation of the structure and dynamics of severe local storms and convective outbreaks:

- (1) Using the '79 SESAME-AVE storm-scale rawinsonde and radar data, improve the methods whereby rapid-scan satellite imagery can be combined with conventional meteorological observations to produce more useful data sets -- this includes improved mesoscale wind fields for at least three levels, and combined satellite and digital radar maps of convection and small-scale thunderstorm features.
- (2) Improve means whereby satellite brightness data can be used both to isolate deep convection and to detect severe weather in its incipient stages.
- (3) Investigate small-scale thunderstorm characteristics, and combine digital satellite and radar data to relate the occurrence of cold domes and overshooting tops to severe weather at the surface.

Accomplishments FY 82:

- (1) Cloud winds: Extended cloud winds in time (from cloud tracers and raobs) for the 2 May '79 case. Included aircraft winds in our analysis - are attempting to remove biases from return legs of aircraft data (See fig.).
- (2) Anvil features such as overshooting tops and other texture patterns were tracked. Tornado tracks for the 2 May '79 case were found to follow paths similar to the tops. Tornadoes and cloud tops had motions similar to the radar echoes.
- (3) Tornado locations were compared to visible and infrared brightness patterns. Tornado genesis appeared in regions of strong cloud top IR gradients and high visible brightness. Conversely, tornado dissipation occurred in relatively warm IR regions with flat gradients and away from peak visible brightness.
- (4) Anvil statistics: Compared areal growth rates at various brightness thresholds for visible and infrared data with severe storm occurrences and areal radar statistics -- few conclusive results as yet.
- (5) Data Processing: Completed data synthesis and radar remapping into satellite projection.

Current Focus of Research Work:

Complete case study of 2 May and synthesize results, and compare with other cases.

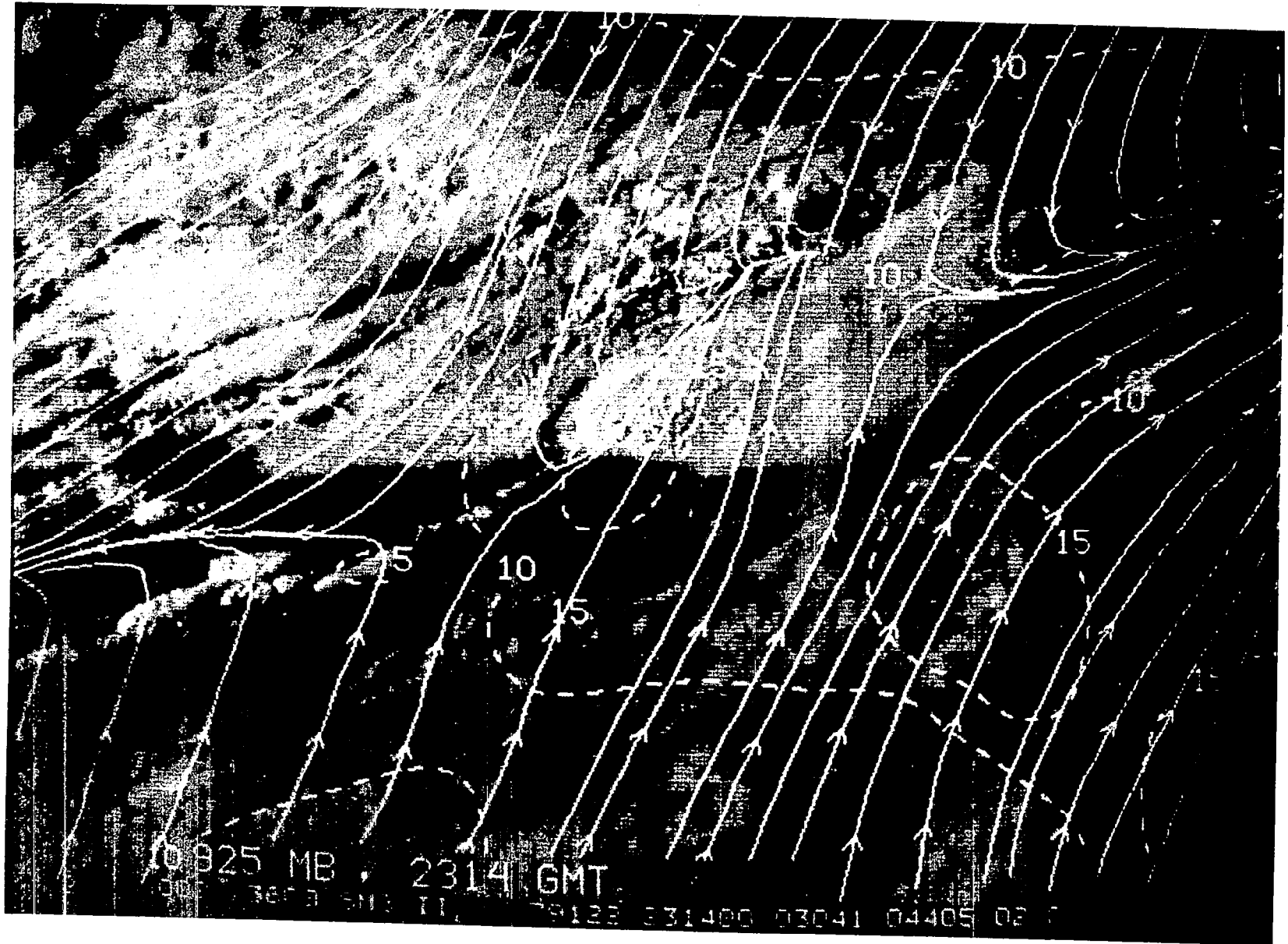
Plans for FY 83:

- (1) Incorporate newly developed stereographic techniques into cloud top analyses.
- (2) Extend above analyses to other days (e.g., a moderately active case - 20 May '79, and one with little activity - 8 June '79). In addition (as a control case), examine the morphology of overshooting tops not associated with severe weather formation.
- (3) Study the behavior of anvil features which are not overshooting tops (e.g., what determines the size, shape, and motion of these features and what can they tell us about the dynamics of the storm).
- (4) Continue our research on the origin, morphology, and group behavior of cloud tops in detail. Do they travel in clusters? How do they relate to severe weather events (singly or in groups)? Are there cloud top "signatures" of surface weather phenomena?

Papers in FY 82:

Goodman, H.M., B. Auvine, D. Santek, 1982: The Relationship of Satellite and Radar Storm Signatures to the Subsynchronous Wind Field. Preprints, 12th Conference on Severe Local Storms, San Antonio, TX, 12-15 January 1982.

Suchman, D., R. Lord, A. Thomas, 1982: Combining and Comparing Satellite and Radar Brightness Statistics During SESAME '79. Preprints, 12th Conference on Severe Local Storms, San Antonio, TX, 12-15 January 1982.



TITLE: STUDY OF SEVERE STORM DEVELOPMENT BASED ON SATELLITE, RAWINSONDE DATA ANALYSIS

RESEARCH INVESTIGATORS:

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SIGNIFICANT ACCOMPLISHMENTS FY-82:

Special rapid-scan satellite visible and infrared observations, in conjunction with rawinsonde and Doppler sounding detections, have been used to study the life cycle of the clouds from the initiation of condensation, through the formation of clouds, the development of towering cumulus, the penetration of the tropopause, the collapsing of an overshooting turret, and the dissipation of the cloud. During the inception and developing stages of the clouds before they penetrated the tropopause, there are very few apparent differences between the cloud which spawned a tornado and that which ended as a thunderstorm. After the penetration of the tropopause, the differences between the two cloud systems are more readily discernible using satellite observations.

The differences of the basic characteristics between the cloud which spawned a tornado and that which ended as a thunderstorm have been studied. The characteristics of the cloud associated with a tornado are (1) a large volume of cold cloud above the tropopause, (2) a higher growth rate for the cloud above the tropopause, (3) a cloud top temperature much lower than the tropopause, and (4) a rapid collapsing of the cloud top immediately prior to the touchdown of the funnel cloud. The characteristics of the cloud which terminates in a thunderstorm based on our study are (1) a small volume of cold cloud above the tropopause, (2) a low growth rate for the cloud above the tropopause, (3) a cloud temperature not much lower than the tropopause temperature, and (4) a gradually dissipating cloud above the tropopause.

CURRENT FOCUS OF RESEARCH:

Our study shows that the temperature of the overshooting turret is much lower than that of the surrounding air, and the density of the turret is much higher than the surrounding air density. The overshooting turret of the cloud associated with a severe storm can only exist as long as it is dynamically supported by intense vertical convection. To support a tall, large and heavy overshooting turret above the tropopause, a large gradient of thermal energy is necessary.

To further develop our understanding along these lines, our current focus is to analyze (1) GOES infrared imagery for areas of large gradients of thermal energy and their correlation with the development of severe storms,

and (2) rawinsonde data for areas of instability and their relationship with the excitation of gravity waves.

PLANS FOR FY-83:

Severe convective storms are a mesoscale phenomena with a short life cycle of a few hours duration. Rapid scans of both infrared and visible imagery from geosynchronous satellite are necessary to ensure obtaining sufficient observations of the storm development. Very frequent and highly concentrated rawinsonde observations of air mass parameters, such as AVE-SESAME data, are urgently required for studying the air mass instability which is responsible for the excitation of gravity waves and the initiation of the updraft motion.

Case studies of both clouds which spawned tornadoes and those that ended only as severe thunderstorms will be continued using (1) rapid-scan GOES infrared imagery to study the formation of steep temperature gradients, (2) AVE-SESAME data to study airmass instability, and (3) U-2 observations to study the development and collapse of overshooting turrets.

RECOMMENDATIONS FOR NEW RESEARCH:

Our study shows that there are very few apparent differences between the cloud which spawns a tornado and the cloud which ends as a thunderstorm at their inception and developing stages. It is recommended that both geosynchronous satellite and rawinsonde observations be used as initial input data in a 2-dimensional cloud model to generate a cloud for comparison with actual radar and GOES rapid-scan imagery. The computer simulation would be useful in classifying possible differences in the early stages of cloud development.

LIST OF PUBLICATIONS PREPARED SINCE JUNE 1981:

- (1) Hung, R.J., and Smith, R.E., Ionospheric Remote Sensing of Medium Scale Gravity Waves and Tornadic Storms, Il Nuovo Cimento, 4C, 339-358, 1981.
- (2) Hung, R.J., and Smith, R.E., Remote Sensing of Tornadic Storms from Geosynchronous Satellite Infrared Digital Data, International Journal of Remote Sensing, 3, 69-81, 1982.
- (3) Hung, R.J. and Smith, R.E., Satellite Infrared Imagery, Rawinsonde Data, and Gravity Wave Remote Sensing of Severe Convective Storms, International Journal of Infrared and Millimeter Waves, 3, July, 1982.
- (4) Hung, R.J., and Smith, R.E., Infrared Optical Sensing of Tornadic Clouds, Photonics Spectra, 16, September, 1982.
- (5) Hung, R.J., and Smith, R.E., Remote Sensing of Tornadic Storms from Space, Proceedings of 12th Space Simulation Conference, pp. 259-270, NASA CP-2229, 1982.
- (6) Hung, R.J., and Smith, R.E., Detection of Convective Storms Based on Penetrative Cloud Top From Satellite Infrared and Rawinsonde Data. Proceedings Sympos. Cloud Dynamics, pp. 38, ed. by S. Ruttenberg, IAMAP, Hamburg, Federal Republic of Germany, August, 1981.

- (7) Hung, R.J., and Smith, R.E., Convective Storms from Geosynchronous Satellite Infrared Data, Proceedings International Raio Science, OS-1, pp. 65, 1981.
- (8) Hung, R.J., and Smith, R.E., Detection of Convective Storms Based on Penetrative Cloud Top from Satellite Infrared and Rawinsonde Data, and Gravity Waves from Doppler Sounder, Cloud Dynamics, ed. by E.M. Agee and T. Asai, Reidel Publishing, Netherlands, August, 1982.
- (9) Hung, R.J., and Smith, R.E., Severe Convective Storm Detection Based on Satellite Infrared Imagery Analysis, 16 Internat. Sympos. on Remote Sensing on Environt., ed. by J.J. Cook, University of Michigan, 1982.

TITLE: The Large-Scale Vorticity Budget Associated with Convective Activity

PRINCIPAL INVESTIGATOR:

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College Station, TX 77843
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SIGNIFICANT ACCOMPLISHMENTS IN FY-82:

The vorticity equation may be written in the form

$$\frac{d\zeta_a}{dt} = \frac{\partial \zeta}{\partial t} + \vec{V} \cdot \vec{\nabla} \zeta + \omega \frac{\partial \zeta}{\partial p} + \beta v = -\zeta_a \vec{\nabla} \cdot \vec{V} + R$$

where all terms and symbols except R have their usual meanings, and R represents a residual term which includes twisting and tilting, frictional effects, and computational error. The two right-hand terms represent vorticity production following the motion. The sum of the production terms may be interpreted as an increase or decrease in the intensity of circulation which usually represents changes in the characteristics of pressure systems.

Terms in the above equation were evaluated at 850, 700, 500, and 300 mb, as well as vertical motion and divergence at several times during AVE VII. The preliminary results show the following.

1. Positive vorticity advection (PVA) at 500 mb when the LND is below this level does not contradict the hypothesis that it (PVA) implies positive vertical motion in the mid troposphere, but it does not strongly support it either. When the LND is above 500 mb, PVA at 300 mb is associated with positive vertical motion at levels below (an expected result in convective areas since convergence usually is present at all levels below the LND).
2. The residual, R, was as large or larger than other terms in the vorticity equation. Even on the synoptic scale, which our analysis represents, processes (presumably primarily twisting and tilting) represented by R are very significant whether or not convective activity is present.
3. In most cases changes in the production terms are accompanied by changes in the local and horizontal advection terms ($\frac{\partial \zeta}{\partial t} + \vec{V} \cdot \vec{\nabla} \zeta$). Changes in R usually are larger than changes in $\zeta_a \vec{\nabla} \cdot \vec{V}$.
4. R is negative in areas of scattered or isolated convective activity, indicating that twisting and tilting contribute to anticyclonic

(or reduces cyclonic) vorticity, while in extensive areas of convective activity R is positive, indicating a contribution to cyclonic (or reduction in anticyclonic) vorticity. This was verified by examining constant pressure charts.

CURRENT FOCUS OF RESEARCH WORK:

The analysis of the vorticity budget will be accomplished for both AVE VII and AVE-SESAME I. Also, we are investigating the effects of the release of latent heat. Results from this effort are not yet available.

PLANS FOR FY-83:

Complete the analyses discussed above for AVE VII and AVE-SESAME I, document results in the form of a contract report, and prepare at least one journal article.

RECOMMENDATIONS FOR NEW RESEARCH:

The age-old problem of determining where, when, and to what extent convective activity forms based on synoptic-scale analyses needs attention. This problem encompasses the problem of scale interaction. Data sets such as AVE, AVE-SESAME, and AVE-VAS, combined with VAS satellite soundings, could be used to address this problem for scales of about 400 km and larger and over time intervals of 3 hr. Even though this limitation probably excludes most initiation mechanisms for convective activity much could be learned about the influence convection has on large-scale systems.

PUBLICATIONS:

None. The research is still in the preliminary stage.

TITLE: A single-level objective analysis scheme for meso- β scale phenomena using surface and satellite data

RESEARCH INVESTIGATOR: Dr. David R. Smith
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SIGNIFICANT ACCOMPLISHMENTS OF FY82:

The Purdue Regional Objective Analysis of the Mesoscale (PROAM) is a scheme designed for the analysis of surface meteorological variables. PROAM permits the analysis of data from the surface observations transmitted through the FAA 604 teletype circuit. The temporal (hourly) and spatial (approximately 100 km) resolution of this data permits the analysis of meso- β scale phenomena such as those responsible for severe convective development.

PROAM has been used to generate analyses of measured (temperatures, dew point temperatures, altimeter settings, wind speeds and directions) and computed (equivalent potential temperatures, vorticity and convergence of wind temperature and moisture) variables that are considered important for identifying areas of potential convective activity. It has proven to be an effective tool in detecting surface mesoscale features that precede thunderstorm development two-four hours in advance.

CURRENT FOCUS OF RESEARCH WORK:

Several modifications have been made to PROAM in order to improve its flexibility and performance as an analysis scheme. The code has been rewritten for use in an interactive computing environment. The multiple iteration correction technique discussed by Barnes (1973) has been implemented to improve the accuracy of the analysis.

The modified version of PROAM has been subjected to a variety of experiments in order to test the scheme using different values of the analysis parameters. Testing has included both analytic distributions and actual atmospheric observations in order to establish error limits for the scheme and evaluate its performance.

A simulation of VAS-type temperature distributions (with large data-void regions, as would be the case in overcast sky situations) was performed. This was accomplished in order to examine the feasibility of such a mesoscale single-level analysis scheme for satellite-measured variables.

PLANS FOR FY83:

Immediate plans include modifications to the analysis scheme so that it will be a generalized code for single-level mesoscale analysis of atmospheric variables. These changes include incorporation of a time-averaging scheme in order to permit proper treatment of data collected asynchronously. This would allow the analysis of satellite data (such as VAS) with the same resolution as the surface data.

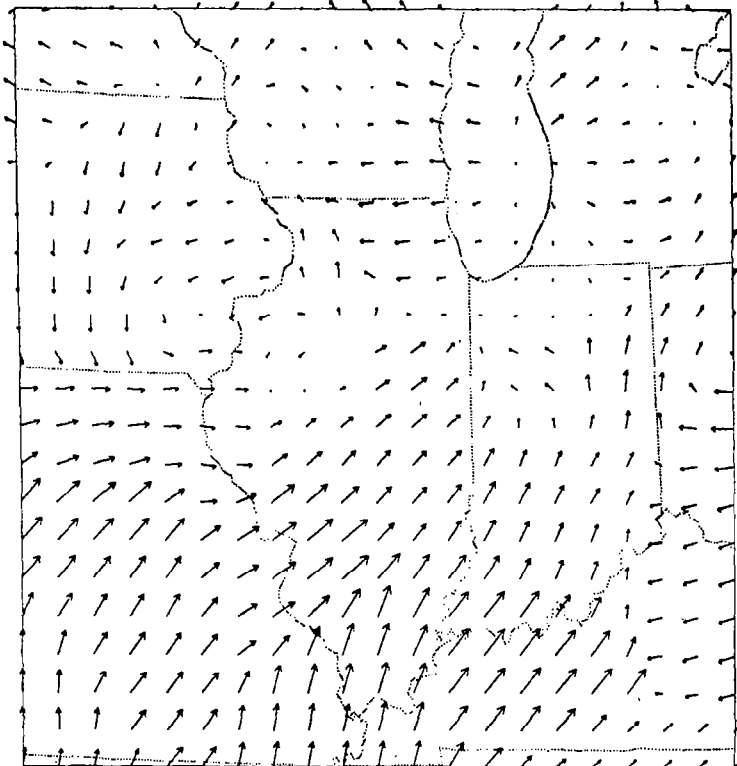
RECOMMENDATIONS FOR NEW RESEARCH:

Future studies will include objective analysis of VAS data sets in conjunction with surface data from the FAA 604 teletype circuit. The focus of these studies will be to determine coupling relationships between surface and upper air features for meso- β scale phenomena. In particular the goal of such analyses will be identifying features that precede severe convective development.

LIST OF PUBLICATIONS PREPARED SINCE JUNE 1981:

1. Brady, R. H., J. T. Snow and D. R. Smith, 1982: Sub-synoptic analyses of the severe weather of 9-10 July 1980. Preprints: 12th Conf on Severe Local Storms, San Antonio, TX, Amer. Meteor. Soc., Boston, MA, 156-159.
2. Smith, D. R., 1982: Modification and evaluation of a Barnes-type objective analysis scheme for surface meteorological data. (To be published as a NASA Contractor Report, 1982 NASA/ASEE Summer Faculty Fellowship Program under Univ. of Alabama contract NGT-01-002-099).
3. Snow, J. T., D. R. Smith, F. W. Leslie and R. H. Brady, 1982: Mesoanalysis of surface variables associated with the severe weather of 9-10 July 1980. (Submitted for publication to Monthly Weather Review).

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MAXIMUM VECTOR

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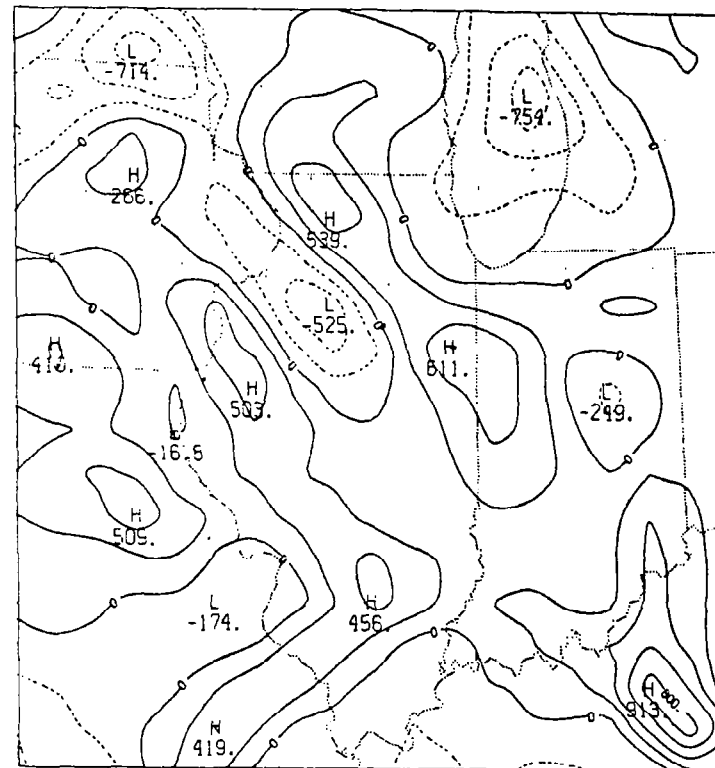


Figure 1. PROAM generated output of surface variables for 10 July 1980 (0100Z). (a) Horizontal velocity vector (units of 10^{-1} ms^{-1}) at each grid point ($\Delta x = 45 \text{ km}$). Velocity is proportional to the length of the vector. (Note scale in lower left hand corner.) (b) Horizontal velocity convergence (units of 10^{-7} s^{-1}), where solid lines correspond to positive (convergence) values and dashed lines to negative (divergence) values. Contour interval is $200 \times 10^{-7} \text{ s}^{-1}$.

Title: THE STRUCTURE AND DYNAMICS OF MESOSCALE SYSTEMS
INFLUENCING THUNDERSTORM DEVELOPMENT

Research Investigator: Gregory S. Wilson/ES84
NASA/MSFC
Huntsville, Alabama 35812

Significant Accomplishments in FY82:

NASA's AVE/SESAME data sets have been extensively analyzed to identify mesoscale structural features and dynamical processes influencing severe thunderstorm development. The primary purpose of this research was to establish the relative importance of mesoscale systems in creating environmental conditions favorable for thunderstorm and severe weather development.

Results for AVE/SESAME I have identified three strong mesoscale systems that were instrumental in creating environmental conditions favorable for strong thunderstorm development. Two of these systems were associated with the development and movement of two separate convective storm complexes including the storm system containing the Wichita Falls, Texas tornado. TIROS-N satellite sounding data and GOES satellite imagery were used extensively to support these conclusions.

The origin and structure of these mesoscale systems were studied in detail in FY82 using GOES-W VISSR data and the newly available, computer-compatible surface data set from the U. of MO. This work has confirmed that the mesoscale circulations responsible for initiation of severe convection on April 10-11, 1979 were created as mixed-mode Rossby-gravity waves in the North Pacific thermal ridge 24 hours before storm formation. These circulations propagated southeastward into the Southern Rocky Mountains and interacted with high terrain before moving into the West Texas-Wichita Falls area (see Fig. 1) during the daylight hours of April 10, 1979.

Current Focus of Research Work:

The relationship between mesoscale surface features and upper-level positions of the three mesoscale systems is being examined to better define the three-dimensional dynamics of these circulations before they initiated severe convection.

Plans for FY83:

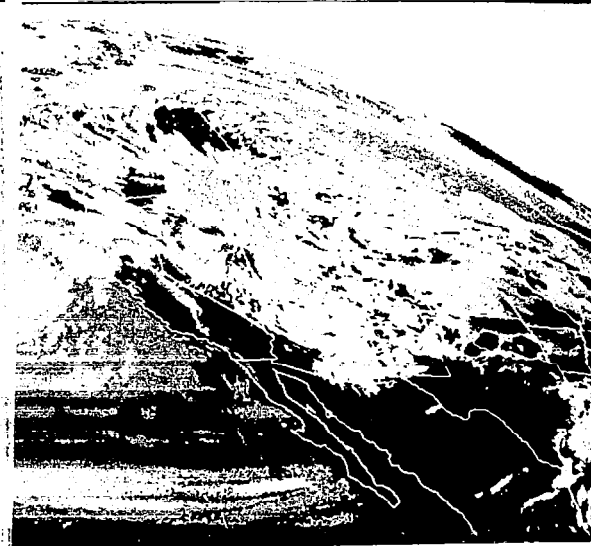
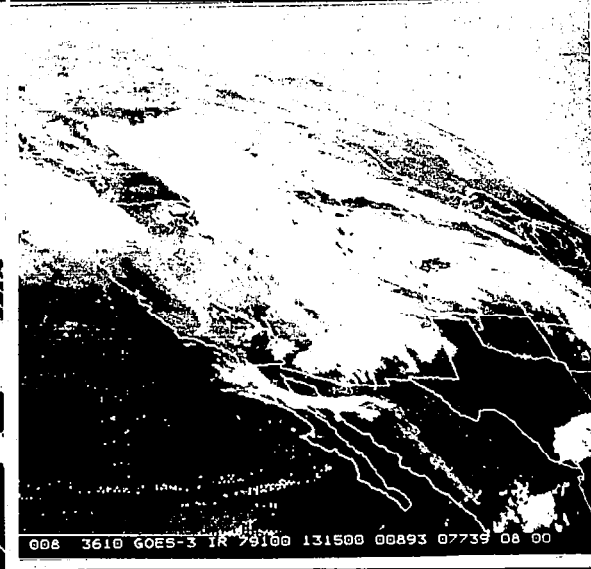
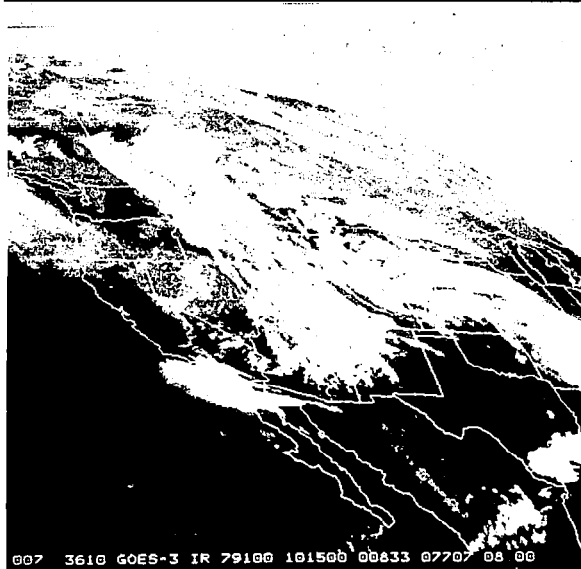
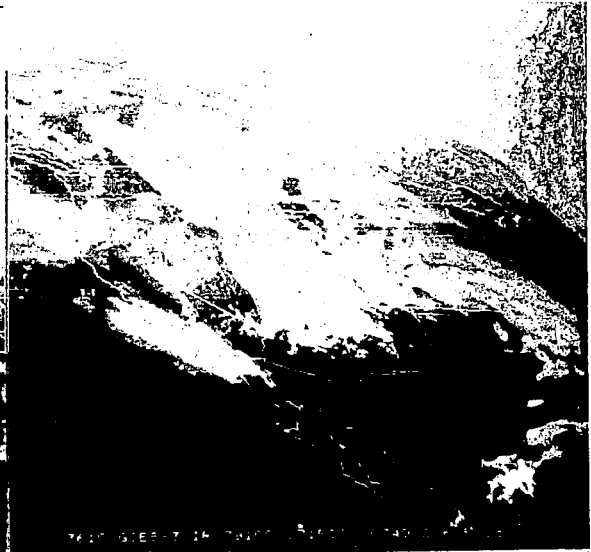
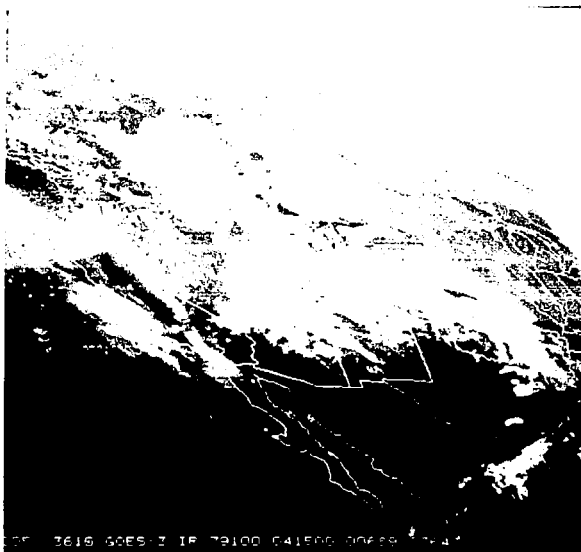
Satellite derived winds from the MSFC automatic system and numerical simulations will be used to examine small mesoscale features important to the initiation of severe convective cells as seen from the GOES visible limited-scan data. Publication of the results is planned for the "Sesame News" section of the Bulletin of the American Meteorological Society.

Recommendations for New Research:

The use of the VAS instrument in this type of study is highly desirable. The execution of AVE/VAS will provide the satellite and ground-truth data to validate the VAS instrument performance and provide new mesoscale data to diagnostically and numerically study these types of mesoscale circulations. Improved understanding and prediction of severe storms depends on this type of measurement/research program. Numerical studies of these systems are also needed since it has been shown that the LFM completely smoothed out these important circulations in both the initial conditions and the predictions.

Publications:

Wilson, G. S. 1982: The Structure and Dynamics of Mesoscale Systems Influencing Severe Thunderstorm Development during AVE/SESAME 1. Preprints of the 12th Conference on Severe Local Storms, San Antonio, Texas, 192-196.



Mesoscale Ageostrophic Circulations
Associated With Baroclinic Jet Streaks

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The principal research thrusts during FY82 continued to focus on studies of ageostrophic motion attending jet streak circulations and the development of deep convection. A completed diagnostic study of AVE-IV severe weather events culminated in a physical perspective of the link between mass circulations imbedded within the MCCs and the direct branch of jet streaks (Keyser and Johnson, 1982). Numerical and theoretical work includes: 1) model development and simulations which emphasize studies of the effect of heating and viscous processes on jet streak circulations, 2) study of a model of ageostrophic motion divided into pseudo-geostrophic and pseudo-ageostrophic components that contain explicit degrees of freedom for the effects of diabatic heating and friction, 3) a comparison of numerical simulations of ageostrophic motions forced by heating and friction that were initialized from geostrophic and pseudo-geostrophic states, 4) completion of a study of the effects of the Asselin time filter upon numerical solutions to the linearized shallow-water equations (Schlesinger, Uccellini and Johnson, 1982), 5) a completion of the study of different methods of pressure gradient computations for circulations in the vicinity of sloped terrain (Johnson and Uccellini, 1982) and 6) the study of the depth of the planetary boundary layer and frictionally forced mass transport as a function of the vertical variation of absolute vorticity through pseudo-geostrophic concepts (Panetta and Johnson, 1982).

Some preliminary results from inviscid and viscous simulations of a propagating jet streak in a channel shown in Fig. 1 point towards the subtle but important role of friction in mesoscale ageostrophic circulations. At the 30-hour mark, the max wind of the jet streak is 47 m/sec in a simulation with free atmosphere friction (boundary viscous stresses were not included), while in the inviscid case, the max wind is 43 m/sec. See Figures 1 and 2. Note the area of the winds above 40 m/sec is considerably larger in the viscous experiments. The reason for increased max wind in the viscous experiments is associated with the increased intensity of the ageostrophic motion of the direct and indirect circulations. The magnitude of the viscous meridional component at 30 hours is two to three times that of the inviscid meridional component. Contrary to the expectation that viscous forces in the free atmosphere would simply reduce the intensity of the jet max through diffusion, the effect of friction in this case served to increase the jet max through an intensification of the secondary circulations. The precipitation for separate 6-hour intervals and a cumulative distribution for the 30-hour intervals are shown in Figure 2. Note that the pattern reflects the ascending motion within the direct and indirect circulations of the propagating jet streak and seems reasonable.

Theoretical studies of the planetary boundary layer were conducted to gain insight for the modeling of physical processes within the sigma domain of the hybrid model. The results from the theoretical model that included nonlinear processes establish that the vertical distribution of vorticity is one of the primary parameters that determines the depth and intensity of the mass transport within the planetary boundary layer. Figure 3 contrasts vertical profiles of mass transport for the planetary boundary layer with vorticity increasing with height, constant with height and decreasing with height. Note the mass transport for profile $C=-1$ is twice the Ekman transport ($C=0$). Such situations occur on the anticyclonic side of jets. Theoretical results dictate that the maximum systematic mass convergence within the planetary boundary layer will occur where the advection of vorticity by the viscous component of

the frictionally forced ageostrophic motion is strongest. Along an extended baroclinic jet this will tend to occur immediately beneath the jet core. A rule used by many forecasters for severe weather prediction is that the severe weather develops beneath the 500 mb zero isobaric relative vorticity isopleth. This is the same region in which the model of frictionally forced mass transport predicts maximum convergence within the planetary boundary layer. The results from this work provide a theoretical basis for the empirical rule used by forecasters and for the patterns of severe convection evident in satellite images.

Current Focus of Research Work:

The current focus is the analysis of a series of numerical experiments contrasting geostrophic and pseudogeostrophic initialization and mass-momentum adjustment in the presence of viscous and diabatic processes.

Plans for FY-83:

The principal work during FY-83 will be to complete a series of numerical experiments for the study of mesoscale ageostrophic circulations of propagating jet streaks and severe weather. The use of geostrophic and pseudogeostrophic initialization provides a means to include ageostrophic motion in fields determined from indirect sensing of temperature by satellites and to retain vertical motion in initialized fields for mesoscale models. In these efforts, the importance of ageostrophic motion in initialized fields for the 0-6 hour prediction of precipitation is being analyzed along with the study of the components of ageostrophic motion that force the development of severe storms.

Recommendations for New Research:

The structure and evolution of ageostrophic motion associated with mesoscale mass-momentum adjustment, precipitation and severe weather events should be assessed in order to ascertain the amount and quality of information needed for successful numerical weather prediction at the mesoscale. The effort to assimilate VAS satellite and conventional data in mesoscale weather prediction will be exceedingly difficult. Particular emphasis should be devoted to ascertaining both the strengths and limitations of conventional and satellite information for initialization and prediction of the mass-momentum structure at the mesoscale.

List of Publications Prepared since June 1981:

- Johnson, D. R. and L. W. Uccellini, 1982: A comparison of methods for computing the sigma coordinate pressure gradient force for flow over sloped terrain. Conditionally accepted for publication in the Monthly Weather Review.
- Keyser, D. A., and D. R. Johnson, 1982: Effects of diabatic heating on the ageostrophic circulation of an upper tropospheric jet streak. Report to NASA on Contract NAS8-33222 (NASA Contractor Report 3497), Space Science and Engineering Center, University of Wisconsin-Madison, 121 pp.
- Panetta, R. L., and D. R. Johnson, 1982: The effects of varying vorticity on Ekman mass transport. (Manuscript)
- Schlesinger, R. E., L. W. Uccellini and D. R. Johnson, 1982: On the effects of the Asselin time filter upon numerical solutions to the linearized shallow-water wave equations. To be published in the Monthly Weather Review.

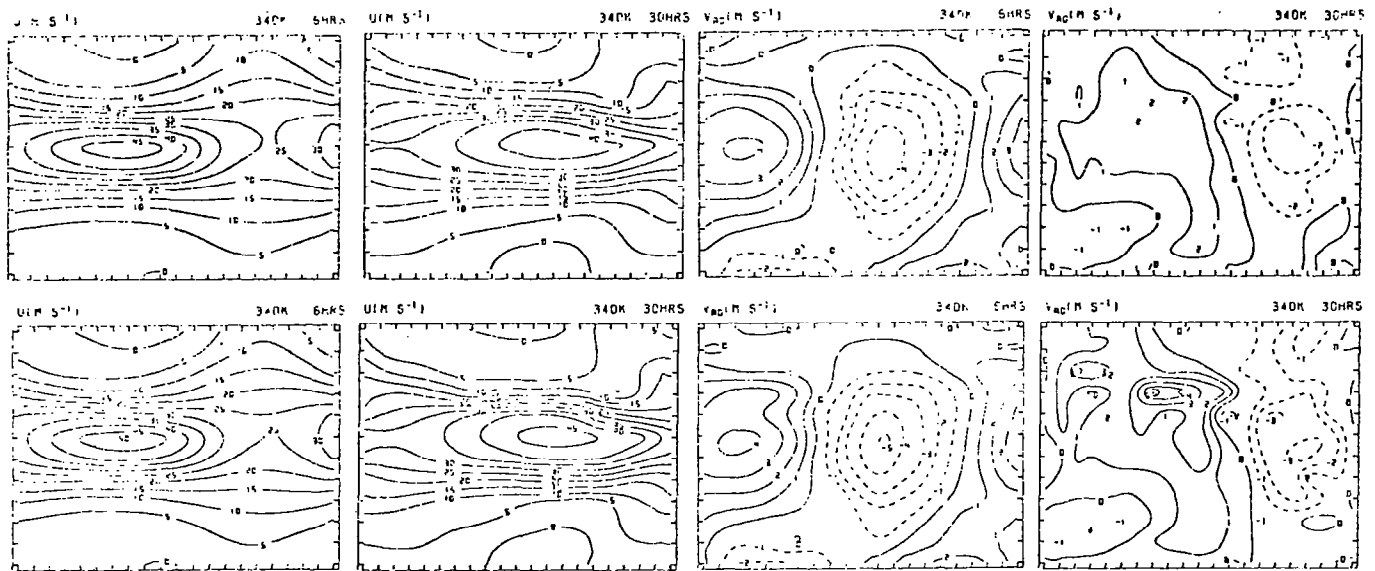


Figure 1. Numerically simulated wind components (ms^{-1}) at 340 K from adiabatic inviscid (top row) and adiabatic viscous (bottom row) experiments: Zonal component (u) at (a) 6 hours and (b) 30 hours; meridional ageostrophic component (v_{ag}) at (c) 6 hours and (d) 30 hours.

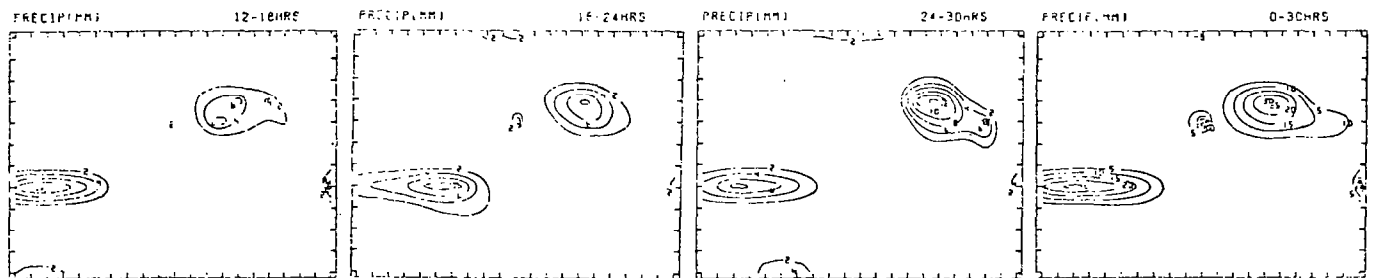


Figure 2. Numerically simulated cumulative precipitation (mm) for (a) 12-18 hours, (b) 18-24 hours, (c) 24-30 hours, and (d) 0-30 hours from the hybrid model.

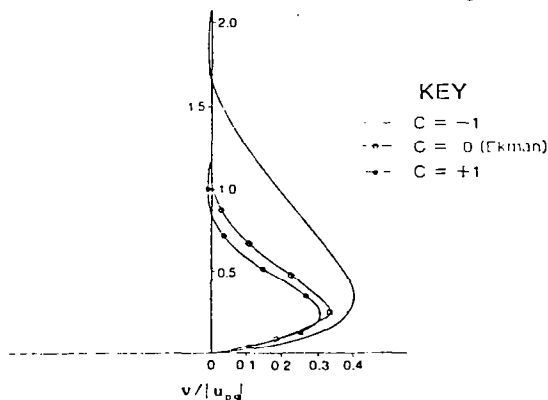


Figure 3. Scaled vertical profiles of ratio of transverse component of velocity within planetary boundary layer to magnitude of pseudo-geostrophic velocity [$U_{pg} = (\zeta_r + f)^{-1} k \times \nabla \theta(\zeta + k)$]. Parameter C is ratio of relative vorticity at top of boundary layer to the earth's vorticity. Ekman solution is given by ζ_r/f equal to 0. (from Panetta & Johnson, 1982)

TITLE: Numerical Simulation of Diabatically Forced Mesoscale Circulation

RESEARCH INVESTIGATOR:

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Atmospheric Sciences Division
Marshall Space Flight Center, Alabama 35812
(205) 453-1944

SIGNIFICANT ACCOMPLISHMENTS FOR FY-82

FY-82 marked the inception for this research activity directed toward the numerical simulation of moist mesoscale phenomena in the atmosphere and how they interact with the synoptic flows in which they are embedded.

The initial accomplishment of this project was to define the research objectives and to select an existing modeling system with which to meet these objectives. In summary the goals defined were:

- Investigate the evolution of unbalanced flow in mesoscale flows as a response to increased detail in initial moisture and temperature fields. Particular attention will be directed toward assessing the impact of VAS enhancement of initial data and expectations for improved precipitation modeling.
- Examine the energetics of interactions between subgrid convective processes and grid scale (> 250 km) features.

Methodology for achieving these goals is described in later discussions.

The Drexel University Limited Area Metascale Prediction System (LAMPS) was selected as an appropriate research tool and efforts have begun to implement the computer codes on MSFC's IBM system. To date, an IFTRAN language preprocessor necessary to run the LAMPS codes has been brought up, and a graphics routine to display model output is nearing implementation.

CURRENT FOCUS OF RESEARCH:

At present, debugging work is proceeding on the graphics package and should be finished in September. Implementation of a routine to process model history tapes (i.e., a graphics routine driver) is proceeding.

PLANS FOR FY-83:

Implementation of codes to perform preparation of initial data as ● well as the primitive equations model and its required utility routines

will begin around September and may require on the order of six months to complete.

Concurrent with this programming effort will be selection and preparation of data for preliminary model experiments. Initial diagnostic investigations with an AVE/VAS data set will examine the origin and maintenance of divergent motions in heated flows and their relationship to the evolving moisture field. Subsequently, a set of model simulations with: (1) no initial moisture, (2) rawinsonde initial moisture only, and (3) VAS/rawinsonde initial moisture fields will be conducted. Diagnostics of modeled flow fields and precipitation will then be compared to those obtained from the verifying data. Specific questions to be addressed will include:

1. Impact of initial moisture structure on the subsequent development of model divergent and ageostrophic winds (via kinetic energy analyses partitioned into divergent and non-divergent components).
2. Comparisons of diagnosed and model induced convective influences on the grid scale flow.
3. Sensitivity of modeled precipitation to initial moisture structure.

Communication and exchange of results between MSFC and two modeling groups at the University of Wisconsin is planned. Dr. Dave Houghton is presently involved with inserting satellite derived winds into the LAMPS model. Dr. Bill Smith and collaborators will be utilizing AVE/VAS data sets in conjunction with a recently implemented regional scale model.

RECOMMENDATIONS FOR FUTURE RESEARCH:

Investigation beyond 1982 will focus on sensitivity of model performance to initial data sets augmented by VAS. Studies will also expand to enhancement of mass and motion fields. Parallel studies to ascertain model weaknesses and ramifications toward (1) model capability to effectively use satellite enhanced data sets, and (2) ability to simulate certain phenomena (i.e., mesoscale instabilities) should also be conducted.

Title: MEDIUM-RANGE OBJECTIVE PREDICTIONS OF THUNDERSTORMS ON
THE McIDAS/CSIS INTERACTIVE COMPUTER SYSTEM

Research Investigator: Gregory S. Wilson/ES84
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Telephone (205) 453-2570

Significant Accomplishments in FY82:

Accomplishments in FY82 were in three areas; 1) objective verification, 2) operational implementation on the McIDAS/CSIS system, and 3) real-time subjective evaluation by NWS forecasters and scientists at NSSFC. Critical-success-index objective verification statistics from LFM/MDR history data show the LFM derived predictions range from CSI values of .5 to .3 for 12-h and 48-h thunderstorm/severe weather predictions during Spring and Summer. For improved display, animation, and subjective verification, the model is currently run operationally on the McIDAS/CSIS computer for scientists at NASA and NSSFC (see Figs 1 and 2 for examples). The limited subjective verification provided by NSSFC has lead to minor changes in the product presentation and schedule. Overall, it has been concluded in FY82 that this product will provide new and needed guidance for severe weather prediction, from 12-48 hours, for the NSSFC convective outlook.

Current Focus of Research Work:

Consistent operational execution of the model on the McIDAS/CSIS computer system remains a problem. Improving product reliability from ~70% to above 95% is currently underway.

Plans for FY83:

Significant improvements to the model will be made by adding boundary layer shear effects and correcting predictions where strong "over-running" produces storms where the PBL is stable.

Recommendations for New Research:

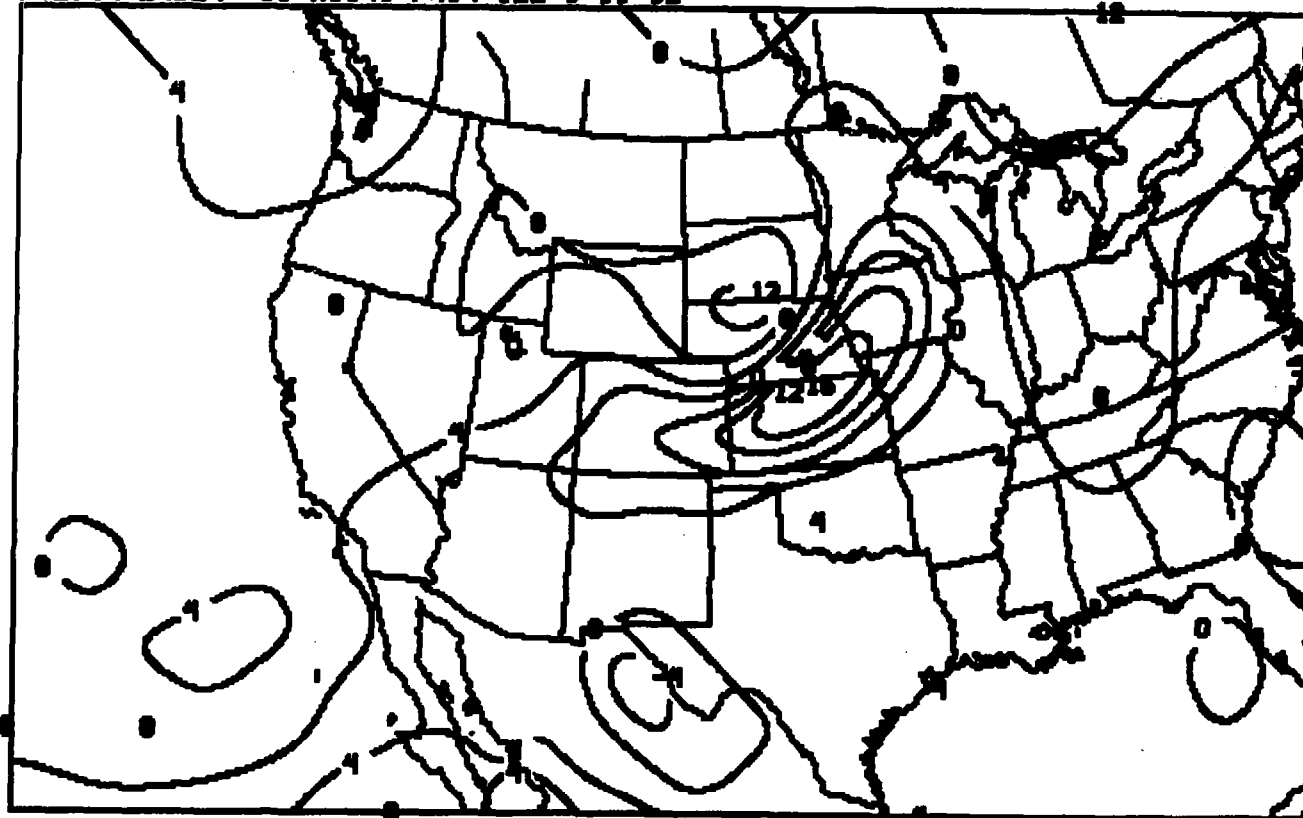
Incorporation of this product as a regular part of the CSIS/NSSFC system is recommended. Also, improvements in the numerical model predictions, either from better initialization using satellite data and/or from new mesoscale models will directly improve the performance of this longer-range thunderstorm prediction system.

Publications:

Wilson, G. S. , 1982: Medium-Range objective predictions of thunderstorms on the McIDAS/CSIS interactive computer system. Preprints of the Ninth AMS Weather Analysis and Forecasting Conference, Seattle, WA, July 1982.

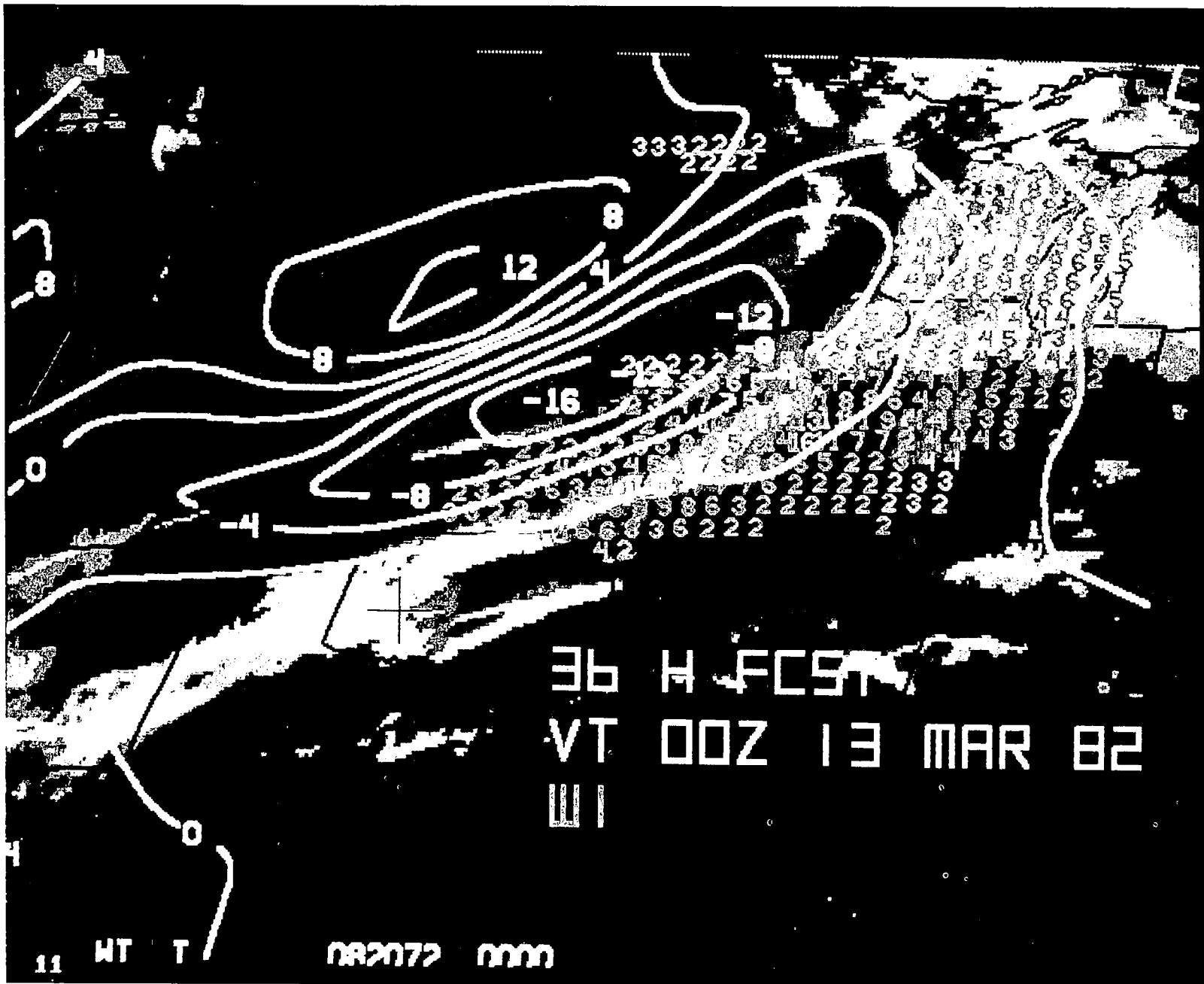
Wilson, G. S., and R. E. Turner, 1982: Objective Predictions of Thunderstorm Location and Severity for Aviation. Journal of Aircraft, 19, 330-338.

MILSON INDEX 36 HOURS FROM 12Z 3-11-92



117

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Title: Cooperative VAS Program with MSFC

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Significant Accomplishments FY82:

In the past fiscal year, the SSEC has: 1) provided MSFC (through their user terminal access to the McIDAS) with processed data which includes TIROS and VAS soundings, GOES cloud winds, and conventional weather products, 2) conducted demonstrations to familiarize MSFC with VAS data processing and products and has discussed the utility of these data products toward depicting and predicting outbreaks of severe weather, and 3) viewed the AVE/VAS data sets in real time jointly with MSFC (from February 6, March 6, March 27, April 24 and May 1 of 1982). They are now being processed to determine the accuracy of the VAS temperature and moisture profiles by comparisons between VAS, TIROS, and RAOB soundings.

Soundings from March 6 have been transferred to MSFC and the ground-based data has been transferred to SSEC. March 6 has received the most attention to date because the AVE/VAS network documented, with three hourly measurements, a mesoscale event consisting of a rapidly moving temperature perturbation with strong horizontal wind shear but shallow vertical extent. The event occurred behind a cold frontal cloud band in clear conditions and thus allows testing of the retrieval algorithms without cloud contamination and with good ground truth. VAS was found to be able to delineate this mesoscale event. It was shown that the nominal retrieval resolution (75km) over-smoothed the thermal gradients in this

case. Single pixel soundings provided much closer agreement with the special network observations. The sensitivity of VAS retrievals to the surface skin temperature and the first guess were also investigated. Improvements in the skin temperature estimate within the retrieval using radiative transfer are under investigation.

The remaining AVE/VAS days are now receiving attention; from working with March 6, it is obvious that a superior data set is available which will enable research of more reliable techniques.

Plans for FY83 and New Research

It is proposed to supplement the existing cooperative VAS program with a nowcasting program for severe storms. This VAS nowcasting exercise will evaluate the importance of VAS data in the subjective/manual and objective/statistical procedures for making short-range predictions. Data from the AVE/VAS days and several interesting VAS days (collected in the transparent VAS mode of operation) will be scrutinized and a post real-time review and optimization of the VAS products will be performed. Statistical models for predicting the areal probability distribution of severe weather will be researched extensively. Newly developed objective methods for forecasting severe weather will be evaluated with the assistance of the Kansas City NOAA forecasters.

Papers (since June 1981)

Hayden, C.M., 1982. Vas Temperature Retrievals for NASA Special Network Observations of March 6, 1982. Presentation at VAS Science Workshop at Goddard Space Flight Center on June 17, 1982.

Title: Mesoscale Initiation of Cumulus Convection
Using VAS Data

Researcher: G. D. Emmitt
USRA Visiting Scientist
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Significant Accomplishments in FY 82:

The primary objective of this research is to investigate the role of meso- γ /convective scale boundary layer convergence in the initiation and enhancement of significant cumulus convection. The research plan includes the use of 3-D mesoscale numerical model, a 1-D cloud model, VAS soundings, rawinsonde soundings, surface data and VISSR products for verification. This past year, the 3-D meso-model (Pielke, 1974) has been acquired and implemented on the NASA/MSFC's IBM 360 computer. This is the first time the model has been run successfully on a non-CDC/CRAY system. Initial model runs have been for Cape Kennedy, Chesapeake Bay area, and central Texas. A 1-D cloud model (Wisner, Orville, and Myers, 1972) has also been obtained for execution on the HP-1000 system. Near real time VAS sounding retrievals, overlaid on the conventional data sets, are now possible through the NASA/MSFC's McIDAS system. The next step is to integrate these various components into an analysis strategy that will lead to a better understanding of boundary layer control of initial convective development.

Current Focus of Research:

Presently, an effort is being made to develop an optimal strategy for using VAS soundings in a simple numerical cloud model. A basic assumption is that the temporal and horizontal information available from VAS offsets any information that is lost in the vertical. Using standard rawinsonde data with the VAS data has been adopted as the best available technique for obtaining both vertical and horizontal information.

Planned Future Research:

A proposal is made to study boundary layer storm initiation by combining the new temporal and horizontal information available from the VAS with the convective scale convergence estimates available from a numerical model to initialize a simple cloud model, whose predictions can be verified with normal VISSR imagery. Recognizing the imprecision in the numerical model physics, VAS soundings, rawinsondes, etc., and analysis approach using many cases (\approx 500-1000) is recommended. The success in demonstrating physical understanding will be expressed in statistical terms based upon a sufficient number of independent events rather than just a few case studies. Non-linear statistical techniques will be used when appropriate.

References:

- Pielke, R. A., 1974. A three-dimensional model of the sea breezes over south Florida. Mon. Wea. Rev. 102, 115-139.
- Wisner, C., H. D. Orville, and C. Myers, 1972: A numerical model of a hail bearing cloud. JAS, 29, 1160-1181.

TITLE: Applications of Satellite Soundings in Numerical Simulation of Clouds

RESEARCH INVESTIGATORS:

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SIGNIFICANT ACCOMPLISHMENTS FOR FY-82

Numerical models of varying capabilities and complexities have been used by many researchers to test hypotheses on formation and growth of convective clouds. Even though the processes simulated in a model may be very complex, the quality of the results obtained from the model are very much dependent on the initial conditions used to describe the environment in which convection is to be modeled. Most of the convective cloud models use an atmospheric sounding describing the vertical structure of temperature, moisture and wind fields as input data. As the cloud models usually do not try to simulate the mesoscale variations of the environment, it is important that the initial conditions represent as best as possible the air mass whose convective properties are to be investigated. In this respect soundings obtained from satellite-borne instruments could prove of great value due to their high spatial and temporal resolutions. To see whether satellite soundings could be used to effectively simulate convective activity, data obtained from VAS (VISSR Atmospheric Sounder) is used here as initial conditions to the two-dimensional time-dependent cloud model developed at the Institute of Atmospheric Sciences, S.D. School of Mines and Technology. The cloud model is described in more detail in 'Numerical Simulation of the Life History of a Hailstorm' by Orville and Kopp (J. of Atmos. Sc., Vol. 34, #10, 1977, pp. 1596-1618.).

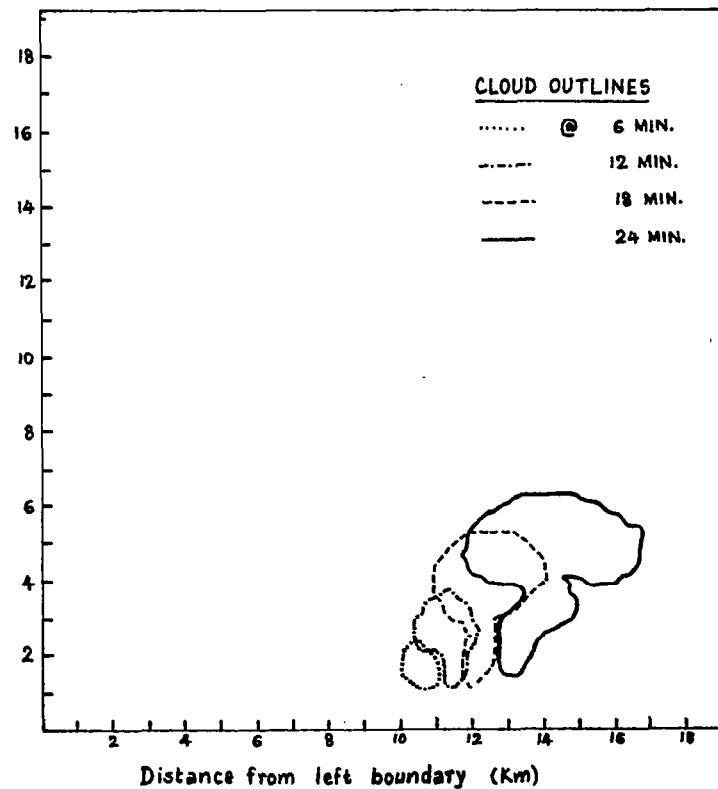
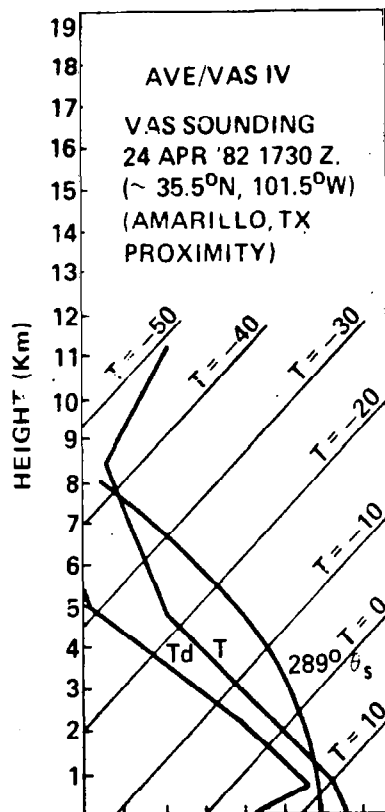
A VAS sounding at 1730 Z, 24 April 1982 over Texas is used as initial conditions to the model. A mesoscale convergence of strength 2×10^{-5} /sec is used in the lower levels of the model. This value for mesoscale convergence has been derived from surface wind observations. Perturbations in the temperature and moisture fields are applied near the surface to initiate convection. Figure shows the sounding used and the cloud predicted by the model at various stages of its development. The model cloud shows very good correlation to the clouds observed that day. The cloud size and cloud top heights are well simulated. The natural clouds and the model cloud show freezing near cloud tops. Precipitation appeared in the model cloud but did not reach the ground. This matches well with the observations.

CURRENT FOCUS OF RESEARCH:

More model runs using satellite soundings representing different environments are planned to further test the use of such soundings as input data to the cloud model.

RECOMMENDATIONS FOR FUTURE RESEARCH:

One should remember that satellite soundings do lack the vertical resolution which are obtainable from rawinsonde soundings. Model runs using satellite soundings should be compared to those using the corresponding rawinsonde soundings to determine the effects of the coarser vertical resolution of VAS data. In many cases the advantage of obtaining a sounding very close in time and location to convection would outweigh the coarser vertical resolution. The cloud model should be modified so that the boundary conditions are made dependent on the 'background environment' (the environment outside the model domain) also. In the course of a simulation occasional soundings obtained from satellite sounders can then be used to update the sounding representing the background environment which the model uses. In this way the convective scale model could be made to feel the mesoscale environment better.



HISTORY OF A TYPICAL CONVECTIVE CLOUD PREDICTED BY THE I A S TWO-DIMENSIONAL TIME-DEPENDENT CLOUD MODEL, IN AN ENVIRONMENT SPECIFIED BY A VAS SOUNDING AND A CONVERGENCE FIELD OF STRENGTH $2 \times 10^{-5}/\text{sec}$.

TITLE: Numerical Simulation of Tornado-Like Vortices

RESEARCH INVESTIGATOR: Dr. Fred Leslie
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SIGNIFICANT ACCOMPLISHMENTS FY82:

During this time period a numerical model in cylindrical coordinates was developed to investigate the behavior of tornado-like vortices in a laboratory simulator. Modeling the simulator rather than the actual natural phenomenon has the advantages of laboratory measurements to compare with in order to validate the code, and easily evaluated boundary conditions. In addition, the present interest lies in a mechanically driven vortex whose morphology depends on certain nondimensional parameters which have been matched to atmospheric conditions. The most relevant parameter is the swirl ratio S which may be thought of as a measure of the imposed circulation relative to the volume flow rate through the convective system. It is proportional to the fluid inflow angle with respect to a radial. As this parameter is varied from zero to unity the vortex structure changes from a thin laminar vortex, to a fully turbulent one with a central downdraft, to a multiple vortex system.

A second governing parameter is the aspect ratio which relates the depth of the inflow (or height of the inversion) to the updraft radius. Although the behavior of the vortex is less dependent upon this parameter, it is important that its value be within certain limits in order to model the natural event and produce tornado-like vortices. Finally, the Reynolds number relates inertial to viscous forces. Because of the differences in scales, this number cannot be matched. However, it turns out that the Reynolds number is unimportant for the large values used in both the numerical simulations and in nature.

The numerical model solves the fully nonlinear, viscous, primitive equations for an incompressible axisymmetric fluid. Employing finite-difference techniques on a 32 x 62 staggered and stretched grid, the code predicts velocity and pressure as a function of space and time. Temperature prediction is an option in the program but thermally driven vortices are not considered here. A Poisson equation for pressure is formed by taking the divergence of the momentum equation and solved iteratively using ADI. The leap-frog scheme is then used

for time-stepping the velocity equations. For runs to a steady state, the time step was varied and taken as large as the CFL stability limit would allow.

The boundary and initial conditions are as follows. At the bottom surface a no-slip condition is used for the velocities. At the center of the vortex (the left boundary of the computational domain), the radial and tangential components are zero while a symmetry condition is applied to the vertical component. The right side of the domain is divided in two: a lower region where the inflow occurs and a quiescent region above. On the former, the radial and tangential velocities are specified, while the vertical velocity boundary condition is one of symmetry. Above this inflow region, the radial velocity is zero and the other components have free-slip. On all of these boundaries the pressure boundary condition is determined from the pertinent equation of motion evaluated at the particular boundary. At the top where the outflow occurs, the radial component is zero and the vertical component has symmetry. The boundary condition on the tangential velocity is $V_{ZZ} = 0$ if $w > 0$ (to avoid having to resolve an unimportant boundary layer) and $V = 0$ if $w < 0$ (to avoid introducing vorticity from the boundary). The pressure at the top is determined by integrating the radial momentum equation. Except for the specified inflow and tangential velocity all velocity components are zero initially.

The evolution of the flow which produces a vortex is of much interest. Shortly after start the meridional circulation develops and the streamlines change very little qualitatively thereafter. The flow enters the domain from the lower right, turns up as it approaches the axis, and then flows out of the system. This circulation carries angular momentum into the domain from the source at the lower right boundary. Although angular momentum is not completely conserved due to viscous dissipation, the tangential velocity begins to increase rapidly as the fluid flows to smaller radii. During this time, the surface pressure begins to fall. After several seconds of experiment time a concentrated columnar vortex forms on the axis and a steady flow is achieved.

Details of the steady state profiles for the velocity are dependent on the swirl ratio imposed but persistent patterns are observed. The radial velocity is highest at the inlet and generally decreases inward. In some cases where there is a strong adverse radial pressure gradient the flow separates from the lower surface and reattaches downstream. Most of the inflow into the vortex core comes through the surface layer where cyclostrophic balance is destroyed by friction.

The tangential velocity near the surface away from the core resembles a potential vortex while the core itself rotates nearly as a solid body (i.e. a Rankine-combined vortex). Far from the axis of the vortex the tangential velocity is independent of height. When the swirl ratio is increased the radial position of the velocity maximum (and by definition the core radius) increases. The vertical position is relatively low to the ground where the fluid approaches close the axis. The height of the velocity maximum also diminishes with increasing swirl so that as the ambient circulation is increased, the location of the velocity maximum gets closer to the ground and increases in magnitude. It is not obvious that the tangential velocity should increase with swirl ratio. Although the ambient circulation is certainly larger, so is the maximum radius to which the flow converges.

The vertical velocity is upward through the system for $S \leq 0.2$. When the swirl ratio is increased, an axial downdraft develops aloft and inside the core of the vortex. This may be interpreted as vortex breakdown where a stagnation point appears on the axis and separates the updraft from the downdraft. As swirl is increased further, the stagnation point descends to the surface and the meridional flow exhibits a two-cell structure - downdraft along the axis to the surface turning upward at the core radius. At higher values of the swirl ratio the radial extent of the downdraft increases along with the core radius.

The surface pressure profiles show slightly increasing pressure approaching the central region. This is due to the radial velocity component decelerating while the tangential velocity is still rather small. Near the vortex core, the tangential velocity increases dramatically and the surface pressure begins to drop reaching a minimum on the axis. The shape of the radial pressure profile agrees qualitatively with the analytic solution for a Rankine-combined vortex with inflow. As the swirl ratio is increased the magnitude of the radial pressure drop also increases. This could account for the onset of the central downdraft. When the tangential velocity reaches very large values the central surface pressure falls until the axial pressure gradient reverses or becomes less than the hydrostatic value.

CURRENT FOCUS OF RESEARCH WORK:

Presently efforts are being made to compute the time evolution of the vertical vorticity and its spatial distribution. The terms of the vorticity equation are also being evaluated to identify the vorticity sources for producing and maintaining the vortex core. Preliminary calculations show that most of the vorticity is concentrated within the (solid body) core while the far field is almost irrotational. The horizontal vorticity produced by the vertical shear in the

boundary layer is tilted upward, amplified by stretching, and carried aloft by vertical advection.

PLANS FOR FY83:

Work for FY83 will include completing the calculation and interpretation of the vorticity fields. In addition, the influence of the roughness of the lower surface will be investigated by incorporating a drag coefficient into the bottom boundary condition. In this manner the effects of various frictional surfaces on the dynamics of tornado-like vortices can be parameterized and examined systematically. Transient effects are of particular interest such as when a steady state vortex suddenly traverses a region of increased surface drag.

Title: Interactive Meteorological Computer Support

Research Investigators: Frederick R. Mosher
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Significant Accomplishments in FY 82:

The McIDAS interactive video terminal has been in operation for over a year and has become a significant resource used by several different programs. The terminal is used continually during normal working hours, except for special projects such as the Shuttle Support Mission when it was used 24 hours a day. The terminal is being used in support of real time activities such as the Shuttle launch support and vectoring the U-2 flights toward thunderstorm activities, etc; in support of research activities such as analysis of lightning location data, VAS and Special Network data evaluation, etc.; and for miscellaneous support activities such as enhancing photographs of the lost Shuttle booster, etc.

Current Focus of Research Work:

The current MSFC McIDAS development effort is to expand the support in order to serve a larger user community. This is to be accomplished by installing a Harris /6 Applications Processing (AP) computer in MSFC, along with a second McIDAS terminal. The AP computer will be connected via a dedicated 9600 baud phone line to the IBM Data Base Manager (DBM) computer at the University of Wisconsin-Madison. The new McIDAS terminal will be the same type as the ones installed at the National Severe Storms Forecast Center (NSSFC) as part of the Centralized Storm Information System (CSIS) program. This expanded McIDAS system will allow more user access to the terminals, an in-house McIDAS programming capability, improved response from the terminals, and an opportunity to develop products and techniques which can be easily transferred to the NSSFC for operational testing and use.

Plans for FY 83:

During the next year the new terminal will be built; the Harris /6 computer will be reconfigured to act as a remote AP computer; data exchange protocols will be developed; and the system will be installed at MSFC. The new terminal will be a copy of the CSIS terminals, with enhanced capabilities as compared with the current McIDAS terminal (more frames, more graphics, more colors available on the graphics, "razzless" TV loads, faster graphic erase, large screen TV monitor, etc.). The Harris /6 computer will be a NASA owned computer transferred from Wisconsin to MSFC. It will have three 80 MB disks, a tape drive, interactive programmer terminals, and the two interactive video McIDAS terminals. The computer will be capable of acting as a stand-alone processor or as a remote applications processor connected to the University of Wisconsin. The link to Wisconsin will be developed so that transfers of satellite images can be made along with supporting files such as navigation, conventional data, etc.

Recommendations for New Research:

The data exchange capabilities between MSFC and the University of Wisconsin should be expanded to include the NSSFC in Kansas City and the World Weather Building NESS, VIRGS, and IFFA, so that developments at MSFC can be demonstrated at the facilities supporting operational severe weather forecasting. This would enhance the transfer and acceptance of these development activities.

Title: Mesoscale and Severe Storms (MASS) Data Management & Analysis System

Research Investigators: John S. Hickey, Shogo Karitani, Mike Dickerson

Atsuko Computing International (ACI)
Huntsville, AL 35801 (205/533-7590)

Significant Accomplishments FY82:

Data Base Management: An AVE data base management software package has been developed and used extensively to convert various AVE-type experiment data into a standard format and store the data into a random access disc file making the data readily accessible to the general purpose plotting and analysis software packages.

Analysis and Display: An interactive hardware/software computer system has been successfully implemented and utilized daily by atmospheric scientists to graphically display and analyze large volumes of conventional and satellite derived meteorological data. Utilizing the analysis and display software package the user can process interactively various AVE-type data (25-mb, Single Level, Grid, Image).

Current Focus of Research Work:

Currently the analysis and display software is being modified to provide for a task scheduler which links the various software programs together thus allowing each to share common data and user input, thereby reducing overhead, optimizing execution, and enhancing the user's flexibility, useability, and understandability of the total software capabilities.

Plans For FY83:

Software Modification--

- o Continue modifications to the data base management software on the HP-1000F computer to process severe storm sounding, single level, grid, and image data.
- o Provide a detailed user-manual of the Data Base Management and Analysis and Display software to assist any scientists using these packages.
- o Integrate the management of the four data types (sounding, single level, grid, image) with the disk, plotting, and video hardware capabilities on the SSL HP-1000F computer.

Hardware Modification--

- o A Perkin-Elmer 3252 and Harris/6-McIDAS computer are to be installed into our current system which will allow for interactive image-processing and numerical weather research related to the use of satellite imagery and soundings.

Recommendations For New Research:

To modify existing AVE-type software and data bases to be easily accessible and useable by the planned integrated HP-1000, Perkin-Elmer 3252 and McIDAS-Harris/6 computer system. In addition the software and data should be made available for access by the Cyber 205 at GSFC.

 ** MASS ANALYSIS & DISPLAY SOFTWARE **

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| AVE50 -- Task Scheduler |
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| Categories: |
| 1. 25-mb Data |
| 2. Single Level |
| 3. Grid Data |
| 4. Image Data |
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| Data Case: |
| 1. AVE/AVESS |
| 2. AVE/SESAME |
| 3. AVE/VAS |
| 4. Other |
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| AVE60--25-mb | | AVE70--S Lev | | AVE80--Grid | | AVE90--Image |
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| Groups: | | Groups: | | Groups: | | Groups: | |
| 1-Rawinsond | | 1-Surface | | 1-Basic | | 1-Satellite |
| 2-Satellite | | 2-Old Winds | | 2-Derived | | 2-Radar |
| | | | 3-Precip | | | | 3-TBD |
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*TBD

*TBD

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| AVE71 |
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| B Map |
| Plot |
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| AVE61 | | AVE62 | | AVE63 | | AVE64 | | AVE65 | | AVE66 |
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| Skew T | | W Spd | | W Vec | | W Dir | | Sound | | B Map |
| Plot | | Plot | | Plot | | Plot | | Print | | Plot |
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NASA/MSFC FY-82 Atmospheric Processes Research Review

Variational Analysis with Satellite Data Project (VASP)

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SIGNIFICANT ACCOMPLISHMENTS FY-82:

The award for this grant has not yet been received. However, we are proceeding to collect and edit data and have begun developing the model theory.

CURRENT FOCUS OF RESEARCH WORK AND PLANS FOR FY-83:

The first year of research leading to the diagnosis of cyclones is just getting underway and will be largely devoted to the selection of cases, gathering and editing the data, and developing the techniques for maximizing information content of satellite data and rawinsonde. The criteria for the selection of case studies for VASP is as follows:

1. There must be retrieval data from at least two polar orbiting satellites equipped with microwave sounders.
2. The studies should focus on major cyclones with extensive non-convective precipitation systems.
3. AVE rawinsonde data sets consisting of rawinsonde data collected over large regions with greater temporal and spatial resolution are needed for the evaluation of parts of the variational theory.
4. The study should be restricted to areas where there exists a dense network of rawinsonde data to allow comparisons with analyses obtained with satellite soundings.
5. The study should be restricted to areas where there are no pronounced orographic or diabatic boundary layer forcings that can greatly complicate the analyses.

Requirement 1 was met by TIROS-N and NOAA-6 from 6-27-79 through 2-27-81 and by NOAA-6 and NOAA-7 from 6-23-81 through the present.

Requirement 2 was met by concentrating the search for case studies on the cold season which extends approximately from 1 October through 15 April.

The fourth and fifth requirements were met by restricting the analysis area to the area between the Rocky Mountains and the Appalachian Mountains.

However, the third criteria was not met. AVE data with single satellite coverage (TIROS-N) was available for SESAME I. The major cyclone did not move out of the Rockies until after the cessation of AVE. The 10-11 April 1979 SESAME I AVE day was selected as a case study day because of the need to have the greater temporal and spatial resolution rawinsonde data necessary for testing the algorithm that estimates the tendency terms which are explicit in the variational formulations.

A second case study period is required in order to apply the variational method to energetics studies of the cyclone. A search of the Daily Weather Map series published by the Department of Commerce for the periods 1 October 1979-1 April 1980; 1 October 1980-27 February 1981; and 1 October 1981-15 April 1982 when there was dual satellite coverage has provided seven cyclones that satisfy the four remaining criteria. After consultation with other members of the cyclone working group (Dr. George Fichtl, Dr. Phil Smith, and Dr. John Clark) the number of possible case studies has been reduced to three. The quality and amount of available data is being investigated before a final decision will be made. The possible case studies include two moderate and one intense cyclone; 29 October-1 November 1979, 29 November-1 December 1981, and April 2-4, 1982.

Once the case study selection process is completed, the data will be gathered and edited, the data will be analyzed apart from the variational model, the variational model theory will be developed and we will develop a time to space conversion scheme to present the satellite sounding data at the synoptic times.

SESSION V

LIGHTNING

NASA's Lightning Research Program includes work that is directed toward the development of a satellite sensor that will detect and locate lightning from geostationary orbit and basic research that seeks to understand the relationships between large storm systems and lightning activity. These studies consist of (1) the lightning mapper development activity, (2) analysis techniques used for the detection and location of lightning events during daylight hours, (3) ground-based experiments to characterize each storm and to improve the ability to interpret data obtained from the U-2 aircraft, (4) efforts directed toward understanding fundamental relationships between storm systems and electrical activity in conjunction with the space sensor, (5) activities focused on RF studies utilizing ground strike location networks, interferometers, ELF, UHF, and slow antenna systems, (6) remote sensing RF systems used in the study of hurricanes, tornadoes and other severe storm systems, (7) RF data correlated with conventional meteorological data sets, doppler radars, satellite data, and measurements acquired during U-2 aircraft operations.

Hugh Christian

TITLE: Thundercloud and Lightning Observations Made from Above
Cloud Tops in Connection with NOSL

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Significant Accomplishments:

Observations of thunderstorms made at night from a high altitude are providing new information on characteristics of lightning discharges in the upper part of the cloud and on the convective structure of thunderclouds.

Although none of the photographs thus far either from the U-2 or from the space shuttle has provided evidence of discharges extending vertically up into the stratosphere, photographs from the U-2 commonly show regions of sharp lightning channels. In most cases, the lightning channel bridges folds in the upper convective cloud surface and extends out of the cloud through clear air back into the cloud again. In other cases, somewhat less frequently, the lightning spark is observed to terminate in the clear air, decreasing in width to a fine filament that then disappears. In such cases occasional dendritic structures are also observed.

Because these lightning structures in the upper part of the cloud do not appear to cast strong illumination on nearby cloud surfaces, it appears that the intensity of these discharges is probably far less than the lightning channels commonly seen beneath the cloud or in the lower portion of the cloud.

Thus far none of the photographs taken either from the NOSL experiment on STS-2 or on STS-4 has shown clear evidence of lightning channels in the storms below. If the lightning that has been photographed from the shuttle is similar to that observed from the U-2, this is not surprising, for the wide angle lens used in all the nocturnal lightning photography from the shuttle would be incapable of resolving the short and weak channels of the sort observed from the U-2.

The photographs taken thus far from the shuttle at night provide very little data on the convective structure of the cloud. This is to be expected because the optical system would scarcely be capable of resolving the fine structure that has been observed from the U-2.

The photographs taken at night from the U-2 by the light of the lightning reveal new details of the structure of the top of the cloud that are not readily apparent from photographs taken during the day. These pictures illuminated by lightning deep within the cloud reveal complexities not readily apparent from photographs taken by daylight. They show that there are many deep folds within the cloud extending to considerable depth that are quite bright at the bottom due to the internal illumination by lightning. These folds separated by something of the order of half a kilometer suggest an extensive structure of downdrafts extending deep into the cloud. If such structures are indeed downdrafts, capable of transporting space charge deep within the cloud, as suggested by ideas of electrification according to Vonnegut (1955: "Possible mechanism for the formation of thunderstorm electricity", Proc. Conf. on Atmos. Electr., Geophys. Res. Papers, No. 42, AFCRC-TR-55-222) and Wagner and Telford (1981: "Cloud dynamics and an electric charge separation mechanism in convective clouds", J. Rech. Atmos. 15, 97-120), the moving surface area of cloud that is transporting charge may be doing so at a rate that is considerably larger than that which has previously been estimated.

Plans for FY 83:

Continue work on reduction from NOSL experiments on STS-4 and STS-6; train new shuttle crew members on use of NOSL equipment; devise improved equipment for future NOSL experiments.

Recommendations for New Research:

In addition to previous recommendations for new research in NASA/MSFC FY-81 Atmospheric Processes Research Review, it is recommended that high altitude balloon-borne

systems be devised and flown to provide more detailed quantitative data on the convective structure of thunderstorms by day and by night.

List of Publications Prepared Since June 1981:

Vaughan, O. H., Jr., and B. Vonnegut, 1982: "Lightning to the Ionosphere?", **Weatherwise** **35**, 2, 70-71.

Vonnegut, B., 1982: "The Physics of Thunderclouds", in **Handbook of Atmospheric**, Vol. 1, edited by H. Volland, CRC Press (Boca Raton, Florida), pp 1-22.

Vonnegut, B., 1982: "Comments on the paper 'The Electrification of Thunderstorms' by John Latham", accepted for publication in **Quart. J. Royal Meteor. Soc.**

Vonnegut, B., 1982: "Deductions concerning accumulations of electrified particles in thunderclouds based on electric field changes associated with lightning", submitted to **J. Geophys. Res.**

Title: Lightning Statistics from U2 Aircraft Research Project

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Significant Accomplishments FY82:

A general statistical analysis of optical pulse sensor data from the summer, 1981 and spring, 1982 U2 flights. This analysis includes the following parameters:

- (1) Number of strokes per flash and amplitude
- (2) Interstroke time interval
- (3) Stroke risetime defined as the time from background level to maximum pulse amplitude
- (4) Stroke width measured by pulse width at the background level
- (5) Amplitude frequency distribution

Current Focus:

Presently, the summer 1982, U2 lightning data is being statistically analyzed. Further analysis will include a detailed look at pulse waveform shape parameters such as half-amplitude pulse width, etc. Development of histograms correlating various parameters is also anticipated. Ground truth lightning data will be used for correlative studies of CG versus IC flash events. Plans for FY83:

Several more U2 flights are expected and will require continued statistical analysis.

Recommendations for New Research:

Spectrometer data should be compared with lightning statistics for purpose of revealing any correlations of flash event characteristics with spectrometer sensor design. Results of this type would have direct bearing on the design of the lightning mapper sensor.

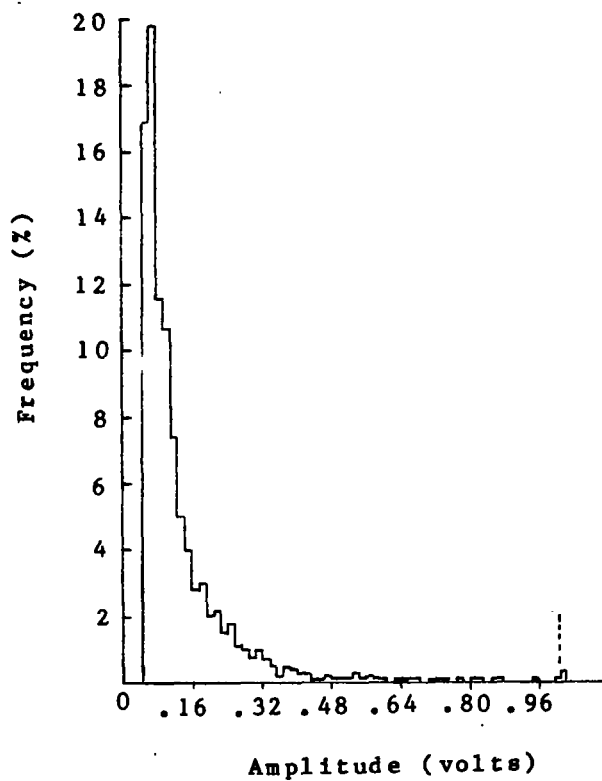


Figure 1: Histogram of lightning stroke amplitude versus frequency of occurrence for the data from Spring, 1982 U2 RTOP field program. The vertical dashed line denotes size category of all strokes greater than 1 volt.

TITLE: Airborne Measurements of Lightning Generated Optical Emissions

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SIGNIFICANT ACCOMPLISHMENTS FOR FY-82

A data and image analysis system has been assembled at MSFC to process lightning generated optical emissions acquired during the U-2 Thunderstorm Overflight Program (TOP). The data analysis system consists of an HP-1000 computer, and Apple III microcomputer, two hard disk drives and two floppy disk drives with a storage capacity in excess of 25 M bytes, a 9-track tape drive, two printers, and a color graphics terminal. This system interfaces with a data acquisition system consisting of a Sangamo-80 14-track instrumentation tape recorder, a high-speed 10-bit A/D converter with a 128 K byte digital storage memory, and a IEEE-488 interface.

CURRENT FOCUS OF RESEARCH:

Five U-2 sorties over thunderstorms, each sortie approximately five hours in duration, were accomplished in May 1982. Of these five flights, two were at nighttime and three during the mid-to-late afternoon. The CCD television camera video imagery and the optical array sensor (OAS) imagery for the May 27 nightflight are being studied initially. On May 27, the U-2 aircraft was tracked by NSSL and aircraft positions were plotted on the WSR-57 radar display. The times of 281 CCD TV lightning images are being compared with the WSR-57 radar and GOES-E satellite imagery of the storm to look at spatial and temporal characteristics of these optical lightning emissions and compare them with storm structure.

PLANS FOR FY-83:

Optical image processing algorithms to enhance the nighttime and daytime lightning imagery will be investigated. These images will be studied for their temporal and spatial variability and will be compared with ground-based RF and optical measurements to determine if intra-cloud and ground-flashes have different signatures above cloud top.

The data analysis hardware will be enhanced by an interface with the McIDAS hardware, the addition of a floating point array processor, and the addition of a color graphics plotter.

RECOMMENDATIONS FOR NEW RESEARCH:

1. Investigate the feasibility of a hybrid lightning mapper which integrates ground-based RF and above cloud-top optical characteristics of lightning discharges.
2. Investigate the usefulness of lightning generated optical emissions as an indicator of lightning storm severity relationships.

PUBLICATIONS:

Goodman, S. J., Doviak, R. J., and MacGorman, D. R., "Lightning Location in a Severe Oklahoma Thunderstorm," Preprints, 12th Conference on Severe Local Storms, San Antonio, Texas, American Meteorological Society, Boston, MA, pp. 326-329.

TITLE: SEVERE STORM ELECTRICITY

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SIGNIFICANT ACCOMPLISHMENTS FY 82:

FY 82 has been a transition year in that earlier initial results in the study of severe storm electricity were completed just prior to FY 82 and more limited research tasks were undertaken. New results have manifested themselves most notably in ground truth measurements during NASA U2 overflights and in initial development of long range cloud-to-ground flash discrimination using ELF techniques (details of the latter are found in a separate report by W. Taylor).

This past severe storm season was the first successful coordination of lightning measurements made with the U2 and NSSL's ground-based systems. CG strike location data were obtained on several flights where storms were at long ranges from NSSL. The high point of data collection undoubtedly occurred on 27 May 1982 when we successfully coordinated with the U2 for data acquisition near NSSL. Through the aircraft communication and tracking capabilities operated by Jean Lee, we were able to provide to the U2 pilot real time lightning location data from NSSL's 23-cm wavelength lightning locating radar, LLP CG locator, and VHF mapping systems. Although time has not yet been sufficient to allow detailed analyses, we know that high quality electric field change, ELF, optical, and lightning radar echo data were obtained and can be compared with the data acquired aboard the U2. In addition, dual-Doppler and radar tracking data were also recorded.

Other highlights of FY 82 include analysis of general aspects of severe storm electricity in our continuing attempt to find electrical parameters that are indicative of storm severity and observable from satellites. One promising result has been that CG flashes appear directly linked to mesocyclone development as determined from completion of data analysis obtained with our University of Mississippi/NSSL mobile laboratory (see Roy Arnold report for details).

We have also analyzed CG flash characteristics obtained with our LLP network during mesocyclones and tornadoes. This is still in progress, but a significant amount of data exists.

Because the handling of so many different types of data with varied resolution requirements is time consuming, we have continued to develop computer techniques, both hardware and software, to allow us to process and assimilate large amounts of data more easily.

CURRENT FOCUS OF RESEARCH WORK:

We are currently involved in analysis of data collected in 1982 and 1981. Particular emphasis is being placed on correlation of measurements made at the ground during the U2 flight of 27 May and on the correlation of lightning activity associated with mesocyclone and tornadic development.

PLANS FOR FY 83:

We anticipate that additional ground truth measurements will be made during U2 overflights of severe storms next spring. Development of ELF detection capabilities for possible use in the hybrid lightning mapper will continue. Prior to next year's spring season, we will be evaluating the cloud-to-ground CG lightning locator system capability to detect +CG flashes. When we have established this, a large data base from 82 measurements will then be available to determine the occurrence of +CG flashes during, and their relation to, severe weather. Significant analysis effort will also be spent on correlating ground base measurements with the overflight data and in analyzing previously collected data during tornadic weather. We feel that new information concerning lightning and severe storms can be obtained through cooperative analysis with MSFC where lightning and meteorological data are combined using the facilities and expertise of personnel in all groups.

PUBLICATIONS SINCE JUNE 1981:

"Positive cloud-to-ground flashes in severe storms", W. David Rust, Donald R. MacGorman, and Roy T. Arnold. Geophys. Res. Lett., 8, 791-794, 1981.

"Layered lightning activity", Donald R. MacGorman, A. A. Few, and T. L. Teer. J. Geophys. Res., 86, 9900-9910, 1981.

"The simultaneous display in a severe storm of lightning ground strike locations onto satellite images and radar reflectivities", R. E. Orville, M. W. Maier, F. R. Mosher, D. P. Wylie, and W. D. Rust. Preprints, 12th Conf. on Severe Local Storms, Am. Meteor. Soc., Boston, Mass., 448-451, 1982.

"Lightning location in a severe Oklahoma thunderstorm", Steven J. Goodman, R. J. Doviak, and Donald R. MacGorman, Preprints, 12th Conf. on Severe Local Storms, Am. Meteor. Soc., Boston, Mass., 326-329, 1982.

"Research on electrical properties of severe thunderstorms in the Great Plains", W. David Rust, William L. Taylor, Donald R. MacGorman, and Roy T. Arnold. Bull. Amer. Meteor. Soc., 62, 1286-1293, 1981.

"Characteristics of lightning echoes and analysis of their distribution in a storm", V. Mazur and W. D. Rust, EOS, 62, 879, 1981.

"Doppler spectra of lightning and precipitation at vertical incidence", Dusan S. Zrnica, W. David Rust, and William L. Taylor. Preprints, 20th Conf. on Radar Meteor., Am. Meteor. Soc., Boston, Mass., 263-270, 1981.

"Preliminary study of lightning location relative storm structure", W. D. Rust, W. L. Taylor, and D. MacGorman. AIAA Journal, 20, 404-409, 1982.

"Radar research on thunderstorms and lightning", W. David Rust and Richard J. Doviak. Nature, 297 (invited review), 461-468, 1982.

Severe Storm Electricity: Analysis near Mesocyclones and Tornadoes

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Our current focus is to concentrate our analysis on the time period of 1615-1700 CST on 17 May 1981 when data was acquired by the mobile laboratory while tracking near a mesocyclone and a tornado each of which moved within 20-30 Km of NSSL's fixed base storm electricity base and within the NSSL's dual Doppler network. This was the first of four mesocyclones and an identical number of tornadoes that were tracked on this day. We feel the data are important because of the close proximity of the mobile lab to both the mesocyclone and tornado as well as NSSL's fixed base meteorological and storm electricity operations.

In FY '83 we plan to continue our analysis of the 17 May 1981 data and correlate our mobile observations with lightning mapping and other meteorological data. If the need arises during later time periods we are prepared to operate the mobile laboratory in support of the U2 overflights; storms within the fixed base storm electricity prime data collection area are fortuitous.

We are confident that our most exciting result is a verification of what we have suspected for several years; the region in and surrounding the main storm updraft is the exciting region of cloud-to-ground (CG) lightning. Lightning and storm dynamics are definitely closely related. We have been unable, however, to verify that intracloud lightning is fairly frequent but not continuous throughout a storm's life, as suggested by sferics mapping. Our data suggests major temporal variation in both CG and intracloud lightning rates.

Publications (since June 1981):

1. W. David Rust, Donald R. MacGorman, and Roy T. Arnold, 1981: Positive cloud-to-ground lightning flashes in severe storms. *Geophys. Res. Let.* 8, 791-794.
2. W. David Rust, William L. Taylor, Donald R. MacGorman, and Roy T. Arnold, 1981: Research on electrical properties of severe convective storms in the Great Plains. *Bull. Am. Meteor. Soc.* 62, 1286-1293.
3. Roy T. Arnold, W. David Rust, and Don Burgess, 1982: A study of severe storm electricity via storm intercept with implications in electrification and lightning production. Tech. Memo. PARGUM 82-03, Physical Acoustics Research Group, University, MS, 48 pp (to be submitted for publication).
4. Roy T. Arnold and W. David Rust, 1981: Single stroke cloud-to-ground lightning in severe convective storms. *EOS* 62, No. 45, 879-80.

TITLE: LIGHTNING CHARACTERISTICS AND ITS RELATIONSHIP TO STORM STRUCTURE

RESEARCH INVESTIGATOR:

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SIGNIFICANT ACCOMPLISHMENTS FOR FY82:

The VHF lightning mapping equipment at our two sites was modified to extend the observable azimuthal sector from 60° to 120°. Observations using the new 120° sector were conducted during the NSSL Spring Program. Thunderstorms within our dual mapping region were very sparse--dual mapping data were obtained on only one day. Single site observations were made on several storms, and the Norman VHF mapping equipment was switched into the vertical looking mode for numerous storms passing overhead.

Analyses of the VHF data from prior seasons continued with emphasis placed on lightning initiation location and progression speeds, and on relating lightning defined by the VHF system with other storm electricity parameters and with storm reflectivity and internal wind structure. High altitude lightning activity--characterized by almost continual small flashes at heights in excess of 10 km--has been found to occur in most storms although its importance was not recognized until we were analyzing our 1980 data. We have processed the VHF data for four storms to determine the characteristics of these small, high lightning flashes. Since these flashes are close to cloud tops, they may have an adverse effect on optically sensing cloud-to-ground flashes from satellites.

ELF (extremely low frequency) observations were conducted at Norman and Huntsville this spring to examine the feasibility of utilizing this technique to detect cloud-to-ground strokes, determine polarity and estimate intermediate current flow. A hybrid system using a ground-based ELF network and a satellite optical sensor may be a practical approach for monitoring lightning flash type and location.

CURRENT FOCUS OF RESEARCH WORK:

We are presently analyzing VHF mapping data collected in 1981 and 1982, integrating these results with data from other storm electricity sensors and from our dual 10-cm Doppler radars, and determining the role lightning plays in severe and nonsevere storms.

Our current primary effort is in the analyses of ELF data collected at NSSL and NASA (by Steve Goodman, MSFC) to determine the reliability of this technique to detect cloud-to-ground flashes, indicate polarity (identify flashes lowering positive charge to ground), and give estimates of return stroke current.

PLANS FOR FY 83:

We plan to continue analyses of data simultaneously obtained from our many severe storm sensors with particular attention given to periods of U-2 overflights.

Through our efforts in determining lightning characteristics from VHF mapping and flash types from ELF waveforms we will continue to help NASA develop techniques that will assist in forecasting, detecting, tracking and warning of weather hazards from lightning observations.

We expect that additional observations and ground truth measurements (particularly during U-2 overflights) will be conducted during the 1983 thunderstorm season in Oklahoma.

RECOMMENDATIONS FOR NEW RESEARCH :

We propose to upgrade the VHF mapping equipment to improve reception range and go to a full 360° azimuthal coverage for a more extended and accurate determination of lightning characteristics.

LIST OF PUBLICATIONS PREPARED SINCE JUNE 1981 :

"Research on electrical properties of severe thunderstorms in the Great Plains", W. David Rust, William L. Taylor, Donald R. MacGorman, and Roy T. Arnold, Bull. Amer. Meteor. Soc., 62, 1286-1293, 1981.

"Doppler spectra of lightning and precipitation at vertical incidence", Dusan S. Zrnica, W. David Rust, and William L. Taylor. Preprints, 20th Conf. on Radar Meteor., Amer. Meteor. Soc., Boston, Mass., 263-270, 1981.

"Preliminary study of lightning location relative to storm structure", W. D. Rust, W. L. Taylor, and D. MacGorman. AIAA Journal, 20, 404-409, 1982.

TITLE: STORM SEVERITY DETECTION (RF)

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SIGNIFICANT ACCOMPLISHMENTS FY-82:

The objective of this program has been to develop severe storm discrimination techniques applicable to space-borne optical/electromagnetic atmospheric electricity sensors. To achieve this objective, an HF radio direction finding system has been used to study directionally resolved atmospheric emissions at 2 MHz. During FY-82, a second phase linear interferometer was fabricated and deployed on the Anderson Road site at Marshall Space Flight Center. The data acquisition electronics consisting of a Data General Nova 3/12 CPU, 10 MByte disk, display console and dual channel receiver were obtained commercially. Interface electronics to the computer were fabricated by SwRI. The antenna array is deployed in an L-shaped crossed baseline. Angle of arrival estimates are computed in 14 milliseconds, provided that the signal exceeds the instrumental noise threshold. A phase linear criterion is used to determine whether or not the wavefront is planar or corrugated. This reduces the incidence of errors caused by multiple sources emitting atmospherics simultaneously.

The systems at MSFC and SwRI are designed to operate in an automatic unattended mode. The data acquisition software is on the fixed 5 MByte disk plotter, and the removable 5 MByte disk cartridge is used for data archive. Typically, 5-6 days of storm activity can be recorded on a single disk. The receiver gain at each receiving site has been calibrated so that the sensitivity and effective range at each site is the same.

CURRENT FOCUS OF RESEARCH WORK:

The HF interferometers at SwRI and MSFC are being operated to detect and record electrical activity in severe storms and hurricanes to distances of 2000 km or greater. Angle of arrival data are being recorded in

14 millisecond intervals, provided the atmospheric exceeds detection threshold, and are logged in azimuth, elevation, day number and time of day resolved to the nearest 10 milliseconds. The time standard used is a WWV satellite receiver. A satellite tag bit is included to indicate whether the clock is synchronized to GOES East or GOES West. The data are recorded on 5 MByte removable disk cartridge and archived on magnetic tape.

PLANS FOR FY-83:

Computer software will be developed to process and correlate data obtained from both the SwRI and MSFC phase linear interferometers. At present, the data from the HF interferometer deployed at MSFC is transmitted to SwRI on 5 MByte disk cartridges and archived on magnetic tape. The disk cartridges are returned to MSFC for further data acquisition. The angle of arrival data recorded at the separated sites will be processed for time correlated events. The intersection of simultaneous bearing estimates will be used to estimate the location of spheric events. Location estimates will be computed in latitude and longitude to the nearest minute. The position data will be formatted on magnetic tape for entry into the McIDAS data base. The lightning location data will be analyzed as a function of storm severity and evolution.

RECOMMENDATIONS FOR NEW RESEARCH:

Based upon the results obtained to date, the following are recommended initiatives:

1. Investigate the electrical signature present when the phase linear criteria is satisfied to determine the breakdown processes which emit planewave atmospheric. This study would provide insight into the physical path tortuosity.
2. Study the electrical signature present over the 14 millisecond data acquisition period. This analysis would provide evidence of the electrical discharge process which appears to be most indicative of meteorological intensity.

LIST OF PUBLICATIONS PREPARED SINCE JUNE 1981:

Johnson, R. L., "Measurements of Atmospheric Electrical Emissions From Hurricanes," 14th Technical Conference on Hurricanes and Tropical Meteorology, San Diego, California, June 1982.

Johnson, R. L., "Hurricane Atmospheric Emissions Observed During 1979 and 1980," manuscript submitted to the Journal of Geophysical Research, May 1982.

Title: Remote Observations of Severe Storms

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SIGNIFICANT ACCOMPLISHMENTS :

1. DMSF Lightning Study

A major step was completed last January with the total digitization of over 32,000 lightning flashes for the year September 1977 through August 1978, from 60°S to 60°N latitude. This data base is now being analyzed for land-ocean ratios, seasonal effects, and coast-line flash density gradients.

2. Absolute Spectral Irradiance Measurements of Cloud-to-Ground Lightning Strokes.

The first absolute spectral irradiance measurements of lightning from 400 to 900 nanometers have been made. Spectral resolution is of the order of 1 nm. The incident energy per unit wavelength can be determined from those curves over any desired band in the region 400-900 nm.

3. Ground Strike Lightning Location System for the East Coast.

In cooperation with the NASA Langley Research Center, a ground strike location system consisting of ten direction finders is being established. Cloud-to-ground lightning is recorded from Maine to North Carolina and as far west as Ohio. New results show high flash rate densities correlating with severe storms along the east coast in June and July.

CURRENT FOCUS OF RESEARCH WORK:

We are analyzing and writing papers on the DMSF and spectral irradiance studies. The largest fraction of our time, however, is devoted to the establishment of the lightning direction finding system.

PLANS FOR FY-83:

We will continue installing lightning direction finders, and we will plan to operate the network through the winter. The acquisition of a MeIDAS terminal in October will significantly advance our capability to study severe storms.

RECOMMENDATIONS FOR NEW RESEARCH:

We believe that new research should include a comprehensive study of all aspects of the severe storm. This will include the ability to examine simultaneously the lightning flash characteristics with satellite visible and infrared data, radar data, and with the evolving synoptic patterns.

LIST OF PUBLICATIONS:

- Orville, R. E., 1982: "Lightning detection from space", in **Handbook on Atmospheric**, edited by H. Volland, CRC Press (Boca Raton, Florida), pp 79-97.
- Orville, R. E., M. W. Maier, F. R. Mosher, D. P. Wylie, and W. D. Rust, 1982: "The simultaneous display in a severe storm of lightning ground strike locations onto satellite images and radar reflectivity patterns", Preprint Vol. 12th Conf. on Severe Local Storms, Jan 11-15, 1982, San Antonio, Texas, pp 448-451.
- Levine, J. S., G. L. Gregory, G. A. Harvey, W. E. Howell, W. J. Borucki, and R. E. Orville, 1982: "Production of nitric oxide by lightning on Venus," **Geophys. Res. Letters** 9, (in press).
- Idone, V. P., and R. E. Orville, 1982: "Lightning Return Stroke Velocities in the Thunderstorm Research International Program (TRIP), **J. Geophys. Res.** 87, C6, pp 4903-4915.

Title: The Optical Characteristics of Lightning

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Purpose of the Investigation: To measure the light intensities radiated by various intracloud and cloud-to-ground lightning processes and to model the effects of clouds on these emissions.

Progress to Date: During the summer of 1982, the University of Arizona assembled and calibrated an ultraviolet radiometer which is sensitive to lightning emissions in a 400 Å window centered on 2750 Å. Our previous sensor, a broadband device covering 4000 to 11,000 Å, was improved and both detectors were exposed to natural and triggered lightning at the Langmuir Laboratory, Socorro, New Mexico. Preliminary analyses indicate that the UV signal amplitude is less than 5% of that in the visible and near IR spectral region and hence is not interesting for the satellite detection problem.

Analyses of light and electric field signatures recorded during the summer of 1981 in Florida have been completed. Values of the space-and-time averaged radiance of return strokes are in good alignment with those measured in 1983; i.e., 3×10^5 to 1.2×10^6 Watts per meter of channel; and very recent results obtained by the University of Florida group suggest that our values for subsequent strokes are about a factor of 3 below the actual peak radiance. By comparing the peak radiance values with the total electromagnetic power radiated by the strokes, we have determined that an upper limit for the radiative efficiency of subsequent strokes is on the order of 1% or less. The implications of this result for the physics of the breakdown process have also been explored.

Title: Lightning Detection and Convective Phenomena Experiment
(LDCPE)

Research Investigators: B. Vonnegut SUNYA
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Significant Accomplishments FY82:

Optical pulse, electric field changes, and photographic data collected during the spring '81 Thunderstorm Overflight Program (TOP) have been analyzed. Lightning channels as long as several km were observed in the clear air above the cloud. Multiple images produced by film and/or aircraft motion indicate numerous repetitive discharges in the same channel. Lightning grating photographs show spectral characteristics that are similar to those photographed at ground level. Optical pulses correlate well with rapid field change events.

Current Focus of Research Work:

- 1) Continue to analyze the summer '81 and spring '82 U-2 lightning and convective data.
- 2) Develop an RF Sensor Experiment for use on the U-2 or Lear jet aircraft.
- 3) Continue the development of possible hardware for a future shuttle experiment and data analysis techniques.

Plans for FY83:

Continue to participate in the Thunderstorm Overflight Program by developing instrumentation for measuring atmospheric electrical phenomena from the U-2 aircraft.

Recommendations for New Research:

Study of the screening layer around the cloud top and other associated electrical and convective phenomena.

Publication:

Observations of Thunderstorm Electrical Activity at Night Looking Down from a High Altitude Aircraft, M. Brook, C. Rhodes, R. A. Duggan - NMIMT, O. H. Vaughan, Jr. - NASA MSFC, B. Vonnegut and R. Orville - SUNYA. To be published.

Title: Experimental Measurements Program in Radio Frequency
Lightning Emissions at MSFC

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Significant Accomplishments, FY82:

Several additions and improvements have been made in the system during FY-82 and are described below.

1) The capability for receiving VHF emission (251mHz) has been added. The interim system, completed near the end of the summer of 1981, included only the 2-gHz receiving capability.

2) Equipment for performing rapid calibration of the system before and after the recording periods has been installed and tested. This equipment includes signal generators and standard-gain antennas which are used to generate known power densities at the receiving antennas over a large dynamic range.

3) A data handling, data storage and computing system has been installed. The 1981 interim system made use of a desk-top computer (HP-9825). Data were stored on a tape cassette, providing very small capacity. The 1982 system includes an HP-1000 computer with a 128K memory, an HP 7096 disk drive, a terminal, a printer and a plotter. The computer, using data storage and retrieval programs, transfers sampled and digitized data from the buffer memory to the hard disc for permanent storage and transfers stored data to the computer for subsequent processing.

4) A video monitoring and recording capability has been added. A TV camera is mounted on the antenna support structure, and provides a view of the thunderstorm cell to the operator at the console. A video recorder permits replay of all observed activity. Location of the visible flash relative to the known pattern of the receiving antenna may be observed and proper amplitude corrections made. The thunder sound is recorded on the audio channel of the video recorder, and provides a means for determining the relative distance from the discharge to the receiving site.

Current Focus of Research Work:

Currently, RF emission data in the VHF and S-Band are being recorded and analyzed.

Plans for FY-83:

- 1) Complete analysis of data collected during the summer of 82.
- 2) Operation of the existing system requires three people. The system will be modified so that only two people are needed to operate it.
- 3) Take and analyze thunderstorm data through the spring and summer of 83.

TITLE: Cloud Microphysics

RESEARCH INVESTIGATORS:

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SIGNIFICANT ACCOMPLISHMENTS:

Experimental studies of ice crystal growth using the laboratory static diffusion chamber are in progress. Growth of discoid crystals on two different substrates (glass and AgI) has been achieved without the use of an extremely cold (i.e., cooled to liquid nitrogen temperatures) fiber for nucleation (see Figure 1). This finding suggests the possibility that discoid nucleation and growth may in fact occur under natural conditions as well as those found during some cloud seeding activities.

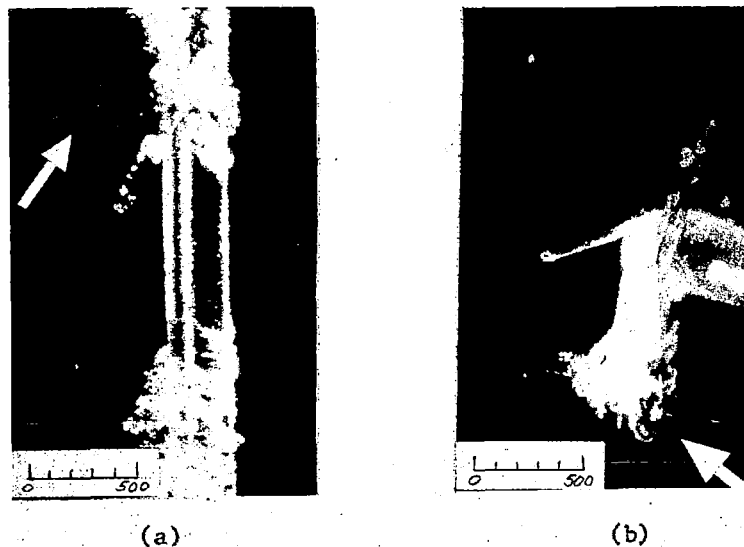


Figure 1. Discoid crystals grown in the static diffusion chamber; (a) on glass, (b) on AgI.

A number of significant improvements have been made in the past year in the data acquisition, control, and plotting software including the capability to simultaneously record routine temperature and pressure data, as well as data from a system independent sensor (see Figure 2). Calibration of the chamber temperature sensors was completed using a platinum resistance thermometer as the reference standard. Eleven of the twelve temperature sensors mounted in the two chamber plates consistently agreed with one another and the temperature standard to within better than 0.1°C . Temperature control of the plates over a period of an hour was also better than 0.1°C .

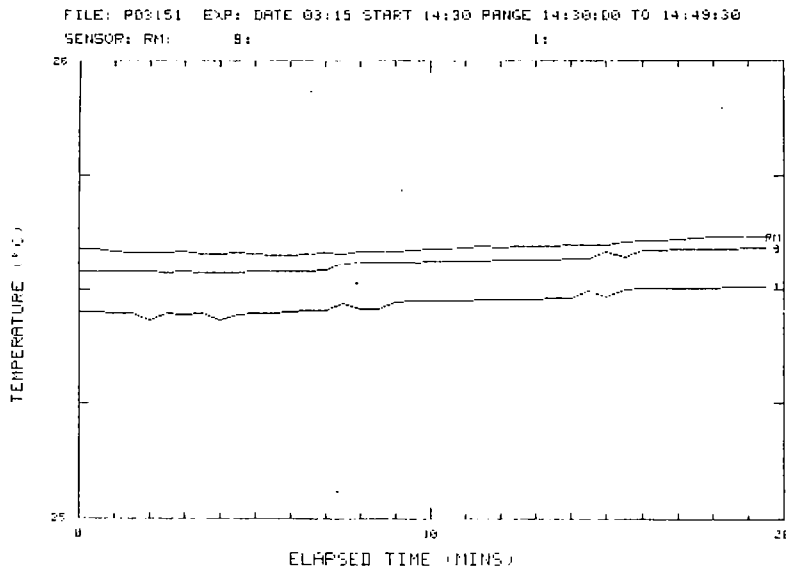


Figure 2. Temperature as a function of time for three sensors in the static diffusion chamber: RM = platinum resistance thermometer (along chamber centerline); 9 = thermistor (top plate); 1 = thermistor (bottom plate).

The effort to develop a high accuracy, highly automated system is relevant to performing cloud microphysics experiments in a low gravity environment where hands-on control by the scientist is often severely limited.

In related studies, a second diffusion chamber, similar to the laboratory model, which also uses an automated system for data acquisition and control, was flown on KC-135 low gravity flights in May 1982 to investigate unattached droplet freezing in low gravity and the likelihood of "ice multiplication" by production of "splinter" particles during the freezing process. Two other experiment packages were flown on KC-135 flights in July 1982. In the one experiment, ice crystals were grown from the liquid in a very sensitive Mach-Zehnder interferometer system to investigate the effect of reduced gravity on the convection and crystal growth processes.

The other package was a reflight of the thermal wave experiment, an investigation of the growth and evaporation of a water droplet cloud in response to an externally imposed sinusoidal temperature field. The reflight was conducted to determine the particle size detection threshold and its spatial variation throughout the chamber volume. It was also used to investigate the effect of maintaining a wetted heat source/sink boundary condition (for the sinusoidal thermal wave) on the propagation of the cloud/clear air interface. Analysis of the data from these flights has just begun.

Specifications were developed and a contracted effort has been initiated for the design and construction of a second generation cloud chamber for KC-135 low gravity experiments. The chamber will be used for completion of the "thermal wave" experiment on droplet growth and cloud formation, an experiment on aerosol scavenging in an electric field, and a prototype for a phoretic scavenging study.

CURRENT FOCUS OF RESEARCH:

The primary experiment currently in progress is determination of the temperature, pressure, and supersaturation regime in which the discoid habit of ice crystals grow as well as the conditions necessary for their nucleation.

PLANS FOR FY-83:

Continuation of the discoid ice studies with the determination of growth rates and habit changes as a function of:

- (a) The thermal diffusivity of the carrier gas
- (b) The water vapor diffusivity of the carrier gas
- (c) Gaseous organic contaminants
- (d) An applied electric field

RECOMMENDATIONS FOR FOLLOW-ON RESEARCH:

Growth of ice crystals at very low temperatures and pressures as well as in atmospheres which simulate those of other planets in our solar system, would be of basic scientific interest. Growth at very low pressures and simulated conditions near spacecraft should be of interest to those concerned with spacecraft environments especially in view of the planned space telescope activities.

The static diffusion chamber is also an excellent facility for studying the deliquescence-efflorescence cycles of cloud active materials, the supersaturation dependence of ice nuclei, and the effects of nuclei on the early stages of ice crystal formation.

PUBLICATIONS:

Keller, V. W. and Hallett, J., "Influence of Air Velocity on the Habit of Ice Crystal Growth from the Vapor," accepted for publication in Journal of Crystal Growth, 1982.

SESSION VI

GLOBAL WEATHER - FLIGHT EXPERIMENTS

The low-gravity environment of Spacelab when in orbit on-board the Shuttle permits the accurate modeling of large-scale geophysical fluid flows in spherical geometry. Gravity is simulated by a radial dielectric force. It is necessary to perform such experiments in Spacelab since the dielectric force cannot be made large enough to dominate gravity at the Earth's surface. At present, two geophysical flow models are being considered. The Geophysical Fluid Flow Cell (GFFC) will model vertically unstable atmospheres such as found in stars and possibly on Jupiter. The Atmospheric General Circulation Experiment (AGCE) will model vertically stable but latitudinally unstable atmospheres such as the Earth's atmosphere.

William Fowles

THEORETICAL STUDIES TO DEFINE AND INTERPRET GFFC EXPERIMENTS

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The character of large-scale planetary and solar circulations is dominated by the effects of rotation and stratification. In particular, the effect of latitude-dependent Coriolis force on nonlinear convection is thought to play a crucial role in such phenomena as differential rotation on the Sun, cloud band orientation on Jupiter and Saturn, and the generation of magnetic fields in thermally driven dynamos. The continuous low-g environment of the orbiting space shuttle offers a unique opportunity to make laboratory models of such large-scale thermally driven flows under the constraint imposed by rotation. For the first time, a physical experiment can be implemented under controlled conditions that accurately models motions on spherical rotating planets and stars. This is possible because polarization forces in a dielectric liquid, which are linearly dependent on the fluid temperature, give rise to an effectively radial buoyancy force when a radial electrostatic field is applied. The Geophysical Fluid Flow Cell (GFFC) instrument consists of a central spherical convection cell that rotates under an optics housing. Thermal contrasts and an electric potential maintained across the hemispherical shell of working fluid serve to drive vigorous convection within that fluid. Our group has been responsible for the overall scientific direction of the GFFC experiment and is responsible for the overview of the instrument development from a science viewpoint to insure that the instrument can meet the scientific goals, for the development of theoretical models of the expected experimental motions, and for the data reductions, analysis, and interpretation.

FY82 Accomplishments in Theoretical and Numerical Modelling and Current Focus of Research Work

The following major studies in support of scenario selection, instrument design, and data interpretation for the GFFC have been completed or are presently underway:

1) We have continued work on a fully nonlinear three-dimensional hydrodynamic code to simulate fluid flow in the GFFC. This model includes $1/r^5$ electrostatic gravity, realistic Prandtl number, and an equatorial insulating barrier as is present in the instrument. So far this code has been used to generate thermal and velocity predictions for scenario camera-timing information, and in a limited scope, to select optimal GFFC experiments. Since the computer time to perform fully three-dimensional simulations is demanding, this code will be used primarily to aid data interpretation after the experimental results are available.

2) A new theoretical model has been developed by Hart that suggests the circumferential jets on Jupiter and Saturn may arise from a type of instability in which sub-cloud layer convective rolls roughly aligned with the rotation axis of the planet feed energy into the zonal circulation via the mechanical transport term in the zonal energy budget $(\partial \bar{U} / \partial z) \bar{u}' w'$. Here \bar{U} is the zonally averaged east-west velocity, with u' and w' being zonally fluctuating velocities associated primarily with thermal convection. The instability mechanism is described as follows. Under very rapid basic rotation (small Rossby number), convective cells necessary to transport heat outward are predicted to be approximately two-dimensional, invariant along the rotation axis of the planet. In the absence of any zonal flow that has a shear across the cells (i.e., varying in the direction perpendicular to the rotation axis), the convection will behave in a manner similar to ordinary two-dimensional parallel plate convection. Now if the convection amplitude is

large enough, and a small zonal shear is imposed across the cells, the cell streamlines will tilt with the zonal shear. This in turn leads to a momentum flux that is up-gradient, strengthening the initial shear. Thus the cells become more tilted and an instability develops in which the shear, according to linear theory based on finite amplitude convection cells with small perturbations in tilt and zonal shear, grows exponentially. The linear theory of this instability for low Prandtl numbers, and a simplified geometry, shows that small imposed shears will amplify if the roll vertical velocities are on the order of 30 diffusion velocities d/v , where v is an effective eddy viscosity in the convection region. The sign of the shear is ambiguous but is probably set by higher order geometric constraints. This instability may be realized at the largest rotation rates possible in GFFC.

3) Hurlburt and Toomre have studied the influence of compressibility on two-dimensional nonrotating thermal convection through the use of a fully nonlinear numerical model of compressible convection. This effort is intended to indicate to what extent the GFFC experimental results may apply to deep planetary or solar atmospheric motions. For motions up to 10 density scale heights in depth, the compressible model predicts qualitatively similar cell structures to those obtained in an incompressible atmosphere. However, net work by pressure forces may become comparable to that by buoyancy, leading to strong downward directed plumes that have no direct analogue within the Boussinesq approximation. These two-dimensional simulations complement the nonlinear anelastic modal studies of convection in the Sun and in A stars by Latour, Toomre, and Zahn.

4) Gilman and Glatzmaier have completed an extensive series of papers on compressible convection in a spherical shell, basing the analysis on linear instability solutions within the anelastic approximation. The latest study uses the eigenfunctions associated with the spherical harmonic expansion to estimate the nonlinear tendencies for the compressible convection to drive differential rotation and meridional circulation. In order to obtain an equatorial acceleration which is large in amplitude relative to the meridional circulation, together with a small equator-pole temperature difference, when the density stratification is large as in the solar convection zone, at least one of two conditions must be met: either the effect of rotation must be large compared to the effects of viscous diffusion and buoyancy, or viscous diffusion must be small relative to thermal diffusion. In either case, the angular velocity increases with depth in the upper part of the convection zone but decreases with depth and is nearly constant on cylinders in the lower part when the global convection extends to deep layers. It is most instructive that global convection, differential rotation, and meridional circulation in the deep layers are similar to those found for the incompressible case, while near the top of the layer they are quite different.

5) Fiedler and Toomre have completed analysis of the importance of turbulent entrainment on wavenumber selection in atmospheric convection. The model relies on turbulent entrainment of dry air for the inversion above a convectively unstable boundary layer to produce very long wavelength instabilities such as observed in the planetary boundary layer by satellites. Two-dimensional nonlinear simulations have been used to show that the time evolution of such instabilities is very similar to that observed in the formation of mesoscale cellular convection.

Plans for Research in FY83

1) Develop linear eigenfunction codes on the VAX for flow in the GFFC. In order to generate the most scientifically significant scenarios, and to interpret the GFFC results, linear instability neutral curves that predict the onset of nonaxisymmetric motions for the anticipated GFFC flows need to be obtained. In the past we have done this by running full three-dimensional numerical solutions of the appropriate hydrodynamic equations as an initial value problem, and looking to see which modes of the initial spectrum of disturbances grow out of the background. This is, however, an inefficient way to generate the stability properties, and can

only practically be used for a small region of our parameter space. Thus we want first to calculate the axisymmetric flow expected in the apparatus when there are both latitudinal and radial temperature gradient externally imposed. Then this two-dimensional steady solution will be used as a basic flow for linearization. The linear stability equations will be solved directly as an eigenvalue problem and coded for the VAX-11/750 computer. Thus the stability curves can be obtained directly.

2) Encode GFFC Read Only Memory (ROM) with flight scenarios. Using the linear stability curves and results from a few full three-dimensional numerical calculations, we shall choose a set of experiments for GFFC. These shall include the preferred ones, along with lower priority ones to be used in case there is a problem with the instrument (e.g., if a thermal measurement device opens up, a set of experiments needs to be run at lower differential temperatures). These scenarios shall be encoded in the GFFC format, and ROMs burned and tested in conjunction with programs developed at MSFC.

3) Laboratory experiments on two-gradient convection. One of the main goals of the GFFC is to elucidate the mechanics of fluids subject to thermal driving in two directions via differential heating in radius and latitude. As part of our effort to provide scientific support for GFFC we plan to carry out a series of laboratory experiments in the terrestrial gravity field that will yield further important information on two-gradient convection. A rotating fluid disc will be heated from below and cooled from above. This is the standard configuration for rotating Benard convection. In addition, an external thermal gradient will be imposed between the inner and outer radii of the disc, thus generating a horizontal basic gradient of temperature in the fluid analogous to the north-south gradient in the GFFC. Experiments will be carried out over a range of Rayleigh and Taylor numbers similar to those in the GFFC, and a regime diagram for the laboratory flows constructed by observing the state of motion for each set of external parameters.

List of Relevant Publications since June 1981

- Fiedler. 1982. "Mesoscale entrainment instability as the cause of mesoscale cellular convection." Ph.D. Thesis, University of Colorado. Three papers in preparation for J. Atmos. Sci.
- Glatzmaier & Gilman. 1981. "Compressible convection in a spherical shell. IV. Effects of viscosity, conductivity, boundary conditions, and zone depth." *Astrophys. J. Suppl.* 47, 103.
- Glatzmaier & Gilman. 1982. "Compressible convection in a rotating shell. V. Induced differential rotation and meridional circulation." *Astrophys. J.* 256, 316.
- Hart. 1981. "Rotating recycling flows over topography." *Tellus* 33, 597.
- Hart. 1982. "Stability of low Prandtl number Hadley circulations." *J. Fluid Mech.*, submitted.
- Hurlburt, Toomre, Massaguer, & Graham. 1982. "Two-dimensional compressible convection extending over multiple scale heights." *Astron. Astrophys.*, submitted.
- Latour, Toomre, & Zahn. 1981. "Stellar convection theory. III. Dynamical coupling of the two convection zones in A-type stars by penetrative motions." *Astrophys. J.* 248, 1081.
- Latour, Toomre, & Zahn. 1982. "Nonlinear anelastic modal theory for solar convection." *Solar Phys.*, in press.
- Massaguer, Latour, Toomre, & Zahn. 1982. "Penetrative cellular convection in a stratified atmosphere." *Astron. Astrophys.*, submitted.
- Mihalas & Toomre. 1981. "Internal gravity waves in the solar atmosphere. I. Adiabatic waves in the chromosphere." *Astrophys. J.* 249, 349.
- Toomre, Gough, & Spiegel. 1982. "Time-dependent solutions of multimode convection equations." *J. Fluid Mech.*, in press.
- Zahn, Toomre, & Latour. 1982. "Nonlinear modal analysis of penetrative convection." *Geophys. Astrophys. Fluid Dynam.*, in press.

DEVELOPMENT OF DATA ANALYSIS
AND INVERSION PROCEDURES FOR GFFC EXPERIMENTS

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Two techniques are used to extract information on the fluid motions with the Geophysical Fluid Flow Cell (GFFC) experiment scheduled for flight on SL3. Details of this electroconvection experiment have been reviewed by Toomre and will not be repeated here. Flows in the GFFC are visualized by taking a time series of photographs of two distinct types. In mode 1, dye lines (as a pattern of 14 dots) are injected into the fluid photochromically by an ultraviolet flash and then are photographed as the fluid motions deform them. These photographs will be analyzed in such a way that the dye displacements can be used to infer the fluid velocities. In mode 2, the folded optics are used as a back-focus Schlieren system. Thus radially averaged horizontal temperature gradients of the whole hemisphere are reproduced in a series of photographs. These will be analyzed and the horizontal temperature field reconstructed. In addition, each film image contains a complete digital description of the external and internal parameters of the experiment (rotation, voltage, boundary temperatures, heat flux, etc.) on a set of diodes recorded on the edges of each frame.

The developed 16mm flight films will be digitized by our Primary Data Reduction System (PDRS) consisting of a vidicon camera whose scanner address is controlled by a PDP-11/03 computer. Under program control the many 16mm frames can be reduced to a manageable amount of data on magnetic tape containing the converted (binary to digital) LED data, dye position data, and rough thermal data (intensity vs. latitude/longitude). These magnetic data tapes then will be read into the VAX-11/750 and higher order processing will be carried out to generate the dynamically significant quantities necessary for interpretation of the experiments.

The TV scanner, film transport, and the PDP-11/03 computer are currently fully integrated and operable. A test film supplied by Aerojet has been used to test out the PDP-11/03 software necessary to recover thermal, dye, and LED data from the film. The following programs have been completed and tested in the PDRS:

- 1) Re-register the film image digitally with respect to either the center of the spherical cell, or with respect to the registration diodes on the film.
- 2) Transfer Schlieren temperature grey levels to magnetic tape with respect to a spherically based latitude/longitude grid.

FY82 Accomplishments

We have now completed the installation and primary software development of the VAX-11/750 computer system used for both the theoretical modelling in support of GFFC and for the detailed data analysis and inversion of the flight experiments. In addition, we have been completing the PDRS software used on the PDP-11/03 system. Although most of the software to run the TV scanner and to transfer the GFFC 16mm film data to tape was completed and tested last year, it was still necessary to develop and test software to recover the data from the digital part of the LED display. This is largely a character recognition problem that needed to be combined with the re-registration subroutines already developed. Secondly, the dye data needed to be read off the film. This was more difficult since the leading

edges of the dye streaks must be recognized and recorded as a function of position and time from several frames of data. Since the dye dispenses and deforms with time, some considerable effort must be spent to insure an accurate determination of the dye position. We have now nearly completed both of these tasks, since we can now read the binary part of the LED data quite reliably and can detect the dye streak positions efficiently.

We have also made significant progress on programming the VAX computer to process the data tapes from the PDRS to give the higher order observational output. The thermal field contouring programs have been attacked first as they will be needed to assist in the comparison of the ground-based test data with theory. The temperature is extracted from the interference patterns (with the experimental errors minimized) first by forcing the temperature gradient to be as curl-free as possible and then by using a least squares fit on this gradient. This second condition reduces to the requirement that the Laplacian of the best fit temperature equals the divergence of the measured gradient field. We have tested such an inversion procedure on a series of simulated Schlieren system data sets based on thermal fields obtained from our three-dimensional convection models. The temperature field inversion results appear to be satisfactory even when noise is added, though actual GFFC calibrated data must be tested when it becomes available from the ground-based experiments that are planned. We have also begun to develop analysis methods and coding to obtain various measures of the velocity fields from sequences of dye streak images, but evaluation of these procedures requires access to good test films.

Plans for Data Analysis and Inversion Developments in FY83

1) Ground-based testing of the GFFC. It is planned to run some tests with the GFFC in the inverted/stable configuration during FY83. In this mode the hot inner sphere is above the cool outer sphere so that the fluid is almost everywhere stably stratified. The induced motions are slow and axisymmetric for a range of thermal boundary conditions and imposed rotation. They can be measured and compared to the results of a simple axisymmetric numerical model already working and tested. This important exercise will give us firsthand experience and serve as a test of all the elements in the GFFC program: the instrument, the PDRS, the data analysis and interpretation programs, and the theoretical models. In addition, it will allow additional indirect calibrations to be made of the instrument's thermal measurement system.

2) Tune the thermal inversion procedures and velocity probing in GFFC. The comparison of ground-based thermal fields with numerically predicted ones for axisymmetric motion in the Earth's gravity field will be completed. These results will be used in part as baseline calibrations of the optical system, and in part to choose parameter values for the Spacelab experiment (e.g., required thermal gradients for optimal imaging). Further, the velocity fields determined from analysis of dye streak deformations in the test data will be compared in detail to those from the numerical models. This should enable us to determine just which are the optimal algorithms for our spatial sampling of the Schlieren and dye streak images with the computer-driven vidicon camera system. Further, these studies should serve to place useful bounds on the errors inherent in the overall inversion procedures for both thermal and velocity field determination.

TITLE: Recent Developments with the GFFC Instrument

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SIGNIFICANT ACCOMPLISHMENTS FY82:

Instrument Hardware: Much of the FY82 work effort on the GFFC instrument was devoted to analyzing the nature of the temperature sensor failures and preparing a more reliable design. Eight of the eighteen temperature sensors failed over a period of a few years and the reliability of the remaining sensors was in doubt, particularly during operation at higher temperature levels. Although many of the planned experiments could still be performed with slightly reduced confidence, any additional failures would have a significant impact on the science. A decision was made to determine the nature of the temperature sensor failures and modify the instrument configuration accordingly.

In February the inner sphere of the GFFC was removed from the instrument and handcarried to MSFC for analysis by Electronics and Control Laboratory. After x-rays failed to identify the source of the temperature sensor failures, destructive testing was approved. The sphere was carefully cut and x-rayed in order to preserve any clues to the problem. Cuts were made parallel to the groove containing the sensors and the surrounding epoxy was dissolved out. Examination of the exposed sensors under a microscope revealed that the 1 mil gold wire bonds had broken contact with the sensor pad on all the failed sensors inspected. No such condition was observed on the remaining good sensors. Another suspicious area was examined, namely where the 1 mil wire is joined with a 5 mil wire. All of these bonds showed no anomalies. Further scrutiny of the sensor pads with a scanning electron microscope showed that little metal transfer occurred during the thermo-compression bonding procedure. This resulted in a very weak bond that was aggravated by frequent temperature cycling.

As a result of the failure analysis, two modifications to the design are being considered to prevent a recurrence of the problem in the new inner sphere. A Delta Critical Design Review was held in June at MSFC to examine these changes in terms of reliability, schedule, cost, and concurrence with the specifications. One approach would require a pull test of the 1 mil wires before final close-out to insure that the bonds are of adequate strength. In addition, a soft epoxy would be used to fill the groove in an

effort to minimize stress placed on the bonds during thermal expansion. Finally, installing four sensors per latitude instead of two would add redundancy which could be utilized without having to disassemble the sphere. A second approach that eliminates the possibility of an open bond would be the use of sensor flatpacks. The flatpack has the same sensor embedded in a protective ceramic substrate which covers the delicate bonding wires. Only the larger more durable wires emerge from the package. Studies are currently underway to examine these two design modifications to insure reliability at minimal cost.

Additional but less important problems which arose were: a dark stain on the sapphire sphere, and a slip-ring short-circuit. The first was a dark band in the field of view of the GFFC data camera which was originally believed to have resulted from a simple optical misalignment but was diagnosed as a ring around the sapphire sphere. This band tends to be misinterpreted by the GFFC automated data analysis system which scans the photographs and deduces fluid velocities and temperatures. Examination of the sapphire sphere indicated that the band resulted from a nonuniform deterioration of a UV anti-reflection coating on the sphere. After a meeting with representatives of Materials Laboratory and a discussion with Aerojet and the PI, it was decided to remove this coating altogether since ample UV was getting to the fluid than originally expected and the visible transmission was better without it. The outer sphere has been sent back to the coating manufacturer for refurbishment.

The second problem area involved two of GFFC's 21 slip-rings which failed early after instrument assembly. The slip-rings transmit electrical signals from turntable-mounted equipment to the rest of the instrument. The entire slip-ring assembly is in close proximity to the housing and apparently two made inadvertent contact creating an electrical short. By reviewing and eliminating two nonessential signals, the GFFC could be operated as designed. The slip-ring assembly will be sent back to the manufacturer to be shortened and calibrated for proper tension. Afterward all of the slip-rings will be functional.

Support Equipment: The power supply and time code generator for ground operation of the GFFC have been delivered to MSFC. The eeprom chips which store operating instructions for the science scenarios have also been received along with a program card set which interfaces between the eeproms and computer hardware. The software for converting the experiment parameters into hexadecimal instructions is complete although further refinements to increase efficiency and check for errors continues. Work has also progressed on the automated data analysis system at the

University of Colorado. Much of this effort has been devoted to improving the system's ability to read and interpret the GFFC matrix diodes and transfer the data to magnetic tape.

Project Plan: The GFFC Project Plan has been reviewed and updated by appropriate management and the Science Team. This document is the basic agreement between NASA, MSFC, and OSSA for accomplishing the GFFC Spacelab experiment. The plan defines the tasks and mechanisms for (1) developing the GFFC and (2) performing a comprehensive experiment program with the instrument. In addition to describing the overall GFFC objectives, the Project Plan briefly summarizes the instrument development, mission operations, scientific support, instrument safety and reliability, the management plan, manpower requirements, and the budget.

Spacelab 3 Mission Interface: Preparations for integrating the GFFC into Spacelab 3 progressed smoothly during FY82. Near the beginning of the reporting period the GFFC successfully passed the electromagnetic interference (EMI) test with only minor modifications. Numerous meetings were held to insure Spacelab 3 compatibility and the more significant ones are briefly summarized below. In November the second Spacelab 3 Payload Ground Operations Working Group meeting was held at KSC. During this time the GFFC operation and integration requirements were presented for pre- and post-flight activities. Personnel from KSC also described their integration procedures and capabilities. The results of these discussions helped revise the Ground Integration Requirements Document to be baselined in FY83. In January the Spacelab 3 Initial Design Evaluation was held to recognize integration problem areas from an overall mission point of view. The interference problem of the GFFC instrument with a rack cable tie strut was identified but appropriate action has since resolved this matter. Results of this meeting will be reflected in the Flight Design Operations Review scheduled for September 1982. Finally, in February the Spacelab 3 Flight Operations Coordination Meeting was held to review Payload Operations Control Center operations and capabilities at JSC during the mission. At this time the electrical ground support equipment with necessary power and cooling requirements were listed.

CURRENT FOCUS OF RESEARCH WORK:

Current efforts for the GFFC instrument are concerned with finalizing the design modifications of the inner sphere and constructing a prototype for extensive testing. In addition, the software for programming the instrument is being optimized to interface efficiently with the forthcoming hardware.

PLANS FOR FY83:

The following activities are planned for FY83: (1) the fabrication and testing of the GFFC instrument will be completed; (2) after delivery of the instrument to MSFC, it will complete its flight qualification with an acoustic, an off-gas, and possibly an abbreviated vibration test; (3) the Integrated Readiness Review will take place in preparation for Spacelab 3 installation; (4) the Ground Integration Requirements Document will be baselined; (5) ground-based testing of the instrument will begin at MSFC and the science scenarios developed; and (6) the instrument will be shipped to KSC to begin pre-level IV integration.

TITLE: Theoretical Analyses of Baroclinic Flows Related to the AGCE

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SIGNIFICANT ACCOMPLISHMENTS:

1. The study of the stability of a Hadley cell in the channel model developed earlier, with respect to axisymmetric perturbations, has been completed. This linear stability model was further extended to study the characteristics of three-dimensional perturbations at small values of the Richardson number. Most of the numerical results pertaining to this study have already been accumulated and are being documented and presented in the form of a paper to be submitted for publication later this year. Simultaneously an experimental apparatus, comprised of a cylindrical annulus with heating maintained at both the upper and lower lids was built by NASA/MSFC to investigate this form of baroclinic instability. The results of the stability analysis are being used to observe the symmetric instability modes in the laboratory.

The results on the instability of the Hadley cell model with respect to symmetric perturbations were presented either in the form of seminars delivered or discussions held at WHOS, MIT and Harvard University in the U.S. and at the RW-Technical University of Aachen in West Germany earlier this year.

2. A computer code is being developed to study finite amplitude waves for an Eady model under the conditions of strong nonlinearity. The model being developed is pseudo-spectral with a Fourier expansion in the horizontal direction and Chebyshev expansion in the vertical. The technique used will allow for the potential vorticity to be a non-vanishing function. It is anticipated that the code will be running later this year.

3. A numerical code has been developed to study the axisymmetric basic state of a rotating, heated spherical annulus. The code is a mixed spectral-finite difference Navier-Stokes solver with Fourier expansion in the latitudinal direction and central difference in the radial direction.

CURRENT FOCUS OF RESEARCH:

The current thrust of research is to complete the three-dimensional stability problem and submit it for publication. Also to finish the

development of the program for the finite amplitude analysis of the Eady problem. At the same time we plan to apply a novel new technique in finite amplitude analysis for studying the strong nonlinearity of the Eady problem. This technique requires a minimum of computational effort thus enabling us to carry out an extensive search in the parameter space on the strong nonlinear instability criteria. It is also intended to continue performing experiments at NASA/MSFC on the symmetric instability in a cylindrical annulus.

PLANS FOR FY83:

Our plans for FY83 is to continue the work discussed in the current focus of research and to try to bring as much as possible of it to a successful conclusion.

LIST OF PUBLICATIONS PREPARED SINCE JUNE 1981:

1. Baroclinic Instability of a Rotating Hadley Cell. B. N. Antar and W. W. Fowlis. J. Atmos. Sci., 38, 2130-2141 (1981).
2. Convective Instability of a Solidifying Binary Alloy Liquid. B. N. Antar and F. G. Collins. Bull. Am. Phys. Soc., 26, 1281, (1981) (Abstract of a paper presented).
3. Symmetric Baroclinic Instability of a Rotating Fluid Layer. Bull. Am. Phys. Soc., 26, 1285 (1981) (Abstract of a paper presented).
4. Symmetric Baroclinic Instability of a Hadley Cell. J. Atmos. Sci., 39, 1280-1289 (1982).
5. On the Surface Tension Stability of a Liquid Layer Cooled from Below. F. G. Collins and B. N. Antar. AIAA J., 20, Sept. 1982.

FLOW REGIME STUDIES WITH A SIMPLIFIED GENERAL CIRCULATION MODEL

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Significant Accomplishments FY82:

A paper presenting the results of our rotating-fluid experiments with an atmospheric general circulation model has been prepared and submitted to the Journal of the Atmospheric Sciences. The objective of this study was to derive a regime diagram for rotating-fluid motions in spherical geometry and to compare it with regime diagrams for rotating-fluid motions in annular geometry. Rather than construct and test a numerical model specifically for this purpose, we found it expedient to modify an existing general circulation model (GCM) of the atmosphere by removing the model physics and replacing the lower boundary with a uniform surface. Thus modified, the GCM becomes a device for solving the nonlinear primitive equations on a rotating sphere, with motion driven by an imposed equator-to-pole temperature difference. Since the dimensions of this model are those of the earth's atmosphere, it is not a model of the Atmospheric General Circulation Experiment (AGCE) device that will fly in Spacelab. We anticipate, however, that application of the data obtained from the AGCE to understanding the large-scale dynamics of the atmosphere will require a model of the atmosphere, such as the one we have developed, which has been modified so that it operates in the AGCE mode.

The operational procedure is as follows. We specify a rotation rate Ω and an equator-to-pole temperature difference ΔT , and spin up a Hadley circulation and associated zonal-wind system. If this axially symmetric flow is unstable, it soon breaks down into wave motion. We note if the flow is stable or unstable, and in the latter case we also note the wavelength and the amount of heat and momentum transported by the wave (or waves). This information is organized by viewing it in a parameter-space diagram of $\Delta T/\Omega^2$ versus Ω^2 , which is known as a regime diagram. The regime diagram is supplemented by other figures showing wave structure and the vertical distribution of wave heat and momentum transports.

There are a number of differences between our model regime diagram and regime diagrams generated from laboratory annulus experiments. The most striking difference is the absence of an upper symmetric regime in our diagram. We think that this is a direct consequence of the

behavior of the zonal jet as rotation rate decreases. The jet then becomes stronger and moves closer to the pole, giving stronger shears, with horizontal shear eventually dominating vertical shear.

A feature of annulus regime diagrams that is also found in our regime diagram is the dominance of a single wavenumber in some of the unstable cases and a tendency for the numerical value of this wavenumber to decrease monotonically with decrease of rotation rate along a line of constant ΔT . Unlike the situation in the annulus, however, the single-wavenumber events are found only for a limited range of ΔT ; that is, in a strip of the regime diagram situated close to the stability boundary separating the wave regime from the lower symmetric regime. Some of our single wavenumber solutions exhibit the phenomenon known as vacillation, but the area of the regime diagram where these cases are found is much smaller than it is in the annulus regime diagram. More significantly, the vacillation cycles in our model appear to be maintained by barotropic processes, while those in the annulus are generally understood to be maintained by baroclinic processes.

The reasons for the absence of baroclinic vacillation in our model are not obvious, but may be related to another puzzling aspect of our single-wavenumber solutions, which is their rather small amplitude. It is always possible to get larger amplitude solutions by going to a larger ΔT , but our model solutions then exhibit irregular wave motion (many waves adding together to produce a pattern evolving randomly in time). It is not clear at this stage of our research whether we are not properly modeling some aspect of the mechanics of large-amplitude, baroclinic-wave vacillation or whether there is something peculiar to the annulus that allows large-amplitude baroclinic waves to vacillate.

Current Focus of Research Work:

As noted above, one of the most important results to come out of our model simulations is that there appears to be no upper symmetric regime in spherical geometry. The question arises as to whether or not this result is due to some of the modifications that we made to the GCM in order to produce our model, in particular, the way in which we heat and cool the atmosphere. In order to answer this, we are undertaking several runs with the unmodified GCM, in which the heating and cooling in the model occur by the same physical processes as in the atmosphere. The question to be answered is whether or not an upper symmetric regime can be found with this model.

Plans for FY83:

We have thus far been unable to find in our model simulations any regime of baroclinic vacillation. We are also concerned about the result that in the part of the regime diagram where single-wavenumber solutions are dominant the amplitudes are small. We will undertake a systematic study of the dependence of our solutions on the damping mechanisms in our model to see if these are limiting wave amplitudes and

wave/zonal-flow interaction. We will also examine the effect of our prescription of the heating and cooling that drives the zonal flow on wave amplitudes.

Publications Prepared Since June 1981:

Geisler, J.E., E.J. Pitcher and R.C. Malone, 1982: Rotating-Fluid Experiments with an Atmospheric General Circulation Model. Submitted to Journal of the Atmospheric Sciences.

TITLE: Numerical Calculation of the Regime Diagram for the Atmospheric General Circulation Experiment

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SIGNIFICANT ACCOMPLISHMENTS FOR FY82:

Thermally-driven, rotating flows in cylindrical and spherical configurations were studied by the use of numerical models developed at the University of Arizona. The bulk of the computer codes had been developed in the previous two years; in FY82 the codes were validated, and some results were produced. For each of the two geometrical configurations, there are two numerical codes: a non-hydrostatic model to calculate an axisymmetric flow and a hydrostatic linear model to test the stability of that flow to non-axisymmetric perturbations.

The cylindrical configuration studied was that of a free-surface, side-heated annulus. Steady-state axisymmetric flows were calculated for a wide variation in thermal Rossby number (Ro_T) and Taylor number (Ta). The results agreed quite well with previous calculations for that point in Ro_T - Ta space which had been previously studied, and the results for all other points were consistent with known characteristics of such flows. Using these axisymmetric fields and the linear model, a "critical curve" was constructed which agreed well with laboratory observations. This curve represents the transition between axisymmetric and non-axisymmetric flow. This series of numerical calculations marked the first time that a theoretical model has been used to quantitatively reproduce the critical curve in the baroclinic experiments, and the results offer a great deal of encouragement that the AGCE can indeed be modelled by calculating an axisymmetric solution to the equations, followed by the use of a linear model to determine the stability of the axisymmetric solution to non-axisymmetric perturbations.

The spherical configuration studied was that of a hemispherical shell, with a fixed temperature profile on the inner and outer boundaries, and with a thermally insulated wall at the equator. The results of the axisymmetric calculations indicate that for the particular configuration studied, non-hydrostatic effects are very small and do not significantly affect the axisymmetric flow away from the pole and the equator wall. The linear calculations indicate that there are some combinations of Ro_T and Ta for which the axisymmetric flow is stable and there are some points

where the axisymmetric flow is unstable. For some Ro_T and Ta , the linear model predicts growing modes which have very strong vertical velocities near the pole and which, therefore, indicate that the hydrostatic assumption may be unjustified. Notwithstanding the weakness in the hydrostatic linear model, several conclusions may be drawn: (1) Some combinations of Ro_T and Ta result in axisymmetric flow. (2) There appears to be no analog of the "upper symmetric" regime in the spherical configuration considered. For fixed Ta , the flow never becomes axisymmetric as Ro_T increases. For fixed thermal gradient, there does not exist a non-zero rotation rate below which axisymmetric flow is observed. (3) Due to the weak static stability caused by the meridional flow into upper latitudes near the outer boundary, and by the resultant required heating from above, non-axisymmetries are most likely to be seen in the outer polar region. (4) The energy source for the waves that have been thus far observed has been baroclinic, rather than barotropic.

RECOMMENDATIONS FOR NEW RESEARCH:

The results of the linear, hydrostatic, spherical model indicate that non-hydrostatic studies should be pursued. Other designs for AGCE, including that with a thermally insulated outer sphere, should be studied.

CURRENT FOCUS OF RESEARCH WORK:

Dr. Miller has quite recently joined the group at Marshall Space Flight Center as a National Research Council research associate, and therefore this research effort will be merging with that of Fowles, et. al., described elsewhere in this review. The current focus and future plans are given there. Dr. Gall will pursue theoretical nonlinear studies of baroclinic flows.

LIST OF PUBLICATIONS:

1. Numerical Calculation of the Regime Diagram for the Atmospheric General Circulation Experiment. Proc. of the International Conf. on Computational Methods and Experimental Measurements, International Society for Computational Methods in Engineering, Washington, DC, Springer-Verlag, NY, 1982, T. Miller and R. Gall.

2. Thermally Driven Flow in a Rotating Spherical Shell: Axisymmetric States. T. L. Miller and R. L. Gall. Submitted to J. Atmos. Sci.

SPHERICAL LAYER CODES FOR AGCE

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Significant Accomplishments FY-82:

We have developed an efficient and rather general computer code for incompressible axisymmetric baroclinic flows in a spherical layer. This code is designed to compute AGCE flows in a variety of proposed configurations, and also to compute flows for various cylindrical laboratory configurations used in previous experiments and in experiments in support of AGCE design. It can also be used to compute two-dimensional flows, in support of related theoretical atmosphere studies.

The axisymmetric code can be run in either of two modes. It can be used to calculate time-dependent flows, by implicit time-stepping. Alternatively, it can be used to obtain a final steady solution, using iterations which are related to time-stepping but with the time step different for temperature and velocity, and varying with position. In this second mode, steady solutions can be obtained very rapidly.

We have also developed a linear stability code, to find the growth or decay rates of small non-axisymmetric disturbances to the axisymmetric steady solutions described above. For AGCE, we must ensure that axisymmetric solutions are unstable, so that flows similar to the atmospheric cyclonic waves will develop. The code uses an iterative algorithm based on the axisymmetric steady-state method. Each iteration updates the complex growth or decay eigenvalue, and updates the complex temperature and velocity fields in a manner based on implicit time-stepping but with the step different for temperature and velocity, and varying with position.

We have validated the axisymmetric code in cylindrical and spherical geometries using comparisons with the computations of Williams and of Miller and Gall.

We have applied the axisymmetric code to a number of proposed AGCE configurations and cases, to find the structure of the resulting flows and the likelihood of instability. Figure 1 shows a steady convection circulation with silicone oil, driven by imposed temperature distributions on the inner and outer spheres.

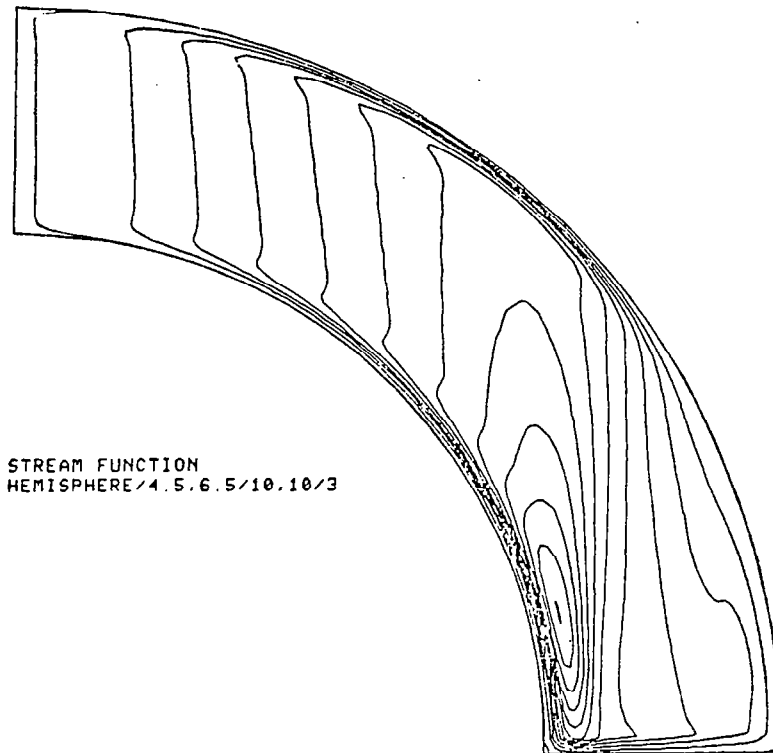


Figure 1: Stream Function for Axisymmetric AGCE Flow with Silicone Oil at 3 Radians/Sec.

We have discovered cases in which there is apparently no steady axisymmetric solution with a single circulation cell, stable to axisymmetric disturbances. In these cases, we obtain either a finite-amplitude vacillation or a steady solution with multiple circulation cells. This is a new result. We have made a movie of a finite-amplitude vacillation.

New Technology:

We believe that three features of our codes constitute new technology. The first is the use of an unstaggered nonuniform mesh in a primitive-variable incompressible fluid computation. The advantage as compared to a staggered mesh is reduced averaging, greater accuracy, and greater efficiency in applying the implicit methods. The disadvantage is additional complexity and poorer resolution in the pressure equation.

The second new technology feature is the iterative method for obtaining steady nonlinear flows. This involves varying time steps as described above, together with the implicit treatment of advection, diffusion, the Coriolis Force, and internal waves.

The third new technology feature is the iterative method for obtaining the linear eigenmodes for the growth or decay of non-axisymmetric disturbances. The eigenvalue is updated each iteration, based on the change in the eigenvector. The complex eigenvector is updated, based on implicit time stepping of the linearized equations, roughly as described above, with varying time steps.

Current Focus of Research Work:

We are presently testing and validating the stability code. The main available data base is the experimental stability diagrams for a cylindrical geometry. The stability results of Miller and Gall are also available.

We are developing a new three-dimensional code for AGCE, using the same flexibly-defined spherical layer geometry as with the prior codes. The new code will compute steady and time-dependent flows. We will use efficient implicit algorithms similar to those described above.

Plans for FY-83:

During FY-83 we will continue to apply the axisymmetric and stability codes in support of AGCE design and of related theoretical and experimental studies. These computations will be mostly in a production mode. As problems arise or new capabilities are required, appropriate code changes will be made.

We will complete the new three-dimensional code, using the same VAX computers as at present. We will use algorithms designed for vector processing, so that the code will run efficiently on the CYBER 205 or on other vectorizing computers.

We will validate the three-dimensional code by cylindrical applications and comparison with available experimental results and with experiments done in support of AGCE.

We will also apply the code to proposed AGCE configurations, within the limits of our time and computer resources.

Recommendations for New Research:

We recommend a program for applying the axisymmetric code to spherical spin-up research. This is an important theoretical problem, closely related to atmospheric boundary layer studies. Such a program would support NASA's new spin-up experiment.

We continue to recommend an extension of the three-dimensional work to an analysis of the stability of steady three-dimensional baroclinic flows. This is important in relation to the atmosphere and to AGCE and cylindrical flows.

Publications:

"The Numerical Design of a Spherical Baroclinic Experiment for Spacelab Flights", W.W. Fowlis and G.O. Roberts, Proceedings of the International Conference on Computational Methods and Experimental Measurements, Washington, D.C., June-July 1982.

TITLE: Experimental and Numerical Studies for the AGCE Design

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SIGNIFICANT ACCOMPLISHMENTS FY82:

1. Experimental Studies with a Cylindrical Version of the AGCE

The closest approximation to the originally proposed AGCE apparatus which can be realized in the laboratory is a cylindrical disc of fluid with radial temperature gradients on its horizontal boundaries. Such an apparatus was constructed with sapphire discs to satisfy the temperature boundary conditions. With this apparatus, for a wide range of experimental conditions and for positive static stability, it was observed that only very weak motions occurred and baroclinic instability was not evident. It was concluded that another boundary temperature configuration, for which more vigorous heating and cooling of the fluid will take place, is required.

2. Experimental Studies with a Shallow Cylindrical Annulus with a Lid

By necessity the liquid in the AGCE apparatus will be a relatively shallow layer with a rigid top in contact with the fluid. Using the conventional cylindrical annulus, previous experimental studies have been

performed for shallow fluids or for a lid in contact with the fluid but not for both of these conditions at the same time. To fill this gap in our knowledge, we performed a systematic set of experiments for a fluid subject to both these conditions. The results showed vigorous baroclinic wave flow for 2 and even 1 cm fluid depth. Clearly, the boundary temperature configuration of differentially heated sidewalls used for the cylindrical annulus is capable of driving strong flows.

3. Experimental Studies of Spin-Up in a Sphere

In a systematic manner, the numerical codes for the design of the AGCE are being checked against experimental and previous numerical results in cylindrical geometry. However, it is also desirable to perform checks against flows in spherical geometry. To fulfill this requirement it was decided to make accurate, disturbance-free, laser-Doppler measurements of spin-up in a spherical cavity. The apparatus for this work has been constructed. This work will also yield new fundamental information on rotating flows in spherical geometry.

4. Dielectric Liquid Survey

A wider range of experimental parameters could be covered in the AGCE studies if the dielectric body force could be increased. The only practical way to increase this force is to find a suitable dielectric liquid with a larger value of dielectric constant than that for the silicone fluids ($\epsilon=2.2$). During the last year, many liquids with higher values for ϵ , satisfactory values of viscosity and satisfactory photochromic compatibility have been examined but they all overheat in the presence of the large electric field because of low values of electrical resistivity (χ). In general, as ϵ increases, χ decreases. Although this survey work will continue, the results to date reaffirm the need for the AGCE to be performed aboard Spacelab.

5. Numerical Design Studies for the Axisymmetric Flow

In a systematic survey the axisymmetric basic states for the AGCE have been determined for different conditions. At first the flow in a hemispherical shell with a rigid boundary at the equator and with temperature gradients on the spherical surfaces only was computed. Then because these flows were weak, the flow in a hemispherical annulus with a high latitude (polar) boundary and with the equatorial boundary and polar boundary maintained at different temperatures was computed. The flow in the latter configuration with a free upper surface has also been computed. For all of these configurations the effects of variable depth, temperature difference and rotation rate were studied.

The resulting flows show many features in common with axisymmetric GCM's and zonally averaged GCM's and real atmospheric data. However a

noticeable difference between the AGCE results and the GCM's and the atmosphere is the latitudinal location of the maximum of the westerly zonal flow (jet). For the GCM's and the atmosphere the jet occurs around 30°N whereas for the AGCE the jet occurs at much higher latitudes.

For the free surface case an axisymmetric vacillating flow has been discovered.

CURRENT FOCUS OF RESEARCH WORK:

Laser-Doppler measurements of the spin-up flow in a spherical cavity and numerical predictions for the same flow are underway.

The dielectric liquid survey is continuing. Measurements of the resistivity of candidate liquids are being performed routinely. One of the nation's leaders on the electrical conductivity of dielectric liquids, Dr. E. O. Forster of Exxon Research and Engineering Co., is being consulted on this problem. Even if no suitable liquid of analytical grade purity can meet our resistivity specification, there is still the hope that purification techniques will raise the resistivity sufficiently.

Substantial effort is being put into examining the discrepancy in the latitudinal location of the jet between the AGCE numerical results and the GCM's and the atmosphere. A major difference between the AGCE and these other systems is the form of the thermal driving force. The AGCE is driven by temperature differences on the boundaries whereas the others are driven by radiational heating and cooling. The consequences of this difference are being explored.

PLANS FOR FY83:

The sapphire disc apparatus will be modified to allow for additional heating and cooling in the form of the conventional cylindrical annulus. It will be possible with this apparatus to examine the effects of temperature gradients on the horizontal surfaces in combination with the heated and cooled sidewalls.

From the theoretical viewpoint it is more satisfactory to drive baroclinic motions in a cylindrical annulus by stratifying the fluid and then differentially rotating the lid. Using mechanical driving of this form, much valuable work has been performed with two-layer fluid systems. We plan to extend this previous work to a continuous fluid system. Measurements will be made using laser-Doppler techniques and data acquisition handled through a microprocessor.

The numerical AGCE design studies will be continued by testing the stability of the axisymmetric states using the linear stability code. This work should result in a regime diagram for the AGCE.

PUBLICATIONS SINCE JUNE 1981:

1. The Numerical Studies Program for the Atmospheric General Circulation Experiment (AGCE) for Spacelab Flights. NASA Conference Publication 2200, edited by W. W. Fowlis and M. H. Davis.
2. Feasibility Study - Atmospheric General Circulation Experiment (2 Vols.). NASA Contractor Report 161889, edited by R. J. Homsey, General Electric Company.
- *3. Baroclinic Instability of a Rotating Hadley Cell. B. N. Antar and W. W. Fowlis. Journal of the Atmospheric Sciences, 38, 2130-2141 (1981).
4. Numerical Solutions for the Spin-Up of a Stratified Fluid. J. M. Hyun, W. W. Fowlis and A. Warn-Varnas. Journal of Fluid Mechanics, 117, 71-90 (1982).
5. Spin-Up Flows in a Cylinder. J. M. Hyun. Proceedings of the Conference on Developments in Theoretical and Applied Mechanics, edited by T. J. Chung and G. R. Karr and sponsored by the Southeastern Conference on Theoretical and Applied Mechanics, Huntsville, Alabama, April 1982.
- *6. Symmetric Baroclinic Instability of a Hadley Cell. B. N. Antar and W. W. Fowlis. Journal of the Atmospheric Sciences, 39 (1982).
- *7. Numerical Calculation of the Regime Diagram for the Atmospheric General Circulation Experiment. T. Miller and R. Gall. Proceedings of the International Conference on Computational Methods and Experimental Measurements, edited by G. A. Keramidas and C. A. Brebba and sponsored by the International Society for Computational Methods in Engineering, Washington, DC, July 1982, Springer-Verlag, New York.
- *8. The Numerical Design of a Spherical Baroclinic Experiment for Spacelab Flights. W. W. Fowlis and G. O. Roberts. Presented at the International Conference on Computational Methods and Experimental Measurements, Washington, DC, July 1982.
9. Numerical Solutions for the Spin-Up from Rest of a Homogeneous Fluid in a Cylinder. F. W. Leslie, J. M. Hyun, W. W. Fowlis and A. Warn-Varnas. Presented at the International Conference on Computational Methods and Experimental Measurements, Washington, DC, July 1982.
10. Numerical Solutions for Spin-Up from Rest in a Cylinder. J. M. Hyun, F. Leslie, W. W. Fowlis and A. Warn-Varnas. Accepted for publication in the Journal of Fluid Mechanics.
11. A General Solution of the Eady-Type Equation of Baroclinic Instability. A. C. Giere and W. W. Fowlis. Accepted for publication in Geophysical and Astrophysical Fluid Dynamics.

*Papers also listed in other presentations.



SESSION VII

GLOBAL WEATHER-SATELLITE DATA STUDIES

0 To learn about global-scale atmospheric processes via diagnostic and theoretical studies, wherein satellite data plays a major role. Emphasis is on 1) the cyclone and the role of latent heat release in cyclone dynamics and 2) evolution and structure of global scale flows.

0 To develop new techniques for using space to study global scale atmospheric processes.

George Fichtl

TITLE: Utilization of Satellite Cloud Information to Diagnose the Energy State and Transformations in Extratropical Cyclones

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Significant Accomplishments FY-82:

A full set of rawinsonde observations was reduced and gridded to use as the basic data set for the proposed diagnostic analyses. These data span North America for the period 9-11 January 1975, a period during which an intense extratropical cyclone developed and propagated across the central United States. From these data complete kinetic energy budget and partial available potential energy budget analyses were made in zonal-eddy partitioned form. These analyses, coupled with sensitivity tests and comparisons with numerical model forecast energy budgets, suggest that: (1) the data set and computational procedures are of sufficient accuracy to permit reliable diagnoses of cyclone energetics, (2) errors should not interfere with our ability to detect influences of latent heat release, (3) the case chosen is one of particularly high energy levels and transformations, and (4) energy quantities represent useful indicators of the evolution of the cyclone.

In order to more directly evaluate the role of latent heat release, latent heating estimates have been made for both the stable and convective components, the latter derived using the Kuo parameterization. These show generally good qualitative agreement between calculated latent heat release distributions, precipitation reports, and radar echo areas. However, there continue to be some areas in which the agreement is poor. To assist in correcting these deficiencies NOAA-4 and SMS-1 visible and IR cloud photographs are being used to modify the original latent heat determinations. Also, hourly precipitation data for the United States have been plotted and analyzed for use as a comparative data set.

Current Focus and Plans for FY 83:

Our current focus is on developing procedures to incorporate satellite cloud photographs. Using the final heating estimates that will result from these efforts we will diagnose the adiabatic and diabatic components of the vertical motion, the generation and release of available potential energy, and the vertical flux divergence of available potential and kinetic energy. These energy quantities are the ones most directly sensitive to latent heat release.

List of Publications Prepared since June 1981:

- Robertson, F.R., and P.J. Smith, 1981: The impact of model moist processes on baroclinic wave energetics. Preprints of the Fifth Conference on Numerical Weather Prediction, Nov. 2-6, 1981, Monterey, CA, 163-170.
- Lin, S.C., and P.J. Smith, 1982: The available potential energy budget of a severe storm-producing extratropical cyclone. Mon. Wea. Rev., 110, in press.
- Robertson, F.R., and P.J. Smith, 1982: The impact of model moist processes on the energetics of extratropical cyclones. Submitted to Mon. Wea. Rev.
- Kenney, S.E., and P.J. Smith, 1982: The role of latent heating and scale regime in the release of available potential energy in an extratropical cyclone system. Submitted to Mon. Wea. Rev.
- Dare, P.M., 1982: A comparison of observed and model energy balance for an extratropical cyclone system. M.S. Thesis, Purdue University.

TITLE: Use of Satellite Data in a Diagnostic Parameterization of Convective Heating

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SIGNIFICANT ACCOMPLISHMENTS FOR FY-82

The major accomplishment of FY82 has been the development of a diagnostic cumulus parameterization which utilizes observed rainfall and satellite derived cloud cover data to infer vertical distributions of diabatic heating, moistening, and mass transport produced by moist convection.

A modification of the cumulus mass flux approach (see e.g., Arakawa and Schubert, 1974 J. Atmos. Sci. and Houze et al, 1980 J. Atmos. Sci.) was developed:

1. 1-D cumulus updraft and downdraft thermodynamic profiles are derived from observed large-scale variables.
2. Digital GOES satellite data is used to determine a cumulus cloud top distribution function. This function serves both to characterize the cloud population according to entrainment rate and to provide the basis for estimating storage of cloud condensate (i.e., anvil production).
3. Cumulus mass flux is constrained to be that which, when combined with cloud thermodynamics, produces precipitation agreeing with the convective portion of the precipitation measured at the ground.
4. Thermodynamic modifications imposed on the large scale heat and moisture fields are given in terms of cumulus induced environmental sinking, detrainment of heat and water, and cloud water evaporation.

The diagnostic effort also involved a sensitivity analysis to determine the impact of model assumptions on derived heating profiles.

CURRENT FOCUS OF RESEARCH WORK:

Current emphasis is on completion of calculations of large-scale modification by cumulus processes during the SESAME '79 experiment. Of prime interest is the validity of the assumption of quasi-equilibrium between static stabilization by ensemble cumulus and the large-scale forcing of instability.

PLANS FOR FY-83:

The main thrust for FY83 will be incorporation of parameterized heating and mass flux profiles into diagnostic energy budgets for the SESAME '79 and January 9-11, 1975 case studies. Primary consideration will be given to: (1) ascertaining how cumulus heating of the environment modifies its ability to support subsequent convection and (2) how convergence/divergence profiles produced by cumulus-scale mass transport alter large-scale ageostrophic motion and the generation of kinetic energy.

RECOMMENDATIONS FOR NEW RESEARCH:

Although the concept of parameterizing cumulus heating based on conservation of cumulus mass flux is not new, the application of quantitative satellite measurements of cloud fields remains relatively untested. It is important that this approach be applied and evaluated in a variety of synoptic settings. A proposal for use of this technique in conjunction with South Pacific FGGE data has already been directed to NASA Headquarters. An additional application to newly acquired AVE/VAS data bases would use the parametrization as a means of determining the ability of VAS data to resolve atmospheric stability structure. Further modification of the method to consider momentum transport by cumulus clouds is also needed.

PRESENTATIONS:

Robertson, F. R., 1982: Use of Meteorological Satellite Data in Moisture Parameterization Schemes, 3rd Extratropical Cyclone Project Workshop, National Meteorological Center, Washington, D.C., March 10-12, 1982.

Robertson, F. R., 1982: Use of Satellite and Radar Data in a Diagnostic Parameterization of Latent Heat Release, AGU Chapman Conference on Rainfall Rates, Urbana, Illinois, April 27-29, 1982.

TITLE: The Effects of Stable and Convective Heat Release on Mid-Latitude Cyclones

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GOALS OF RESEARCH

- 1) diagnose the effects of latent release due to stable ascent on extratropical systems by performing analysis of the vorticity and thermodynamic budgets using vertical motions derived from the quasi-geostrophic and semi-geostrophic omega equations.
- 2) develop methods to use satellite data to estimate stable and convective heat release.
- 3) develop parameterizations of convective heating.

SIGNIFICANT ACCOMPLISHMENTS FY-82:

a) OBSERVATIONAL STUDY

We have just about completed our analysis of the effects of latent heat release due to large-scale ascent in the cyclone of March 10-12, 1978. The vertical motion field with and without the effects of latent heat release has been computed using the traditional quasi-geostrophic as well as the semi-geostrophic approaches. The latter method accounts for the advection of momentum by the ageostrophic as well as geostrophic wind fields. We anticipated that ageostrophic advection could be important near frontal zones as well as regions of the upper troposphere and near the lower boundary. All computations have been made over a fixed $2.5^\circ \times 2.5^\circ$ grid covering eastern and central U.S.A. Orography and Ekman pumping at the lower boundary and a radiation condition at the tropopause were imposed. Active areas of latent heat release were determined using a combination of satellite data and precipitation measurements.

The semi-geostrophic calculations were accomplished by transferring all data from the regular grid to a regular array in geostrophic momentum coordinates. The omega equation takes on a form very similar to the quasi-geostrophic equation in the transformed coordinate and this is readily amenable to numerical solution.

By using observed rates of change of vorticity, the quasi and semi-geostrophic vorticity budgets have been analyzed with and without latent heating and the residuals attributed to meso and convective scale vorticity sources. The residuals at 16 model levels have been divided into areal averages and deviations. Inferences as to the rate of latent heating on the wave and mean vorticity budget are drawn.

b) THEORETICAL ANALYSIS

It has become evident from our analysis of precipitation patterns and the words of other scientists that convective precipitation can play an important role even in stable wintertime cyclonic systems. Even in warm frontal overrunning situations there seems to be a tendency to organize the precipitation into convective patterns, Hobbs (1978).

There is little fundamental understanding of how the convection interacts with both meso and synoptic scale systems at mid-latitudes. Emmanuel (1979) has shown that with background shear the convection can organize itself into disturbances parallel to the shear due to conditional symmetric instability of the synoptic scale flow. Observations by Browning et al (1973) indicate that often convection associated with warm frontal overrunning is not organized into lines but rather tends to be randomly distributed. We have undertaken a stability analysis of disturbances in a conditionally unstable atmosphere without large-scale shear. We are particularly interested in determining whether there is a preferred scale for the instability and the structure of that disturbance. The wave CISK parameterization of the convective wave interaction mechanism was used. An energy balance model which leads to a time-lag between the convection and the large scale boundary layer convergence was developed. The calculations are critically dependent on the predetermined vertical distribution of the in-cloud latent heating and extra-cloud heating due to subsidence.

With a heating pattern peaking in the upper troposphere preferred horizontal scales of 200-300 m developed. Model calculations by Fritsch and Brown (1982) indicate that there is appreciable cooling below the convective clouds due to rainfall evaporation. It is very interesting that when our stability analysis was redone allowing for this cooling, the growth rates were doubled although the preferred scale was unaltered. The cooling was phased with the subsidence pattern associated with the wave such that the growth enhancement resulted.

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PLANS FOR FY-83

- 1) apply our vorticity and thermodynamics diagnostic schemes to a few more cases including a storm to be studied by participants in the mid-latitude cyclone project.
- 2) evaluate the effects of large-scale shear and non-linearities as the growing CISK disturbances achieve finite amplitudes.
- 3) develop a method to parameterize cumulus effects on the large scale by evaluating the eddy transport effects of the meso-scale disturbances growing by the wave CISK mechanism.

PUBLICATIONS

Clark, J.H.E. and Qin Xu, 1982: A wave-CISK model of meso-scale disturbances at mid-latitudes, submitted to Monthly Weather Review.

Clark, J.H.E., C.S. Shie, C.A. Staver, 1982: An analysis of the vorticity and thermodynamics budget of a mid-latitude cyclone using quasi and semi-geostrophic vertical motion fields, submitted to Monthly Weather Review.

NON-QUASIGEOSTROPHIC EFFECTS IN BAROCLINIC WAVES WITH LATENT
HEAT RELEASE

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Significant Accomplishments FY-82:

Saltzman and Tang (1972, 1974, 1975, 1982) developed a second-order, non-quasigeostrophic, baroclinic wave theory which can reproduce many features observed on the weather maps, including the poleward and eastward displacements of the intensifying cyclonic circulation systems and the equatorward and eastward displacements of the more diffuse anticyclonic circulation systems in low levels, the formation of a cut-off low aloft with a "splitting" of the jet stream, the development of an S-shaped frontal zone, and the development of a "bow-shaped" descending region south of the surface low center with accompanying "comma-shaped" rising region which resembles the comma-shaped cloud region frequently observed on the satellite pictures. However, the effects of latent heat release was excluded in the model. Tang and Fichtl (1982) developed a quasi-geostrophic baroclinic wave theory to study the effects of latent heat release with disturbances assumed to be independent of the meridional coordinate. In order to study how the effects of latent heat release are manifest in the non-quasigeostrophic terms, the model of Tang and Fichtl (1982) was extended by considering the small amplitude wave disturbance in that paper and designating it as the first-order solution and substituting it in the non-quasigeostrophic terms to generate the second-order solution. The governing equations for the non-quasigeostrophic contribution consist of a nonlinear (thermodynamic) integro-differential equation and the nonhomogeneous (vorticity) differential equations. The nonlinearity is a direct result of latent heat release associated with pseudo-adiabatic ascent, i.e. saturated ascending air parcels and dry descending air parcels. The inhomogeneity arises from the non-quasigeostrophic terms in the vorticity equations.

The results are summarized as follows: For the first moist mode, due to the non-quasigeostrophic effects, both the trough and ridge are intensified at the upper level with stronger intensification of the trough, and are weakened at the lower level with considerable weakening of the ridge. The formation of the frontal zone on the east side of the descending region is a feature similar to that in the dry model with non-quasigeostrophic effects. For the second moist mode, due to the

non-quasigeostrophic effects, both the trough and ridge are weakened at the upper level, but they are intensified at the lower level. The temperature profile in each region is nearly symmetric. For the first and second moist modes, the total vertical motion field is asymmetric in each region. The main characteristics of the energetics are described mainly by the transports due to the first-order eddy. The transport due to the second-order eddy has only minor influence except for large F (rotational Froude number) such as $F \approx 10$ for the first mode and except for ϵ near unity for the second mode.

Current Focus of Research Work:

The theory of the role of latent heat release on quasi-geostrophic baroclinic waves without β -effect has been extended to include the effect of Ekman pumping. Preliminary study indicates that the role of Ekman pumping at the lower boundary in a two-level quasi-geostrophic baroclinic wave model is to reduce the eastward phase speed of the unstable wave.

Plans for FY-83:

The analytical theory of the role of latent heat release in baroclinic waves (Tang and Fichtl, 1982) is for a saturated extratropical atmosphere with stable precipitation. We plan to include the effects of cumulus convection in such model.

List of Publications Prepared since June 1981:

- Tang, C.-M., and Fichtl, G. H., 1982: The role of latent heat release in baroclinic waves--without β -effect. J. Atmos. Sci. (in press).
- Tang, C.-M., and Fichtl, G. H., 1983: On non-quasigeostrophic effects in baroclinic waves with latent heat release.

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- Saltzman, B., and Tang, C.-M., 1972: Analytical study of the evolution of an amplifying baroclinic wave. J. Atmos. Sci. 29, 427-444.
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SATELLITE-OBSERVED CLOUD EVOLUTION AS A SIGNATURE OF
THREE-DIMENSIONAL MOTION IN BAROCLINIC WAVES

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Goals of Research:

Since this project is just beginning, we shall present a brief review of our objectives. Over the last ten years we have been developing an analytical theory of the finite-amplitude evolution of the baroclinic waves that dominate the behavior of the extratropical atmosphere (cf., Saltzman and Tang, 1972, 1974, 1975a, b, 1982). A review of these studies including the relevant equations is given in the 1982 paper, wherein it is noted that many of the observed synoptic features of these waves can be accounted for analytically by considering simple harmonic wave forms in non-geostrophic models. Among the deficiencies of these models, however, is the lack of any provision for the spatial variations of static stability, frictional effects, and nonadiabatic effects. We propose now to include these factors in a more complete theory with the particular aim of accounting for the condensational processes and cloud patterns revealed by satellite measurements. This will require that we add additional equations to those already considered: the continuity equations for water vapor and cloud water, parameterized forms of friction and of heating due to small scale convection, radiation, and the latent heat release associated with the rising motion in the baroclinic wave system.

More specifically, we are pursuing the following objective aimed at enhancing the capability of the satellite as an instrument for measuring wind and rainfall distributions in middle latitudes: the development of a deductive theory of the evolution of cloud distributions as a signature of the evolution of the field of motion in baroclinic storms. With the above mentioned additions to our previous model it should be possible to demonstrate how typical cloud formations develop in relation to the growing baroclinic wave (cf., e.g., Anderson and Veltishchev, 1973). For one example, it has been noted (e.g., Weiss, 1977) that as a baroclinic storm evolves the cloud pattern tends to rotate cyclonically around an axis that is far to the east of the center wave vorticity. We believe that our proposed model can account rigorously for this behavior. Another distinctive feature of a developing middle-latitude wave is the so-called "baroclinic-leaf" shaped cloud (Weldon, 1977) which, again should be deducible as part of a comprehensive theory of the evolution of extratropical cloud patterns.

Accomplishments and Current Focus of Research:

At this time we have begun the formulation of the new model, particularly the continuity equation for water vapor. This involves an expansion of the water vapor field into a mean zonal state and a sequence of higher order perturbations that are compatible with a similar expansion of the wind field described in Saltzman and Tang (1972, 1975). As a first, simplest, step the water vapor fields forced by the three dimensional field of motion, coupled with the temperature fields generated as part of the baroclinic wave solution, will be used to infer the cloud distribution from diagnostic formulas (cf., e.g., Lewis, 1957).

Plans for FY-83:

During the next fiscal year we plan to pursue the Goals of Research described above. As noted, our ultimate objective is to relate the observed evolution of satellite cloud sequences to the three-dimensional field of motion that generates the cloud patterns.

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- Saltzman, B., and C-M Tang, 1975: Formation of meanders, fronts, and cut-off thermal pools in a baroclinic ocean current. J. Phys. Oceanogr., 5, 86-92.
- Saltzman, B., and C-M Tang, 1975: Analytical study of the evolution of an amplifying baroclinic wave: Part II. Vertical motions and transport properties. J. Atmos. Sci., 32, 243-259.
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- Weiss, C.E., 1977: First glances can be misleading in locating vorticity centers. NWS/NESS Satellite Applic. Inf. Note 2/77. U.S. Dept. Commerce. 50 pp.
- Weldon, R.B., 1977: An oceanic cyclogenesis - its cloud pattern interpretation. NWS/NESS Applic. Inf. Note 77/7 U.S. Dept. Commerce. 11 pp.

TITLE: Science Issues for a Shuttle/Spacelab Atmospheric
Science Experiment (SASE)

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SIGNIFICANT ACCOMPLISHMENTS:

Initiation of this project in FY82 was stimulated by the need for a new research oriented meteorological satellite platform available in this decade.

Studies began in January 1982 to identify several meteorological research problems which could be effectively addressed with current sensor technologies and which could be studied within the low earth orbit, seven day mission limitation of the Space Shuttle. The objective of SASE would be to assess the capabilities of newly developed meteorological sensors which, when flown on missions of longer duration, would provide a research data base needed to address several key atmospheric science issues.

A preliminary document has been prepared which suggests potential research areas:

- 1) Determining spatial structure of atmospheric moisture and quantitative precipitation mapping.
- 2) Lightning mapping
- 3) The role of tropical convective systems in producing poleward and interhemispheric mass, momentum and thermodynamic energy transports.
- 4) Extratropical cyclone intensification over oceanic regions.

CURRENT FOCUS OF RESEARCH:

At this point in the development of the SASE concept inputs from researchers involved in sensor development are being solicited. Evaluation of the concept by those interested in analyzing the scientific data is also solicited. Further definition of scientific issues and an assessment of sensor availability are underway.

PLANS FOR FY83

A planning meeting for interested scientists and instrumentation specialists is anticipated this fall. It is hoped that through this discussion, a concise definitive statement of science issues and strawman payloads can be developed for soliciting support for SASE.

OUTLINE OF RESEARCH ACTIVITIES

Theory and Modelling of Atmospheric Turbulence

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SIGNIFICANT ACCOMPLISHMENTS FY 82:

There exist two approaches of modelling of turbulence: one is to start from an open hierarchy of profiles and high order correlations, and the other is to formulate a closed sequence of transport processes: evolution of mean profiles, eddy transport coefficients (i.e. viscosity, diffusivity, and damping or amplification rate), and relaxation or memory loss for the approach of the transport coefficients to equilibrium. The former approach uses an ambiguous closure, or an arbitrary hypothesis of the length scale of mixing. The latter approach is based upon a theory of transport and the analysis of the spectral structure of turbulence. We follow the latter and develop a new kinetic method.

There are several schools of kinetic theories of turbulence, as represented by : Misguich (France), Balescu (Belgium), Lundgren, Dupree, Weinstock, Horton (USA), Monin, Tsytovich, Kadomtsev, Klimontovich (USSR). Their theories mainly devoted to the 1-particle distribution function and weak turbulence, and are not fully ready for the analysis of the strong mode-mode coupling and spectrum in strong turbulence. Two new characteristics are important in our kinetic method to make it suitable for determining the spectrum and the transport coefficients:

(a) The group-scaling of the 1-particle distribution function derives the kinetic equation and the evolution of the spectrum, without the need of the 2-particle distribution function. The scaling into three groups represents the evolution of the spectrum, the transport coefficients, and the memory loss or relaxation as a closure. The macro-group forms that portion of the spectrum integrated up to a wavenumber k , so that a simple differentiation yields the spectral distribution. The initial difficulty of the fluid turbulence arises already from the nonlinearity in velocity and the inhomogeneous character by the presence of the forcing field in the hydrodynamical equations that describe the microdynamical state of turbulence. Our kinetic method does not inherit this difficulty by transforming the hydrodynamical equations into a nonlinear master equation whose new nonlinearity can be postponed and resolved ultimately by an equation of state for the self-consistent field.

(b) The probability of transition determines the propagator, or the operator of evolution of the Lagrangian trajectory in the phase space in a form which may be exact, free flight, quasilinear, and nonlinear. These forms calculate the relaxation by memory loss and determine the transport coefficients. Our theory of the probability of transition is developed to be consistent with the kinetic equation.

We conclude that our kinetic method develops a system of two equations: a kinetic equation of 1-particle distribution derives the evolution of the spectrum, and an equation of probability of transition determines the Lagrangian functions along the phase trajectory, and transform them into Eulerian functions with a closure by relaxation. The transport coefficients and the spectrum are found.

Our kinetic method with group scaling derives the cascade transfer across the spectrum and is presented in Paper No. 1. The theory performs the transformation of the Lagrangian correlation in the physical and phase spaces into the Eulerian correlations without the independence approximation. This is not the case with other kinetic method and with the method of Direct Interaction Approximation.

By keeping the double memory in the kinetic equation (one memory in the velocity diffusivity and the other in the transfer function), we find that the transfer function is controlled by an eddy viscosity in small scale transports of the gradient type, and by a damping rate in large scale transports of the non-gradient type. See Paper No. 2.

The two-dimensional geostrophic turbulence has a vorticity transfer and yields a spectrum k^{-3} for the kinetic energy. See Paper No. 3.

CURRENT FOCUS OF RESEARCH WORK :

The transports of the gradient and non-gradient types govern the direct and reverse cascades, respectively. Both cascades are found to yield a spectrum k^{-3} in the two-dimensional turbulence. If the geostrophic turbulence is driven by a random distribution of vorticity sources, the spectrum takes the power law k^{-4} . These results will be reported in Paper No. 4.

In conclusion, our kinetic method has derived the kinetic equation and the transition equation to calculate the transfer function and the relaxation, respectively. We have identified the transport of the gradient type as controlled by an eddy viscosity and the transport of the non-gradient type as characterized by a damping coefficient. We have derived the Kolmogoroff law $k^{-5/3}$ in the Navier-Stokes turbulence and the spectral laws k^{-3} , k^{-4} in the enstrophy transfer of the two-dimensional geostrophic turbulence, in the absence and in the presence of the randomly distributed vorticity sources, respectively.

PLANS OF RESEARCH FOR CONTINUED SUPPORT IN FY-83:

Our kinetic method, as described above, has demonstrated its applicability to atmospheric turbulence. We plan to extend the method to include the shear turbulence, the presence of the Coriolis force, the coupling between the various transports (momentum, heat, and humidity), and to determine their transport coefficients. We expect that anomalous transport will govern the turbulent atmosphere having gradients in different directions, e.g. the mean velocity and temperature have gradients in both the vertical and horizontal directions. The transport coefficients will be obtained as functions of these gradients through an analysis of the relevant spectrum. This will enable us to model the turbulent profiles directly by their equations of evolution without the high order correlations. The following problems are in our consideration.

1. Clump and Intermittency in the Phase Space

The presence of clumps and intermittencies in the turbulent medium

produces a screening effect on the velocity diffusivity and causes a reduction of the transport coefficients.

2. Kinetic Method of Shear Turbulence

The theoretical development in Papers No. 1-4 has found applications in a turbulent medium without mean gradient. In a shear turbulence, the effects of gradients are expected to appear in both the production function and in the transfer function. A preliminary estimate finds that the former effect yields a k^{-3} spectrum and the latter effect finds a k^{-1} spectrum. These laws are to be followed by the Kolmogoroff spectrum $k^{-5/3}$ of the Navier-Stokes turbulence at the large wavenumber end of the spectrum. Measurements in the stormy atmosphere by the NASA Langley Research Center have found a clear evidence for the existence of the k^{-1} spectrum.

3. Investigation of the Transport Properties in Shear Turbulence

The eddy viscosity in the presence of a shear, or in the presence of a Coriolis force will be investigated. It is expected, from a preliminary calculation, that the eddy viscosity is proportional to f^{-1} , and f^{-2} in strong turbulence and weak turbulence, respectively, where f is the Coriolis parameter. The transport theory requires a prior analysis of the spectrum.

4. Anomalous Transport with Gradients and Without Gradients

It is visualized that in small scale turbulence, the gradient transport is valid, and is proportional to the mean gradient and the mean intensity of the larger scale vorticity. However, for transports by large scale turbulence, the background formed by the small scale turbulence which is present in the medium will play the role of a damping.

In conclusion, the kinetic equation and the transition equation in our kinetic development will determine the transport coefficients as functions of the mean flow parameters. This result will serve as the basis for the modelling of the atmospheric turbulence. This modelling will need one single profile equation only for each profile without the usual high order correlations forming a hierarchy. The coupling between the mean profile and turbulence is made explicit by the transport coefficients, under the various types of transport: gradient, non-gradient, and counter-gradient. The equations of evolution of the mean profiles are nonlinear, not only through their own and cross couplings, but also through the nonlinear expressions of the transport coefficients. The nonlinear equations are drastically easier to compute than the customary uncertain high order correlation equations.

RECOMMENDATIONS FOR NEW RESEARCH:

1. Modelling of Mean Profiles that are Directly Coupled to Turbulence

Many mean profiles are coupled to turbulence and can be modelled through eddy transport coefficients. The simplest shear flow is the neutral boundary layer. The kinetic method that determines the transport coefficient can calculate not only the logarithmic profile but also the numerical value of the von Karman constant.

Other shear flows which are more complex can be computed, once our kinetic method delivers the transport coefficients.

2. Modelling of Mean Profiles Combined with Coherent Wave Motions or Cellular Motions that are Coupled to Turbulent Motions

Rotating flows, e.g. between rotating cylinders, present layers perpendicular to the axis of rotation.

Under a mean density gradient decreasing with height, internal gravity waves are amplified, but are damped by turbulence, instead of by the molecular viscosity. The modelling can compute the minimum vertical wavelength of the internal gravity waves.

PUBLICATIONS:

1. Kinetic Basis of Cascade Transfer in Turbulence, Nov. 1981
2. Kinetic Theory of Turbulent Transfer with Double Memory, Feb. 1982
3. Group Scaling Theory for The Enstrophy Transfer in Two-Dimensional Turbulence. May 1982
4. Direct and Reverse Cascades in Two-Dimensional Geostrophic Turbulence and Driven by Randomly Distributed Vorticity Sources, Aug 1982

PREDICTION OF ZONAL WIND INTENSITY

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MOTIVATION AND GOALS OF THE RESEARCH:

The goal of our research at Penn State is to combine the observational capabilities of satellite systems with dynamical knowledge and principles to obtain an enhanced capability for understanding and predicting the structure and evolution of global weather phenomena. Satellite technology encourages a global view of atmospheric events and structure, and there is some hope that global-scale processes might be predictable over longer time periods than are smaller-scale synoptic processes.

Our preliminary studies have indicated that these goals may be accomplished by focusing on the cyclic oscillations in the strength of the mean zonal component of the wind. These oscillations have been known as the index cycle and are associated with the blocking phenomena that are important in determining local weather.

ACCOMPLISHMENTS IN FISCAL 1982 :

Our research has produced significant results in a number of related areas:

1. Theoretical and Numerical Studies. The mathematical concept of subharmonic bifurcation of flows provides a basis for understanding the existence of the (nominally) 5, 10, and 20 day periods we observe in the zonal wind intensity (Dutton and Henderson, 1982). This same behavior has been produced in a quasi-geostrophic spectral model (Clark, 1982). The results of the model demonstrate that the index cycle behavior depends on the forcing owing to topography as well as thermal forcing related to baroclinity.

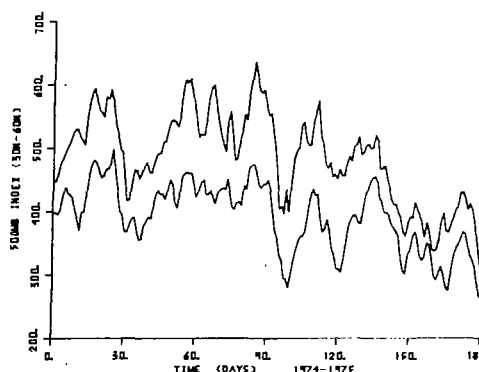
2. Heat Budget Studies. From a dynamical standpoint, the latitudinal temperature gradient is the essential control on the strength of the zonal wind. This temperature gradient, in turn, is affected by the strength of the eddy motion that effects the necessary heat transfers. We have attempted to clarify the interactions and to ascertain which thermal fields must be considered in global forecast models through use of polar-cap heat budget studies based on satellite data.

A unique opportunity has been provided for the winter of 1974-1975 by the Earth Radiation Budget (ERB) experiment. Twice-daily global coverage of incoming and reflected solar radiation as well as outgoing infrared from the polar-orbiting NOAA 3 and 4 satellites are available. We have undertaken a study of the index oscillations using conventional as well as ERB data.

We have divided the northern hemisphere into 15° wide latitudinal belts and have calculated time series of net large-scale heat transport convergence, net radiative heating, heat storage, and sensible plus latent heating. The mean strength U of the zonal westerlies, as well as their vertical shear ΔU , has been monitored also. Spectra of U , ΔU , and the heat transports reveal strong peaks at periods of 4, 10, and 20 days. The radiative components do not have strong signals at these periods and we have a first indication of the essentially dynamic nature of the index oscillations. Cross-spectra between most of the measured quantities have also been calculated. An interesting finding has been a tendency for U , ΔU , and the heat transports all to oscillate at periods in the 5 to 10 day range in late fall and early winter, but to suddenly begin executing large-amplitude 20-day oscillations in mid-winter. It appears that the large-scale motion field has undergone a sub-harmonic bifurcation (Dutton and Henderson, 1982; Clark 1982) in response to some external influence. It is intriguing that the differential net radiative heating at mid-latitudes achieves a relative minimum in mid-winter just about the time the 20-day periodicities are evident.

3. Observations of the Index Cycle. The analysis of observational data to confirm the existence of the index cycle in the atmosphere has involved data from the three winters 1974-1977. The results are reported in Dutton and Henderson (1982).

4. Development of a Forecast Model. We have completed the analytic development of a quasi-geostrophic prediction model based on a spectral decomposition utilizing empirical orthogonal functions to represent the height field. The empirical orthogonal functions were determined from the 500-mb height field for the 1975-77 winters. Comparison of the coefficients and the index revealed that those associated with functions 1, 2, 3, 4, 8, and 11 had the highest correlations. These, then, form a six-coefficient spectral model for predicting zonal wind intensity. A comparison of the index calculated from this six function representation and the actual index is shown in the figure. Evidently, if we can make long-period forecasts of these coefficients, then we can predict the intensity of the zonal wind.



Comparison of observed index (upper curve) and index from eigenfunction representation (lower curve - displaced down 100 units) for 1974-75.

CURRENT FOCUS AND PLANS FOR FISCAL 1983:

1. Theoretical and Numerical Studies. The apparent relation between topographic variations and the subharmonic oscillations associated with the index cycle and blocking events will be investigated both analytically and with further numerical studies.

2. Heat Budget Studies. We will extend the studies of the polar cap heat budget to include additional satellite data and additional time periods. Mechanisms for incorporating satellite radiation measurements into the zonal wind prediction model will be developed.

3. Development of the Forecast Model. We intend to complete analytic work and to write the necessary computer routines to execute the six-coefficient quasi-geostrophic model at 500 mb. The performance of this model will be useful in planning for development of a three-dimensional spectral model. Currently available eigenfunctions and observed data will be used in this initial development effort. Tests with conventional and satellite data will be designed and executed.

PUBLICATIONS SINCE JUNE 1981:

Clark, J. H. E., 1982: The Effect of Topography on the Evolution of Unstable Disturbances in a Baroclinic Atmosphere. Submitted to J. Atmos. Sciences.

Dutton, J.A., 1982: Fundamental Theorems of Climate Theory — Some Proved, Some Conjectured. SIAM Review, 24, 1-33.

Dutton, J.A., and H. W. Henderson, 1982: Prospects for Prediction of Zonal Wind Oscillations. Proceedings, Ninth Conference Weather Analysis and Forecasting, American Meteorological Society, 315-332.

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Shirer, H.N., 1982: Toward a Unified Theory of Atmospheric Convective Instability. In Cloud Dynamics, E.M. Agee and T. Asai, Editors, D. Reidel Publishing Co. In Press.

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Yost, D.A. and H.N. Shirer, 1982: Bifurcation and Stability of Low-Order Steady Flows in Horizontally and Vertically Forced Convection. J. Atmos. Sci., 39, 114-125.

APPENDIX A

NASA/MSFC FY82
ATMOSPHERIC PROCESSES RESEARCH REVIEW
October 19-21, 1982
BUILDING 4723/ROOM 111
MARSHALL SPACE FLIGHT CENTER

TUESDAY, October 19

8:45 a.m. WELCOME

INTRODUCTORY REMARKS William W. Vaughan

9:00 a.m. SESSION I - UPPER ATMOSPHERE AND COUPLING - Robert E. Smith, Chairman

- o Apparent Evidence of Solar Induced, Changes in Tropospheric Planetary Waves - B. Springer
- o Atmospheric Emissions Photographic Images on Spacelab - G. Swenson
- o Modifications to the Ionospheric Doppler System - W. Johnson

10:30 a.m. SESSION II - AVIATION SAFETY - ENVIRONMENTAL HAZARDS - Dennis Camp, Chairman

- o B57B Gust Gradient Program - W. Campbell
- o The Joint Airport Weather Studies (JAWS) Project - C. Kessinger
- o Clear Air Turbulence Detection and Prediction Using a Diagnostic Richardson Number Tendency - J. Keller
- o Charged Particle Fog Dispersal Program - W. Frost

12:00 noon LUNCH

1:15 p.m. SESSION III - DOPPLER LIDAR APPLICATION - Dan Fitzjarrald, Chairman

- o Airborne Doppler Lidar Science Activities - D. Fitzjarrald
- o Ground-Based Lidar Engineering Activities - M. Krause
- o Doppler Lidar Participation in the JAWS Experiment - D. Fitzjarrald
- o Ground-Based Research Using the NASA/MSFC Doppler Lidar Systems - D. Emmitt

(SESSION III, Concluded)

- o Determination of Atmospheric Backscatter at 10.6 nm - W. Jones
- o Atmospheric Backscatter Model Development for CO₂ Wavelengths - G. Kent

3:15 p.m. SESSION IV - SEVERE STORMS SATELLITE DATA STUDIES - Gregory S. Wilson, Chairman

- o The 1982 AVE/VAS Correlative Field Experiment - J. Scoggins
- o VAS Demonstration Correlative Research - G. Jedlovec
- o Automated Mesoscale Winds Determined from GOES Satellite Imagery and AVE/SESAME/VAS Data - R. Atkinson
- o Mesoscale Satellite Sounding Research - W. Smith
- o Interactive Meteorological Computer Development - F. Mosher
- o Analyses of Satellite Data for Sensor Improvement. - T. Fujita

WEDNESDAY, October 20

8:30 a.m. SESSION IV (Continued)

- o Storm-Environment Interactions Determined from AVE-SESAME and Satellite Data - H. Fuelberg
- o Utilization of AVE-VAS/SESAME Data in the Study of Mass-Derived Winds and Ageostrophy in the Mesoscale Environment - J. Moore
- o An Integrated Satellite and Surface Evaluation of Precipitation Characteristics - J. Arnold
- o Application of the AVE-SESAME Data Sets to Mesoscale Studies - D. Suchman
- o Study of Severe Storm Development Based on Satellite and Rawinsonde Data Analysis - R. Hung
- o Mesoscale Ageostrophic Circulations Associated with Baroclinic Jet Streaks - D. Johnson
- o Numerical Simulations of Diabatically Forced Mesoscale Circulations - F. Robertson

(SESSION IV, Concluded)

- o Medium-Range Objective Prediction Model for Thunderstorms Using the McIDAS/CSIS Interactive Computer System - G. Wilson
- o VAS Cooperative Program and Nowcasting Research - P. Menzel
- o Mesoscale Initiation of Cumulus Convection Using VAS Data - D. Emmitt

12:00 noon LUNCH

- 1:15 p.m. SESSION V - LIGHTNING - Hugh Christian, Chairman
- o Overview of the Lightning Research Program - H. Christian
 - o Observations of Nocturnal Thunderstorms from High Altitudes - B. Vonnegut
 - o Optical and RF Measurements of Lightning - M. Brook
 - o Lightning Statistics from U-2 Research - P. Gillaspay
 - o Airborne Measurements of Lightning-Generated Optical Emissions - S. Goodman
 - o Severe Storm Electricity - D. Rust
 - o Severe Storm Electricity Analysis Near Meso-Cyclones and Tornadoes - R. Arnold
 - o Lightning Characteristics and Their Relationship to Storm Structure - W. Taylor
 - o Storm Severity Detection (RF) - R. Johnson
 - o Remote Observations of Severe Storms - R. Orville
 - o Optical and RF Field Signatures Produced by Lightning Return Strokes and the Optical Effects of Clouds - P. Krider
 - o Experimental Measurements in Radio Frequency Lightning Emissions - A. Dunkin

6:00 p.m. BUFFET (Alabama Space and Rocket Center)

8:00 p.m. GUEST SPEAKER: L. E. Powell - Manager, Space Station Project Office
Subject: NASA Space Station Study: Rationale, Plans and Potential

THURSDAY, October 21

8:30 a.m. SESSION VI - GLOBAL WEATHER -
FLIGHT EXPERIMENTS - William Fowlis, Chairman

- o Overview of the GFFC Program - J. Toomre
- o Theoretical Studies to Define and Interpret GFFC Experiments - J. Toomre
- o Development of Data Analysis and Inversion Procedure for GFFC Experiment - N. Hurlburt
- o Recent Developments with the GFFC Instrument - F. Leslie
- o Overview of the AGCE Program - W. Fowlis
- o Theoretical Analyses of Baroclinic Flows - B. Antar
- o Flow Regime Studies with a Simplified General Circulation Model - E. Pitcher
- o Numerical Calculation of the Regime Diagram for the Atmospheric General Circulation Experiment - T. Miller
- o Spherical Layer Codes for AGCE - G. Roberts
- o Experimental and Numerical Studies for the AGCE Design - W. Fowlis

12:00 noon LUNCH

1:15 p.m. SESSION VII - GLOBAL WEATHER SATELLITE
DATA STUDIES - George Fichtl, Chairman

- o Prediction of Zonal Wind Intensity - J. Dutton
- o Theory and Modeling of Atmospheric Turbulence - C. Tchen
- o Utilization of Satellite Cloud Information to Diagnose the Energy State and Transformations in Extratropical Cyclones - P. Smith
- o Use of Satellite Data in a Diagnostic Parameterization of Convective Heating - F. Robertson
- o The Effects of Stable and Convective Heat Release on Mid-Latitude Cyclones - J. Clark

(SESSION VII, Concluded)

- o Non-Quasigeostrophic Effects in Baroclinic Waves with Latent Heat Releases - C. Tang
- o Satellite-Observed Cloud Evolution As a Signature of Three-Dimensional Motion in Baroclinic Waves - B. Saltzman
- o Science Issues for a Shuttle/Spacelab Atmospheric Science Experiment (SASE) - F. Robertson

4:30 p.m. SUMMARY REMARKS ON REVIEW

- o John Theon
- o James Dodge
- o William W. Vaughan

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APPENDIX C

Organizations Whose Sponsored Research Efforts
are Included in the
FY-82 Atmospheric Processes Research Review

Arizona State University
Atsuko Computing International
Battelle Pacific Northwest Laboratories
Boston College
Boston University
City University of New York
Columbia University
Drake University
Drexel University
Fort Valley State College
FWG Associates, Inc.
General Electric
Institute for Atmospheric Optics and Remote Sensing
Lassen Research, Inc.
Lockheed Corporation
Los Alamos National Laboratories
Marshall Space Flight Center Information and Electronics
Systems Laboratory
Marshall Space Flight Center Space Science Laboratory
National Center for Atmospheric Research
New Mexico Institute of Mining and Technology
National Earth Satellite Service, NOAA
National Severe Storms Laboratory, NOAA
Pennsylvania State University
Purdue University

Raytheon Corporation
Saint Louis University
Science Applications, Inc.
South Dakota School of Mines and Technology
Southwest Research Institute
State University of New York at Albany
Texas A&M University
The University of Alabama in Huntsville
The University of Arizona
Universities Space Research Association
University of California, Davis
University of Chicago
University of Colorado
University of Dayton
University of Illinois
University of Manchester, England
University of Miami
University of Mississippi
University of Nevada
University of Tennessee, Tullahoma
University of Wisconsin
Utah State University

THE ROLE OF ATMOSPHERIC ELECTRICITY IN SOLAR-TERRESTRIAL COUPLING

Investigator

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Background and Overview

Since this is a new project in the program a brief description of the background of this work will be given. During the last 10 years the PI has been investigating the possible role of atmospheric electricity in sun-weather relationships. This approach was taken because atmospheric electrical processes seemed the most likely way that solar variability could modulate energetics in the lower atmosphere. A series of related investigations have been conducted including:

1. A statistical study that showed a relationship between United States thunderstorm activity and solar magnetic sector structure (1). This work introduced the time of the earth crossing solar sectors as a parameter for sun-weather research. Use of this approach turned out to be important as it led to the finding by Wilcox and co-workers of a relationship between solar sectors and the vorticity area index developed by Roberts and Olson; this finding greatly stimulated interest in the sun-weather problem.

2. Development of methodology for measuring the temporal variation of the global electrical circuit through aircraft atmospheric electrical measurements over the ocean (2). Correlation of the ionospheric potential with the variation of thunderstorm activity, which we hope to obtain from the "lightning mapper", may provide the first direct test of the Wilson global circuit hypothesis.

3. A mechanism based on the Wilson global circuit was proposed to explain how solar variability could modulate the earth's overall electric field intensity through changes in ionizing radiation over thunderstorms (3).

4. The solar wind velocity was subsequently introduced as a sun-weather parameter when it was found to be inversely correlated with ionospheric potential (4). This is the only correlation that has been reported between solar wind velocity and a meteorological element. This study also found that cosmic radiation was inversely correlated with solar wind velocity which implied that cosmic ray variations modulated the global circuit.

5. Investigating cosmic radiation directly, they were found to be directly correlated with ionospheric potential (5). Thus it can be inferred that solar modulation of the global circuit occurs in the thunderstorm generator because enhanced ionization in the fair-weather portion of the circuit would lower ionospheric potential. This means that thundercloud electrification is being controlled by ionizing radiation in agreement with the proposed mechanism.

6. Another implication of this finding is that there is a thunderstorm charging mechanism that is sensitive to changes in ionization in the vicinity of developing cumulus clouds. Since it is possible that thunderstorm intensity electric fields play a role in cloud physical processes (e.g., coalescence of raindrops and growth of ice crystals) with the potential for releasing large quantities of latent heat, there exists a viable mechanism by which variable solar-activity may be able to control atmospheric circulation from the cloud scale to the general circulation (6).

Recommendations for Future Research

A particular advantage of the atmospheric electrical sun-weather mechanism--which may be unique among proposed mechanisms--is that every step of it can be tested experimentally with existing technology as schematically illustrated in the included diagram. Not depicted are optical and electromagnetic sensing of variable solar activity on the sun's surface, monitoring of variations in the interplanetary magnetic field including ionizing radiation from solar flares and cosmic radiation, and measurements of cosmic radiation with neutron monitors at the earth's surface.

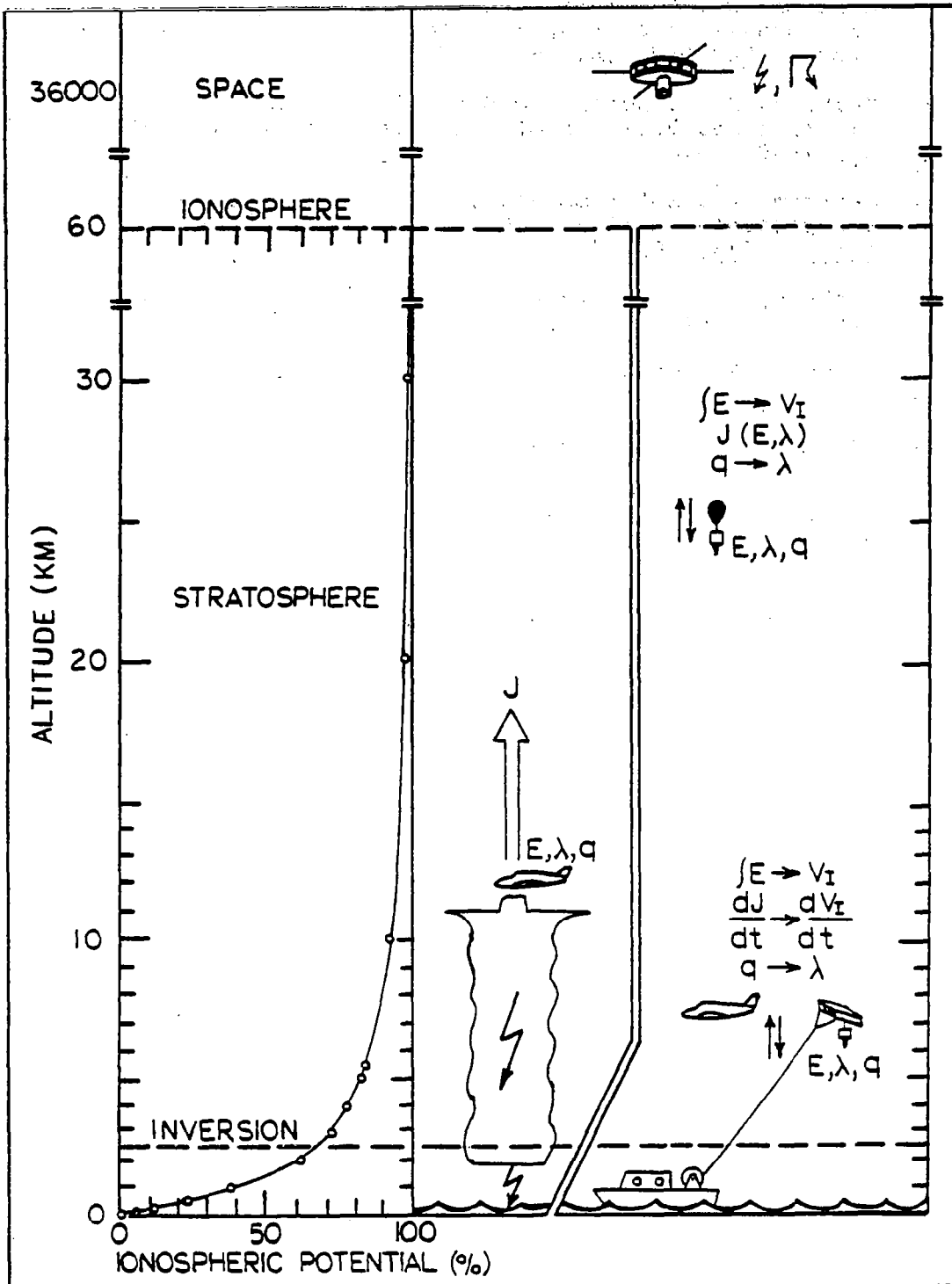
The left panel of the diagram indicates the variation of ionospheric potential with altitude in clean air over the ocean. The center panel illustrates measurement of the conduction current between a thunderstorm and the ionosphere as a function of cloud top structure: the electric field (E) times the total conductivity (λ) is the conduction current density (J). Ion production rate (q) is also measured. The right panel shows a free balloon making up and down soundings from the earth's surface to 30 km. By integrating the electric field profile, the ionospheric potential (V_I) can be determined. The sounding balloons also measure λ and q profiles. The continuous (or extended duration) measurement of ionospheric potential variation (dV_I/dt) is obtained by a radiosonde hanging under a parafoil kite flown on a non-conducting tether. The ship's movements can control lift for the kite. (Tethered balloons are blown down by strong winds and are logistically more difficult to operate than kites.) The radiosonde measures E , λ , and q . It can be raised and lowered to determine V_I . Aircraft can also measure E , λ , and q . By flying well above the exchange layer at constant altitude they can observe the variation of V_I through measurement of dJ/dt . They can determine the absolute value of V_I by making soundings of E . Aircraft have the capability of obtaining the most accurate measurements of globally representative atmospheric electrical parameters because they can locate and stay within clean cloud-free air masses. The top panel depicts a geosynchronous satellite with the capability of obtaining the required continuous observations of the temporal and spatial variation of lightning and thunderstorm-type clouds.

Plans for FY-83 and FY-84

Under the present contract we are going to investigate possible sun-weather effects through analysis of satellite data. Particular emphasis will be placed on deep convective thunderstorm-type clouds and their byproducts. In this study we will attempt to provide conclusive evidence supporting or negating the reality of solar variability affecting weather. If such effects can be identified, we will attempt to determine the mechanism.

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2. Markson, R., Ionospheric potential variations obtained from aircraft measurements of potential gradient, J. Geophys. Res., 81, 1980, 1976.
3. Markson, R., Solar modulation of atmospheric electrification and possible implications for the sun-weather relationship, Nature, 273, 103, 1978.
4. Markson, R. and M. Muir, Solar wind control of the Earth's electric field, Science, 208, 979, 1980.
5. Markson, R., Modulation of the Earth's electric field by cosmic radiation, Nature, 291, 305, 1981.
6. Markson, R., Solar modulation of fair-weather and thunderstorm electrification and a proposed program to test an atmospheric electrical sun-weather mechanism, presented at the Second International Symposium on Solar-Terrestrial Influences on Weather and Climate, Boulder, Colorado, August, 1982, in press.



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16. ABSTRACT A review of the NASA/MSFC FY-82 Atmospheric Processes Research Program was held in Huntsville, Alabama, October 19-21, 1982. The review covered research tasks sponsored by the NASA Office of Space Science and Applications, Environmental Observations Division, in the areas of upper atmosphere, global weather, and severe storms and local weather. Also included in the review was research sponsored by the NASA Office of Aeronautics and Space Technology on aviation safety-environmental hazards. This report contains the research project summaries, in narrative outline form, supplied by the individual investigators together with the agenda and other information about the review.					
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