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CONTENTS

INTRODUCTION

This document is prepared in response to a provision of the NCAR-NSF contract that calls for an annual scientific report "containing a scientific description of all programs conducted by NCAR staff and NCAR visitors during the previous year." Its major purpose is to correlate the activities of the past year with those to be presented in NCAR's Program Plan for the coming fiscal year. Its primary audience is the NSF staff responsible for monitoring UCAR's performance as operator of an NSF-sponsored national laboratory. It may also be of interest to our colleagues in the scientific community who wish an overview of NCAR activities during the past year.

The imperatives pushing atmospheric research are both practical and scientific. The nation's concerns with atmospheric problems related to energy development, environmental protection, food and water supply, and prediction and warnings of severe weather need no elaboration here. What is often overlooked, however, is that understanding the interlocking chemical, physical, and dynamical processes of the atmosphere presents us with some of the most challenging scientific and technical problems encountered in any area of science.

NCAR's mission is to serve as a focal point for attacks on these problems, particularly where commitments of scientists and technical resources over periods of years are required. The report reflects the many ways NCAR interacts with the scientific community in pursuit of that mission:

o Collaborative research among NCAR scientists and university colleagues;

o Major organized research efforts requiring extensive field experiments;

o Direct facility support to university and other outside scientists;

o Participation in and support of national and international atmospheric research efforts;

o Improvement, development, and deployment of advanced computing capabilities and observing and data-handling techniques and resources;

o A variety of gatherings bringing together atmospheric scientists on national and international scales to assess the state of knowledge in given areas of atmospheric science, to identify promising paths for future research, and to allow scientists to determine how their own research interests fit within the mosaic of scientific work required to attack major fundamental problems.

Also reflected in this report is work by individuals and small groups at NCAR that keep NCAR in readiness for collaborative work and joint programs that will emerge in the future.

Because so much of NCAR's work involves collaboration with and advice from colleagues elsewhere in the scientific community, no report is complete without an expression of appreciation to them for the time and energy they have devoted to our common purpose.

Francis P. Bretherton, Director
John W. Firor, Executive Director

ATMOSPHERIC ANALYSIS AND PREDICTION DIVISION

OVERVIEW OF RESEARCH ACTIVITIES

Introduction

The Atmospheric Analysis and Prediction (AAP) Division is concerned with the study of the macroscopic behavior of the atmosphere--i.e., with phenomena whose space scales range from kilometers to thousands of kilometers and whose time scales range from hours to decades. More specifically, it deals with phenomena in the lower atmosphere, where the dominant processes of change are dynamical and thermodynamical, rather than magneto-electrodynamical or chemical. Examples are the development of thunderstorms, the growth and movement of large-scale cyclones and anticyclones, and anomalous seasonal or interannual variations of climate.

The primary objective of AAP's research is to understand the processes governing the structure and behavior of the atmosphere and to develop the means for predicting its behavior. This research embraces a wide variety of more or less distinct but complementary kinds of activities that can be roughly classified as observational or theoretical. Although each type of research requires some degree of specialization, each is pursued most effectively when direct contact with the other is maintained.

AAP's observational studies are aimed at reconstructing a complete and accurate picture of what actually happens in the atmosphere by analyzing meteorological data of many different kinds and by devising ways of displaying and viewing them to reveal most clearly which processes are dominant and how they interact to produce distinctive structures and behavior. In this regard, AAP's activities are characterized by their use of advanced computing techniques to assimilate and process large masses of heterogeneous data in an optimal and compatible way, including the use of interactive graphics for rapidly selecting and modifying preliminary analyses.

AAP's theoretical studies are aimed at clarifying how a single important process or how several processes acting together result in some type of behavior that is actually observed, or in seeing how the lack of some important mechanism leads to consequences that are not observed. Formulations of such simplified systems may be thought of as prototypes for more complete mathematical models or as components of a model whose behavior simulates that of the true atmosphere. The ultimate purpose of these studies is to construct models that simulate atmospheric behavior with as great fidelity as existing observations allow, and to specify the accuracy of prediction that is attainable under practical limitations of observing systems with varying degrees of completeness, accuracy, and cost.

The complexity of mathematical models has far exceeded human capacity to predict their behavior by exact analytic methods. Hence, the major part of AAP's research effort has gone into the development of numerical models whose evolution can be calculated by NCAR's computer complex. This mode of research, which has emerged in the past two decades, is actively pursued at this scale and level in about six centers (of which NCAR is one) in the United States and abroad.

Although these various kinds of activities are made to appear distinct for purposes of description, there is considerable overlap in each of AAP's sections. For management purposes, in fact, the administrative subdivisions of AAP correspond to project objectives or to subject areas that define a homogeneous group of subproblems, rather than a particular kind of expertise. Thus, the administrative components of AAP are:

- Climate Section (Dickinson)
  Climate Sensitivity Group (Kellogg)
  Empirical Studies Group (Newton)
  Global Climate Modeling Group (Washington)
- Oceanography Section (Holland)
- Large-scale Dynamics (Kasahara)
- Mesoscale Research Section (Lilly)

The activities of the research staff of AAP are complemented by the work of university visitors at NCAR and by various joint undertakings, as is evidenced by the attached list of publications many of which are the result of collaborative efforts.

The following are fairly complete reports of the activities and accomplishments of each of the four sections of AAP during the period January 1979 to January 1980, and describe that work in some detail. In is appropriate, however, to preface this account with a brief discussion of rationale and motivation for significant changes of research direction, together with highlights of the past year's work.

Research Directions

Until a few years ago, given the inability to distinguish clearly between prediction errors originating in inadequate data, numerical procedure, or defects of the physical models, AAP gave considerable attention and effort to the development of numerical techniques--i.e., to improving the accuracy of approximate numerical methods and to increasing the effective spatial resolution of the models. More recently, it has been found that models based on entirely different numerical methods (and with similar, but not identical, formulations of the physics) suffered from the same characteristic types of error--notably, an inability to predict correctly the very large scales of motion. With the suspicion that there may be some defect in the basic formulation of all current physical models, AAP has concentrated more of its effort on understanding basic physical mechanisms and on making finer distinctions between various characteristic types of motion and the way in which they interact.

A direct outgrowth (and stimulus) of this change in emphasis over the past year has been the development and application of the so-called nonlinear normal-mode initialization (NLNMI) by the Large-Scale Dynamics Section. Described briefly, the NLNMI is a procedure for extracting the meteorologically important components of motion from a complete set of initial data and for excluding the nonmeteorological "noise." This method immediately established a previously missing connection between the dynamics of the prediction model and the problem of prescribing the correct initial conditions for the prediction model. As important by-products, the application of the NLNMI has also provided a powerful means of diagnosing the behavior (or misbehavior) of the models, as well as a sound basis for the theory of meteorological observing systems. Details of these and other aspects of the section's work are given later in this report.

In the Mesoscale Research Section (MRS), studies of the dynamics of large convective storms have been continued and extended through Project SESAME (Severe Environmental Storms and Mesoscale Experiment), a multi-agency observational program that has provided a wealth of special observations and Doppler radar data during a period of intense thunderstorm activity over the southern and southwestern United States. Parallel experiments with numerical models of idealized storms have been successful in predicting the "splitting" of large storms into a dipole structure.

The major changes of emphasis in the MRS program have been the gradual phasing out of efforts in subsynoptic-scale data analysis and modeling, and the strengthening of planetary boundary-layer studies. Responsibility for regional analyses and testing of limited-area, nested-grid models is being transferred to the Large-Scale Dynamics Section, where this work can be more easily coordinated with related efforts in synoptic-scale analysis using almost identical methods. With regard to studies of the planetary boundary layer, considerable attention is being given to the structure and evolution of stable boundary layers, which are subject to strong orographic influences, and to cloud-capped boundary layers such as are found along the eastern shores of the oceans. An understanding of the structure of all types of boundary layers is essential in simulating the effects of vertical heat, moisture, and momentum exchange in numerical models of the large-scale circulation of the atmosphere.

Much of the work of the Climate Section (CS) over the past year has focused on the development of a more realistic and less costly general circulation model to be used for studies of the climate's sensitivity to changes in external energy input or chemical composition.

This model, the third in a series of increasingly detailed ones, incorporates improved treatments of cloud-radiation feedback, surface physics, hydrologic cycle, sea ice, ocean circulation, and air-sea interactions. Using less detailed interim models of the energy-balance type, CS has investigated long-term average temperature changes that might result from the CO_2 released as a by-product of increased burning of fossil fuels. It has been found that the time required for the oceans (one of the main reservoirs for CO_2) to reach diffusive equilibrium is about 20 years, so that there is a correspondingly long lag time between equilibrium response and an impulsive increase of CO_2 content. This, in turn, drastically affects our estimates of short-term response.

A crucial factor determining climate and climate change is the state of the oceans--their temperature, circulation, and ice cover. Accordingly, the Oceanography Section has undertaken separate but related studies of the oceanic factors in climate, concentrating on the role of mesoscale eddies and other features of the ocean circulation that affect heat and salinity transport. The mesoscale eddies, vortices some tens of kilometers in diameter that are apparently shed from meanders in the unstable northern reaches of the Gulf Stream, are being investigated by a combination of theoretical studies, numerical modeling, and field observation. Although these features are small, they contain an unexpectedly large amount of kinetic energy and may have an important effect on oceanic transport.

AAP Division Office

Over the past six months, Philip Thompson's activities have been centered on two main problems, both concerned with the development and testing of methods for excluding or suppressing solutions corresponding to gravity waves. The first of these deals with the modification of the dynamical equations necessary and just sufficient to exclude gravity-wave solutions. Two conditions must be met: first, the initial state must satisfy a generalization of the balance equation and second, the divergence field at all later times must be constructed in such a way that the condition of balance is maintained. The latter condition, taken together with the equations for conservation of potential vorticity and potential temperature, provides the basis for an "intermediate" short-range prediction model that is well within computational feasibility.

The second problem is that of constructing stable stationary solutions of the "shallow-water" equations. Although singular solutions for nondivergent flow are known, it would be desirable to find less special solutions for purposes of testing numerical procedure. The stationary solutions found so far consist of an isolated circular vortex with a superimposed dipole secondary circulation that is just strong enough to balance the north-south variations of the Coriolis parameter. In fact, their structure resembles that of "blocks" in the westerly flow of the atmosphere. These solutions will be used as initial conditions for a shallow-water primitive-equation model in order to test the nonlinear normal-mode initialization (NLNMI) in cases where the initial flow is made up of a spectrum of Rossby modes. If the solutions do not remain stationary, these tests should provide some insight into the deficiencies of numerical procedure.

Cecil Leith carried out an analysis relating the NLNMI procedure to classical quasi-geostrophic theory. He shows that the vertical velocities computed diagnostically from the classical omega equation provide a first approximation to those generated by NLNMI. As part of the analysis, he introduces the concept of the slow manifold, a nonlinear manifold in the dynamical phase space of a model atmosphere on which the states and orbits lie which are free of unrealistic gravity-wave oscillations. The concept of the slow manifold is playing a key role in the development of theories of observation, analysis, and initialization of prediction models.

During the past year, Jackson Herring's basic turbulence research has focused on: (1) a continued development of theoretical procedures to treat the detailed aspects of scalar turbulence (flows containing temperature or humidity fluctuations); (2) continued investigation of turbulent bispectra including temperature fields; and (3) the development of numerical procedures to treat with better accuracy and understanding buoyantly active turbulence (thermal convection and gravity waves in a stratified medium). The scalar turbulence work was an outgrowth of an earlier study with Gerald Newman (Southeastern Massachusetts University) in which spectral closure methods were employed to compute the wavenumber spectrum, and other details, of a scalar convected by turbulence. This work has been extended this past year in collaboration with Marcel Lesieur (Institut de Mécanique, Grenoble) and Daniel Schertzer (Direction de la Météorologie, Paris) to include detailed calculations of various turbulent time and length scales. Some of this collaborative work was presented at the London shear-flow conference and in subsequent conference proceedings. The remainder is presently being prepared for publication. Topics touched upon include theoretical predictions of eddy viscosities and conductivity and their universality, the decay laws for total energy and scalar variance, and a comparison with data of certain small-scale parameters of the turbulence. Overall, theoretical results appear in satisfactory accord with existing data at all Prandtl numbers for which data exist. Certain numerical aspects of this work will continue to be an active area of collaborative research in the coming year.

The bispectra study, begun earlier, was continued and extended to include investigation of scalar bispectra. Bispectra appear to be the simplest measurable dynamical quantities that are sensitive to the nonlinear dynamics of a system. As such, their comparison to experimental measurements should give insight into whatever nonlinear dynamics is active. This work relies rather heavily on interactions with the experimental turbulence group at the University of California, San Diego (Charles Van Atta and Kenneth Helland). Comparisons of theoretically computed temperature bispectra with atmospheric data revealed serious discrepancies between the two, and efforts to understand this problem remain an active area of current research. More effort must be devoted to comprehending the "ramp" structure of the temperature field, and how such apparent large-scale phenomena affect the very small scales. Such a discrepancy between theory and experiments did not occur in the velocity field data.

The thermal convection project has been a potential topic for some time, and it is only now that this project is passing beyond the testing phase. The work is in collaboration with Steven Orszag (Massachusetts Institute of Technology--MIT) and we expect to employ the code to investigate not only thermal convection but also the passive scalar problem and, later, stably stratified turbulence with gravity waves present.

LARGE-SCALE DYNAMICS SECTION

Overview

The Large-Scale Dynamics Section's approach to the problem of predicting the large-scale behavior of the atmosphere is essentially deterministic. That is, even if the forecast is stated in terms of the probability distribution of an ensemble of predictions, each individual member of the ensemble is a prediction based on time integration of a set of deterministic dynamical equations, starting with given initial conditions. There are thus three major sources of error that may contribute to the inaccuracy of forecasts: (1) errors in the initial conditions due to incomplete observations of the atmosphere's current state or to poor analyses of the initial state; (2) defects of the dynamical model itself, e.g., incomplete or incorrect formulation of the physical principles that underlie the model; and (3) errors of numerical approximation and procedure. The route to improved prediction therefore lies through the isolation and estimation of these various sources of error with a view to modifying the model, the method of analyzing the initial data, or the numerical procedure in such a way that the total error is minimized, or at least reduced.

There is growing evidence that the specification of the initial atmospheric state contributes as much to errors in numerical weather forecasts as the mathematical formulation of the model or the parameterization of physical processes.

The process of transforming observed data from irregularly spaced locations at various times to numerical values at the grid points at fixed times is called the analysis of meteorological data. Since the observations are not necessarily fixed in space nor measured at the same time, the interpolation of data is performed in time as well as in space. Although some analysis schemes can incorporate the statistics of observational errors and relationships among different meteorological variables, analysis procedures eventually mix together observational errors and interpolation errors. After the analysis, the data once more go through adjustment, called the initialization, before they are fed in as initial conditions for the primitive-equation models.

In last year's Annual Scientific Report, we reported significant progress in improving the initialization procedure based on a new concept of nonlinear normal-mode balancing. The atmosphere as an oscillating system possesses certain preferred modes of oscillation, called normal modes. By projecting actual motions onto the normal modes of the atmosphere, we can identify the types of wave motions in the atmosphere. With the help of the nonlinear normal-mode balancing procedure, we can suppress the unwanted meteorological noise generated by the primitive equations.

It turns out that nonlinear normal-mode balancing has a wide application not only to initialization, but also to diagnosis of the atmosphere. During 1979, a great deal of research effort was spent in applying the nonlinear normal mode balancing procedure to formulate an analysis scheme which consistently combines the statistical objective analysis or optimum interpolation procedure and the initialization of primitive-equation models.

Our objective of improving objective analysis procedures is, of course, motivated by this year's special event, the Global Weather Experiment (GWE). The GWE, which began in December 1978 and continued throughout 1979, is the major observational effort of the Global Atmospheric Research Programme (GARP). The GARP is an international effort to improve our understanding of the large-scale motions in the atmosphere. The important contribution of the GWE is that the atmosphere and the oceans are monitored globally by all possible means of instrumentation, including satellites and ocean buoys, and that it will fill in the data-void areas of the current surface and upper-air networks, particularly in the southern hemisphere. We have started to analyze the data from the GWE.

Analysis of Data from the Global Weather Experiment

David Baumhefner and Thomas Bettge made a preliminary study of the behavior of the planetary wave structure during the GWE Special Observation Period I (SOP I), January 5-March 5, 1979. The observed 500 mb geopotential and the three-day hemispheric forecasts produced by the National Meteorological Center (NMC) were examined at 40° and 60°N. The planetary waves for this particular period were quite active, with distinct regimes lasting 10-14 days and with rapid transitions to other patterns. There was some indication that forecast skill at three days became worse during these transition periods. Further examination will be made, using the special level III-B analyses now being produced by several GWE data centers. Roland Madden (Climate Section) has analyzed the unusual behavior of wavenumber 1 at high latitude during this period and will be collaborating with us on our future investigations.

Thomas Schlatter evaluated TIROS-N temperature profiles over the United States for a two-week period in late March and early April 1979 by comparing them with similar profiles derived from NMC final-cycle analyses. All profiles consisted of mean virtual temperatures in layers bounded by mandatory pressure surfaces. These layers were up to 200 mb thick. From a sample of over 1500 soundings, Schlatter calculated statistics based on differences between retrieved and analyzed temperatures and stratified them according to sounding type--clear, partly cloudy, or cloudy. Because these temperature differences include both the NMC analyses errors and the TIROS-N retrieval errors, they tend to overestimate the true retrieval errors.

TIROS-N temperatures tend to be too high near the surface, too low through the mid-troposphere, and too high near the tropopause.

These tendencies are accentuated in cloudy soundings. Since the retrieval error changes sign several times in the vertical, the integrated temperature error for an atmospheric column is quite small, less than 0.5°C. In an atmospheric column extending from 1000 to 50 mb, a temperature error of 0.5°C is equivalent to a thickness error of only 44 m. Provided good reference level data are available, it is therefore likely that satellite data are at least as good as radiosonde data in estimating geopotential heights in the lower stratosphere. Root mean square (rms) temperature differences for clear soundings range from 1.5° to 2.0°C in all layers except for the 70-50 mb layer, where the rms difference is near 3.0°C. Cloudy surroundings have larger rms differences than clear soundings, primarily in the lower troposphere.

The horizontal correlation of retrieval error is too large to ignore in any data assimilation scheme that distinguishes among observing systems; it exceeds 0.5 at separation distances up to 500 km. Only a crude estimate of the vertical correlation of retrieval error can be made. This correlation is sizable only between layers close together; it is positive or negative depending upon whether the two layers are on the same or opposite sides of the tropopause.

Horizontal temperature gradients inferred from TIROS-N soundings are consistently too weak. In most cases, the inferred temperature gradient is only 70% to 85% as strong as the analyzed temperature gradient. The S1 scores computed for TIROS-N soundings in each layer are discouragingly poor. The scores improve slightly as the separation between soundings increases. These findings suggest that it is hazardous to compute geostrophic wind shear from satellite-derived temperature gradients. Such an approximation to the actual wind shear will occasionally succeed in troughs, but only because the geostrophic shear overestimates the actual shear in cyclonic flow.

Effects of Initial Data on Forecasting

In order to investigate the sensitivity of predictability of the ultra-long planetary waves to initial data, Richard Somerville, assisted by Boris Shkoller, developed a primitive-equation model to make hemispheric or global real-data forecasts. To reduce as much as possible the effects of physical processing on forecasting, the model incorporates only limited physics, namely, orography, convective adjustment, and surface friction. Numerically, the model is similar in structure to the Goddard Institute for Space Studies model except that the present model has a finer horizontal resolution of 2.5 degrees in longitude and latitude. The 2.5-degree grid for the present model yields substantially improved forecasts relative to a 4-by-5-degree grid. Despite the lack of comprehensive parameterizations of source/sink terms, the model's forecasting skill is comparable to that of operational models.

This model was used to examine the influence of southern hemisphere data on forecasting weather in the northern hemisphere. Somerville and Baumhefner found that the ultralong wave forecasts produced by the hemispheric version of the model are markedly less skillful that those made by the global version, especially in the latter part of the forecast period (five days). When the initial state of the hemispheric version was modified by using extrapolated data in the tropics instead of analyzed observed data, the skill of the prediction was degraded further, and the effect was apparent early in the five-day period.

The hypothesis that some of the planetary wave forecast error was caused by poor data analysis in the tropics and/or integration in the hemispheric domain was further examined by Baumhefner, using the Bourke-Puri Australian spectral model and the Branstator spectral model. Based on the same set of initial data, the spectral models essentially reproduced the same change in the error fields as found in the Somerville finite-difference model. However, the change in error was somewhat less and the overall effect was more data-dependent.

Joseph Tribbia investigated the mechanism by which a data deficiency in the tropics or southern hemisphere influences forecasts in the northern hemisphere in a relatively short period of time. As a starting point of the investigation, the shallow-water equation model was used to see how much of the midlatitude sensitivity is explained in terms of simple barotropic dynamics. It appears that the large-amplitude height deviations of the planetary-scale waves at 40°N may be caused by the meridional propagation of large-scale gravity waves, particularly of the Kelvin waves, generated artificially by the lack of southern hemisphere data or by the extrapolation technique.

If the presence of large-scale gravity-inertia waves in the initial data does explain a significant portion of midlatitude variance, then the observed longwave sensitivity may be an initialization problem and not due solely to an information deficiency.

Nonlinear Normal-Mode Initialization (NLNMI)

The latter conjecture on the effects of initial data on forecasting clearly suggests the need of combining an initialization procedure with the meteorological data analysis. As mentioned previously, we now have a good understanding of the problem of data initialization through the nonlinear normal-mode balancing.

One way to combine the analysis and the initialization is to utilize the four-dimensional data assimilation technique that has been developed to cope with the large quantities of asynoptic data received from the new remote observing system. In this analysis method, an atmospheric model is integrated in time with observed data inserted into the model whenever they become available.

Roger Daley and Kamal Puri (Australian Numerical Meteorological Research Centre) examined the four-dimensional data assimilation process in terms of the normal modes of the assimilating model and the slow-manifold concept of Leith. The problem of "data rejection" and the spurious excitation of transient gravity waves can be shown to have a simple geometrical interpretation in the slow-manifold methodology. Using these ideas, it is possible to define an ideal assimilation technique. Various realizable assimilation techniques which approached this ideal have been proposed and tested.

David Williamson and James Sethian (University of California, Berkeley) continued development of a normal-mode package for the global Somerville-Shkoller model. The complete set of normal modes of the model has been found and an expansion procedure developed to project model grid point fields onto normal mode space.

The NLNMI procedure evaluates the gravity-inertia wave components diagnostically. Hence, if this initialization procedure is applied at every time step of integrating a primitive-equation model, the procedure acts as a filter of the time evolution of gravity-inertia waves, and gravity waves behave passively, responding to the nonlinear interactions of slow, meteorologically significant waves. Daley investigated the application of nonlinear normal-mode balancing to the Bourke-Puri Australian spectral model to take a longer time step than that normally required for solving the primitive-equation model explicitly. Daley found that the scheme is numerically stable and accurate and can be easily implemented compared with the semi-implicit technique.

Williamson, Joseph Wakefield, and Thomas Mayer developed the normal-mode initialization procedure for the third-generation general circulation model (GCM). This package will be introduced into the GCM to allow use of longer time steps and will be a very useful tool for diagnostic studies.

One problem that has been noticed by all groups who have applied NLNMI to analyses of observed data is that in some cases the procedure produces relatively large changes in analyses even over data-rich regions. Williamson, Daley, and Schlatter began a project to determine the source of imbalance in the analyses. Potential sources are the analysis or interpolation methods themselves, errors in the observed data, data-void regions, or significant differences between balanced atmospheric states and the corresponding balanced model states. Using simulated balanced observed data, the multivariate optimum interpolation scheme developed at NCAR, and a spectral barotropic model with its associated normal-mode procedure, they are in the process of isolating the various potential sources.

In the design of a rational global observing system, one of the most important questions is, What are the best variables (wind, temperature, etc.) to observe for the optimal specification of the initial conditions for a numerical forecast model? Daley investigated this question, based on the slow-manifold concept of Leith and the geostrophic adjustment theory, and found that under most conditions wind measurements optimally specify the initial state.

Using a low-order, spectral f-plane model, Tribbia studied conditions under which nonlinear normal model balancing does not lead to realizable velocity fields. The relationship of this nonrealizability condition to the standard ellipticity condition for the classical nonlinear balance equations was examined. The results of time integrations have shown that gravity-wave excitation is inevitable. A similar analysis of local circulation systems was performed with a high-resolution shallow-water model on the sphere. The relationship between the local f-plane results and the global results was analyzed showing a strong correlation between regions of nonrealizability and the breakdown of the nonlinear normal-mode iteration scheme. Tribbia concluded that moderately strong anticyclonic disturbances in the equatorial region can act as regions of energy exchange between rotational and gravitational modes. Also, the climatological existence of these regions implies the necessity of forcing to maintain them in the atmosphere and in numerical models.

To represent atmospheric data spectrally in three indices (zonal wavenumber, and meridional and vertical modal indices), Akira Kasahara and Puri proposed to use three-dimensional normal-mode functions (NMFs) to express the wind and mass fields simultaneously. The NMFs are constructed from the eigensolutions of a global primitive equation model and they are orthogonal functions. The vertical parts are obtained from the solutions of the vertical structure equation with the equivalent height as the eigenvalue. Each vertical modal index is associated with a different value of the equivalent height. The horizontal parts of NMFs are Hough harmonics with zonal wavenumber and meridional modal index as two-dimensional scalings. The expansion of global data in terms of NMFs permits the partition of energy into two distinct kinds of motions--gravity-inertia modes and rotational modes of the Rossby/Haurwitz type. Both kinds of motion are also partitioned into different vertical modes. Results of the spectral distribution of atmospheric energy, obtained from hemispherical data of the NMC, were analyzed. Information obtained will be useful in selecting proper horizontal and vertical computational resolutions for representation of atmospheric data.

Williamson and Jean-Pierre Volmer (French Meteorological Office) continued to investigate the use of spectral representations for the vertical coordinate in atmospheric models. Spectral methods have proven to be useful for horizontal approximations in atmospheric models; however, there have been only a few attempts to use spectral approximations in the vertical. Williamson and Volmer concentrated on the use of Laguerre functions applied to the vertical coordinate $-\ell n\sigma$. These functions are Laguerre polynomials times an exponentially decreasing factor and thus go to zero exponentially with height. Because of the vertical integrals in the hydrostatic equation, the constant function must also be added to the basis set, resulting in the need for a closure assumption in the thermodynamic equation. They developed a three-dimensional global spectral model to find out if the misrepresentation due to various closure assumptions is compensated by the numerical advantages of the spectral method. This work is continuing.

Studies of Planetary-scale Waves

Nicholas Lordi (Environmental Research and Technology), Kasahara, and Shih-Kung Kao (University of Utah) formulated a 26-level primitive-equation spectral model for the study of stratospheric sudden warmings. Two cases for wavenumber 1 forcing at the tropopause were studied, one allowing wave-wave interaction as well as wave-mean flow interaction, and the other allowing only wave-mean flow interaction. The evolution of the warming due to wavenumber 1 forcing in the case of wave-wave interaction compares favorably with that of the major warming of January-February 1973. Nonlinear wave-wave interaction appears to be important in the evolution of the flow field (and the temperature field) in the middle to upper stratosphere, as manifested by the split in the initial polar vortex into a quasi-wavenumber 2 pattern during a wavenumber 1 forced warming. There is evidence that waves up to and including wavenumber 4 play an important role in the evolution of meteorological fields during a stratospheric sudden warming.

Kasahara also completed research concerning the effect of zonal flow on the free oscillations of a barotropic atmosphere. Madden recently presented evidence of westward propagating planetary-scale waves (wavenumber 1), clearly identified at a five-day period and a period near 16-18 days. Madden suggested that these waves are free oscillations of the external type with the equivalent height of 10 km in Laplace's tidal equations. Kasahara calculated normal modes of Laplace's tidal equations by taking into account a climatological zonal motion and determined the effect of realistic mean zonal wind distributions on the period and the horizontal structure of free oscillations of the second kind (Rossby/Haurwitz type). The results show good agreement with those based on long records of surface and upper-air data and analyzed by Madden.

Grant Branstator has recently developed a global, steady-state, forced shallow-water model which is linearized about an arbitrary background flow. The model has biharmonic diffusion, linear drag, and orography. It uses Hough functions as basis functions. The model can be used in two ways: to simulate the steady response of the external mode to a given basic state and forcing, and to diagnose the forcing required to produce a given flow.

This model is being used to investigate the forcing required to produce the observed steady response of the atmosphere's external mode. In preliminary experiments, the observed mean January 500 mb height and wind fields were used as a first approximation to the external mode's steady response to midwinter forcing. It was found that a significant part of the forcing required to give this flow could be attributed to the earth's mountains, but a substantial amount of additional forcing is needed to reproduce the observed atmospheric state. The nature of additional forcing is currently being examined.

Of course, a model as simple as this one cannot be expected to simulate perfectly the steady external mode. However, the importance of some omitted processes (e.g., nonlinearity) can be determined, while the effect of others (e.g., baroclinic processes) is thought to be small. In spite of the model's drawbacks, the study will provide insight into the various processes which force the atmosphere's external mode.

Diagnostic Studies of Synoptic-scale Systems

The section also devoted time to research related to the regional-scale analysis and prediction problem. Baumhefner and Donald Perkey (Mesoscale Research Section) have initiated a limited domain, high-resolution model forecast intercomparison to benchmark the 48-hour forecast skill of several limited-area models. Initial data, including mass, motion, and moisture fields, for eight interesting events over data-rich North America have been supplied to several modelers. By defining a standard verification format to reduce problems involving different forecast domains, the skill of each model is evaluated, especially the smaller scale quantities (e.g., vertical motion, vorticity, etc.). A preliminary evaluation of two models, the NCAR limited-area version of the second-generation GCM and the Drexel University/NCAR regional-scale model, shows that the skill in forecasting the large-scale features is very good. However, the finer scale features of the forecasts evolve quite differently in the two models, and both models have lost skill in forecasting the small-scale features of vorticity and kinetic energy by 36 to 48 hours.

Bettge and Baumhefner studied the effects of increases in horizontal and vertical resolution upon prediction of a baroclinic wave by separating the spatial scales of each forecast. With the exception of horizontal (2.5° to 0.625°) and vertical (3 km to 0.75 km) resolution, no model changes were made. Increases in horizontal resolution had a much greater effect than did increases in vertical resolution at all scales. While the finer resolutions more accurately predict amplitudes, especially in the smallest scales, phase errors are changed very little. Better skill is achieved during the 24-hour forecasts with the finer resolutions, but errors in phase produce equal or lower skill in the medium and fine scales by 48 hours.

Schlatter and Dayton Vincent (Purdue University) have investigated the possibility that deep and widespread convection may supply kinetic energy to the synoptic-scale flow. In many studies of the kinetic energy budget in limited areas, the dissipation term, which is usually calculated as a residual, comes out with the wrong algebraic sign. The "extra" energy which causes the wrong sign must be accounted for. By examining the kinetic energy budget of a developing extratropical storm as it interacted with a tropical depression, Schlatter and Vincent found good correspondence between the areas of positive residual and the areas of strong convective activity. The "extra" kinetic energy appeared first in the 700-500 mb layer, but later was more evident from 500 mb to 300 mb. The amount of extra energy compares favorably with predictions based on a theory by Miller and Moncrieff about the conversion of convective-scale available potential energy to the large-scale kinetic energy.

Williamson continued testing his vortex representation in which individual high- and low-pressure systems are represented by mathematical functions with a few parameters for each system. The parameters for a representation at any time are determined by a nonlinear least-squares fit to the observed data at that time. One advantage of this representation is that the parameters represent properties of highs and lows commonly considered by meteorologists such as magnitude, location, size, and shape. For a case in December 1970, Williamson showed how the parameters can be used for forecast verification. This case also illustrated the potential of using the parameters as a basis for statistical correction to numerical forecasts.

Wakefield and Linda Thiel (Computing Facility) have brought the section's Interactive Graphics System (IGS), a minicomputer-based analysis and display system, from the developmental phase into an operational status during 1979. The IGS is a tool for enhancing the quality and efficiency of the NCAR objective analysis system and for displaying and processing observed data and model output. The IGS now facilitates the subjective assessment of the objective analysis product. It allows rapid access to the analyses and easy comparisons of raw data to analyzed fields, as well as intercomparisons among different fields at the same or different levels in the atmosphere. Subjective editing of the data is also possible in an interactive manner directly through the graphics displays themselves, without any knowledge of the data organization.

The IGS also supports other projects requiring data editing and graphics display. Within the section, Baumhefner and Bettge are using the system to display the output from a regional forecast model, and Daley and Mayer are processing data for a joint Goddard Laboratory for Atmospheric Sciences/NCAR study of model analysis errors. Other users during 1979 were Paul Julian and Dennis Shea (Climate Section), who edited tropical constant-level balloon data; and Walter Roberts, Roger Olson, and Dean Shroeder (Aspen Institute), who examined the sun's influence on global circulation. The IGS is in a state of continual development, and its features are designed to accommodate the needs of a broad range of users.

MESOSCALE RESEARCH SECTION

Administration and Planning

The Mesoscale Research Section (MRS) included on 31 December ten Ph.D. scientific positions and seven supporting staff. Most research activities can be classified into one of three categories: convective storms, boundary layer, and subsynoptic meteorology, with significant interaction among all of these. Project SESAME remains a principal observational focus for all of these activities. The transition between the diminishing activities of the GARP Atlantic Tropical Experiment (GATE) project and related typical studies and the strengthened convective storm and boundary-layer efforts is now essentially complete. By 1 January 1980, one Ph.D scientist and one support staff will have been added to each of these latter two areas. The move to a nearby building, in which the Convective Storms Division and MRS will be collocated, is scheduled for May 1980.

During the past year, the MRS completed procurement of a satellite computer system. The computer was installed in June 1979 and has been in productive use since July. It is expected that the Remote Job Entry function of the system (which allows scientists to submit jobs to the CRAY-1 and Control Data Corporation 7600 computers from the satellite computer) will be in operation some time in February 1980; all other functions of the satellite computer are already in use. Very powerful capabilities result when a convenient interactive system like this is used in conjunction with the computing power of the CRAY-1.

Severe Storms Research

Project SESAME 79. The MRS participated in the first field phase of Project SESAME, a multi-agency multi-year program of intensive investigation of severe convective storms. The field program occupied most of April, May, and early June 1979 and involved special observations from stations and facilities spread over the southwestern and central United States, as well as an intensified program of satellite sensing. Douglas Lilly was chairman of the SESAME Steering Committee through the observational program and remains a member, along with a more recent appointee, John Wyngaard. Within its limitations of observational facilities and duration, SESAME 79 was effective and successful. Probably the most unique aspects of the data set are the records from the special regional sonde network, which operated during the 10 April tornado outbreak and two other interesting synoptic events, and the coordinated three-minute western and eastern satellite imagery from the Geostationary Orbit Environmental Satellite, taken during the daylight hours of about ten observational days. The storm-scale operational period was mostly characterized by episodes of wet but not severe convection, but several notable storm events passed through and were observed by the intensively instrumented network. The most serious need for future SESAME-like programs remains a reliable and economic wind and humidity sounding array.

Numerical Simulation. During 1979 a major portion of the convective storm research conducted by Joseph Klemp progressed in collaboration with Robert Wilhelmson (University of Illinois) and Peter Ray (National Severe Storms Laboratory) as a part of the Cooperative Observational and Modeling Project for the Analysis of Severe Storms. Intercomparisons of three-dimensional model simulations and analyzed Doppler data for a supercell, tornadic storm revealed significant success in representing important features of the storm. These combined results suggest a mechanism for formation of strong rotation through storm splitting, describe the self-preserving nature of the mature storm, and reveal that the decline of the storm is caused by cold downdraft outflow near the ground progressing cyclonically around the updraft, restricting its moisture supply. Storm simulations were also conducted to supplement Doppler radar observations which documented the apparent merging of two strong isolated storms into a single storm. As part of the continuing efforts to improve both modeling and observational capabilities, multi-Doppler radar data sets have been simulated by scanning storms generated within the three-dimensional model domain. Various experiments are currently being conducted to evaluate and improve the reliability of Doppler data-analysis procedures.

Collaboration has continued with Richard Rotunno (Cooperative Institute for Research in Environmental Sciences) in the study of subcloud-scale tornado dynamics. Initial experiments with rotational flow in a higher resolution version of the cloud model have generated strong concentration of low-level rotation and associated warm downdrafts along the central core. Recently the cloud model has been converted to reinitialize itself and provide higher resolution within a smaller subsection of the integration domain. With this capability the model will simulate flow within the rotating updraft obtained from a cloud-scale simulation.

With the assistance of Morris Weisman and Ronald Krubeck, Klemp has converted analysis routines for model output and radar data to the MRS Satellite Computer. This minicomputer has greatly enhanced the analysis capabilities of the convective storm project, providing convenient and powerful procedures for interactive evaluation of data sets as well as computation and display of trajectories and management of data and programs.

John Brown and Kevin Knupp (Colorado State University) completed analysis of a unique anticyclonic-cyclonic tornado pair and its parent severe thunderstorm. Despite the apparent rarity of strong anticyclonic tornadoes, major structural features of the parent thunderstorm were in correspondence with the supercell model proposed by Browning and others. A strong low-pressure area of $\sim$50-km scale, induced by the convection and centered south of the tornadoes, appears to be associated with their unique tracks and with the development of the anticyclonic tornado.

Motivated by his study of Florida cumulonimbus clusters completed earlier, Brown, in collaboration with Klemp, has been investigating the feasibility of using the Klemp-Wilhelmson cloud model to investigate the water budget of clouds growing in environments with weak shear and substantial available buoyant energy. It appears that accurate single-cell cumulonimbus simulations in such environments can only be obtained using horizontal mesh lengths of a few hundred meters or less, much smaller than is necessary for simulation of persistent supercell thunderstorms. Experimentation has been limited to environments with vertical wind shear uniform in direction so that symmetry about the direction of shear could be assumed. Despite environmental vertical wind shear $\lesssim 10^{-3} s^{-1}$ in the simulations, a strong vortex doublet develops in the updraft and appears to play an important role in the water budget through entrainment of environmental air into the downshear side of the updraft.

Aircraft Observations of Tropical Cumulonimbus Clouds. Edward Zipser and Margaret LeMone have virtually completed a major analysis project describing the essential characteristics of cumulonimbus clouds observed in GATE. While the GATE data set is of much higher quality than historical sets, some useful comparisons are possible. The updraft and downdraft cores in GATE clouds are weaker by a factor of two to three than those measured in the continental United States during the Thunderstorm Project. They are only slightly weaker than hurricane cumulonimbus drafts. The diameter distributions are similar to those in other data sets. These new quantitative results will require some time to be assimilated by modelers. One question raised by these results is, How is it that tropical cumulonimbus clouds can reach the upper troposphere at all if their updraft cores in mid-troposphere are 1-2 km in diameter with vertical velocities often in the 2-5 m s^{-1} range? We believe that a part of the answer is to be found in the mesoscale environment.

A Possible Solar-weather Linkage. The observations of a substantial change in the electrical properties of the midtroposphere resulting from major solar events (70% increase in air-earth current) has prompted research into the effect these changes have on thunderstorms and other highly charged clouds of the troposphere. Doyne Sartor has applied these observations to theoretical growth of electrical conditions in thunderstorms and found that vorticity created this way compares with the rate of vorticity production dynamically on the convective scale, the mesoscale, and possibly on the small synoptic scales. The calculations will be extended to other types of clouds in the mesoscale range.

Sartor and William Boeck (Niagara University) and Donald Olson (University of Minnesota) have mounted a long-term effort to extend the Mauna Loa Observatory measurements of air-earth current density (product of the conductivity and the electric field) to include automatic IR and solar-cell observations of clouds. Long-term benchmark observations demonstrate the observatory's superior qualities for obtaining atmospheric electric data.

Boundary-layer Research

Experiments. Donald Lenschow and Borislava Stankov, along with J. Chandran Kaimal (National Oceanic and Atmospheric Administration/Wave Propagation Laboratory--NOAA/WPL) compared concurrent aircraft and tower measurements at 150 m and 300 m above the ground obtained during the Boulder Atmospheric Observatory (BAO) Site Evaluation Study and found that in the convective daytime boundary layer the means, variances, and spectra of wind and temperature agreed well with each other even in a region of moderate horizontal surface inhomogeneity. The turbulent flux of ozone was also measured during two of the BAO flights using a fast-response ozone sensor developed by Anthony Delany (Atmospheric Quality Division) and Donald Stedman (University of Michigan). This may be the first successful attempt to measure directly the turbulent flux of a trace atmospheric constituent (other than water vapor) in the boundary layer from an aircraft. It may now be possible to measure all the significant terms in the mean ozone budget from an aircraft except for the contribution of chemical reactions, which may be estimated as a residual.

During May, Lenschow and Stankov participated in the SESAME Nocturnal Boundary Layer Experiment. An NCAR Queen Air aircraft and a tethered balloon were used to probe the nocturnal boundary layer from the surface on up through the level of the nocturnal jet. A special radiosonde network was also implemented in support of this experiment. The aircraft measured values of wind shear and lapse rate as high as $0.4\ s^{-1}$ and $0.3\ K\ m^{-1}$, respectively, in the vicinity of the nocturnal jet. They expect to continue analysis of these data jointly with Larry Mahrt and Robert Heald (Oregon State University) and G. David Emmitt (University of Virginia).

In September, Lenschow and Stankov flew the two NCAR Queen Air aircraft in formation in an attempt to measure the coherence between measurements of winds, temperature, and humidity on each aircraft as a function of both horizontal and vertical separation. The data from each airplane appear to be satisfactory, but no coherences have as yet been calculated. Leif Kristensen (Risø National Laboratory, Denmark) is planning to cooperate in this study. An improved fast-response ozone sensor, developed by Stedman and Richard Pearson (University of Michigan) was also flown on one of the Queen Airs. Preliminary analysis indicates that the ozone sensor has significantly less noise than the previous instrument, but that further noise reduction would be desirable. The ozone-flux measurements corroborated those made earlier during the BAO experiment, indicating a flux of ozone into the ground of from 0.1 to $0.2\ \mu\ gm\ m^{-2}s^{-1}$.

Fair Weather Boundary-layer Analysis. While analyzing subcloud layer spectra from several GATE fair weather days, LeMone found peaks at 10 km to 20 km--scales several times larger than expected for a mixed layer of depth 500-600 m. Analysis of several "sea-surface mapping" patterns at 510 m (several parallel flight tracks spaced about 10 km apart) reveals that the peaks were associated with well-defined banded structures. The alignment of the structures with respect to the wind was different for different cases. They were clearly associated, however, with cloudiness, which was concentrated over regions of moist, cool upward-moving air. LeMone and Rebecca Meitín are analyzing several cases to determine the wind field, structure, and alignment of the bands with the mean wind or shear, and the sources and sinks of energy.

Data from the Electra aircraft taken during the Air Mass Transformation Experiment (AMTEX) were used by Lenschow, Wyngaard, and Stankov to construct budgets of turbulent kinetic energy, temperature and humidity variances, and temperature and humidity fluxes, as well as mean temperature and momentum in a baroclinic convective boundary layer. These results are of considerable importance for testing and refining boundary-layer models. In addition, Lenschow and Pamela Stephens (formerly of University of Oklahoma) used the AMTEX aircraft data to analyze the structure of thermals. They found that thermal properties such as size and number, as well as velocity, temperature, and humidity excesses and variances followed mixed-layer scaling throughout most of the boundary layer.

Wyngaard and LeMone completed an analysis of the turbulent refractive index structure of an entraining convective boundary layer. They derived similarity expressions for the vertical profiles of ${C_T}^2$, C_{TQ}, and ${C_Q}^2$ (the temperature, temperature-humidity, and humidity structure parameters) in the surface and mixed layers, and they also obtained expressions for the peak values of these structure parameters in the overlying entrainment layer. These expressions were successfully tested with data from a number of sources. A manuscript based on this work has been submitted for publication.

Modeling

The Sommeria-Deardorff three-dimensional numerical model of the boundary layer was converted to the CRAY computer by Robert Ubelmesser, Jean-Luc Redelsperger (Centre Nationale de la Recherche Scientifique, C.N.R.S., Paris), and LeMone. The model simulates a fair weather boundary layer with clouds. Redelsperger extended the model to include precipitation and has completed a simulation, the results of which he and Gilles Sommeria (C.N.R.S.) presented at the International Conference on Tropical Cyclones in Perth, Australia, 25-29 November 1979.

Wyngaard completed a critical analysis of the state of second-order modeling of the convectively driven planetary boundary layer.

He found that recent advances have greatly improved transport (third-moment divergence) parameterizations in these models, but that substantial difficulties remain in current parameterizations of dissipation rates and pressure covariances.

Cloud-topped Mixed Layers

A detailed analysis of the data from the 1976 Stratospheric Exchange Experiment (STRATEX) has begun. During this experiment, the NCAR Electra made five flights off the California coast; each flight lasted about six hours and covered several levels below and within the low-level stratus layer.

The goals here are to understand the structure and dynamics of cloud-topped boundary layers. We will analyze the STRATEX data set to determine the mean and turbulent structure, paying particular attention to assessment of the instrument performance in the cloud environment. Richard Brost, Lenschow, Sartor, and Wyngaard are involved in this effort.

Subsynoptic Analysis and Prediction Research

NCAR/Drexel Prediction Model. Research this past year using the Limited Area Mesoscale Prediction System, developed as part of a joint project between Perkey and Carl Kreitzberg and associates (Drexel University), has concentrated on testing and evaluation of the system on several cases. Included in these cases are the eight events chosen by Baumhefner and Perkey for limited-area, fine-mesh model intercomparison studies. Preliminary results comparing this model with the limited-area version of the second-generation global circulation model and two NMC models were presented at the Fourth Conference on Numerical Weather Prediction, in Silver Spring, Maryland, 29 October-1 November 1979. All tests to this date indicate that the system compares quite favorably with other models of this type.

In addition to NCAR and Drexel University researchers, several other scientists have used the system this year. Douglas Boudra (University of Miami) used the system to initialize a fine-scale model of the Great Lakes. Results from his studies were presented at the Fourth Conference on Numerical Weather Prediction. David Houghton and Dong Lee (University of Wisconsin) also presented at the same conference results of their studies on the insertion of mesoscale satellite cloud-derived winds into a mesoscale model. Other users included Martin Leach (Brookhaven National Laboratory), Frederick Hassler (Goddard Space Flight Center), and Tsing-Chang Chen (Iowa State University).

Mesoscale Fields and Organized Cumulonimbus Systems. A detailed study of a mesoscale cumulonimbus line by Zipser, Meitín, and LeMone is also near completion. The relationship between the cumulonimbus scale and the mesoscale, usually obscure, was clarified in this instance. Quantitative mass transports in cumulonimbus cores agreed very closely with transports computed on the mesoscale. The low vertical velocities in convective cores were reflected in the large tilt of the clouds and of the entire cloud system. Mesoscale ascent at low levels ahead of the system appears to be a necessity to initiate and maintain the cumulonimbus ascent. Further, mesoscale ascent in the "anvil" above the melting level, directly above the precipitation-driven mesoscale descent region, is an important part of the entire system.

MONEX Observations and Analysis

Sartor is spending one-half of his time with the Monsoon Experiment (MONEX) Project Office processing the cloud physics data and related air-motion measurements from MONEX '77 (Somali Jet), Winter MONEX '78 (Malaysia), and Summer MONEX '79 (Arabian Sea). The processed data are to be made available to the other MONEX investigators.

A numerical method for prediction models on nested grids has been developed by Katsuyuki Ooyama, and one-dimensional tests with the shallow-water equations have demonstrated its remarkably clean handling of interface problems. The method, tentatively called a quasi-pseudospectral method, is a theoretical spin-off of his objective data analysis method, based on the spectrally controlled representation of fields by local cubic splines. His objective analysis of GATE upper winds has been completed. The results will be released to any interested users as soon as an appropriate format is chosen.

Downslope Windstorms

Analysis and experimental prediction of downslope windstorms in the Boulder-Denver area remains a limited but continuing effort in MRS. A five-station telemetered network, developed by MRS and NOAA/WPL, is now in operation along an approximately north-south line through Boulder. Data from it are available at one-minute intervals for research and operation (National Weather Service) purposes. The data will become rapidly available to a larger number of users when the NOAA Prototype Regional Observing and Forecasting Service takes over data management. This network is also being used as a test band for new techniques for obtaining fine-scale wind data at minimal cost.
This winter (January-Februrary 1980) a special program for observing downslope winds and other winter weather phenomena on very fine scales is being conducted by a group of scientists at various institutions, led by NOAA/WPL. MRS will be participating by providing experimental wind forecasts and monitoring parts of the observational network.

CLIMATE SECTION

Introduction

The Climate Section, headed by Robert Dickinson, has continued to develop a research program in response to national needs and scientific opportunities. Various members of the section and other NCAR staff have played a major role in structuring the U.S. National Climate Program; hence, the section's goals and activities coincide with those of the "Climate System Research" component of the National Program, and some of the section's effort is devoted to research in the "Climate Impacts" area.

The Climate Section consists of three research groups: the Climate Sensitivity Group (CSG), led by William Kellogg; the Empirical Studies Group (ESG), led by Chester Newton; and the Global Climate Modeling Group (GCMG), led by Warren Washington. CSG studies the processes important for climate and uses models to reveal the role of their processes in the response of the climate system to external changes such as increasing carbon dioxide in the atmosphere. ESG analyzes historical meteorological observations to establish statistical connections between various features of the atmospheric general circulation. GCMG has been concerned with the development, testing, and operational aspects of large three-dimensional global climate models and coupled ocean models, as well as development of statistical procedures for analyzing the results of model simulations.

Climate Sensitivity Group

The CSG's activities have centered around "focal points," that is, simple model studies, cloud-radiation feedbacks, other physical processes, and certain climate impact studies.

Simple Model Studies. James Coakley and Bruce Wielicki have challenged the basis for the usual derivations of empirical energy balance models (EBMs). They demonstrated that when the parameterization techniques commonly applied to the earth are used on fields generated by a GCM, the resulting EBM, even though it recovers the climate to which it is adjusted, gives large errors in modeling the climate changes exhibited by the GCM. The parameterization techniques evidently fail to account for the feedbacks that govern the GCM climate change. The implication is that similar failures are bound to plague attempts to model the earth's climate. They conclude that in the development of parameterizations more emphasis should be given to physical details and less to curve fitting.

Veerabhadran Ramanathan, in collaboration with Jack Fishman and Paul Crutzen (AQD), has studied the effect of increasing tropospheric ozone on global temperature. This ozone increase is projected from recent chemical modeling of the effects of the CO_2, NO_x, and hydrocarbons emitted from fossil-fuel combustion.

Another important aspect of the fossil-fuel/climate problem that has not yet received sufficient attention in the literature concerns the early detection of a surface warming (due to CO_2 increase) if and when it occurs. Madden and Ramanathan examined this question and concluded, judging from analysis of interannual variability of surface temperatures at 60°N, that the warming predicted by current climate models should be detectable between the present and the year 2000. They also discuss the feasibility of using satellite measurements to isolate CO_2 effects.

Ramanathan, with Robert Cess and Ming-Shih Lian (State University of New York at Stony Brook), has described the radiative heating of the troposphere and surface due to increased CO_2 as a function of latitude and season, and inferred the resultant latitudinal and seasonal warming of the surface using an energy balance climate model.

Advanced Study Program (ASP) student Leo Donner and Ramanathan have developed a model for treating the radiative effects of CH_4 and N_2O and have computed, from the radiative energy budget effect of the present-day concentrations of these species, that these two gases now contribute about 2 K to the global mean surface temperature.

Stephen Schneider and Starley Thompson (University of Washington) have continued the application of their two-level zonal energy balance model to the problem of the transient response of the surface temperature to CO_2 increases. Previously, they pointed out that the vertical mixing between upper and lower oceanic layers would increase the effective long-term heat capacity of the ocean, thereby delaying for decades the approach of the global average surface temperature toward its equilibrium response. They have now considered the approach toward equilibrium of individual latitude zones under two different assumptions for the ocean mixed layer depth: (1) a uniform global value and (2) latitudinal-dependent values. Under both sets of assumptions (but particularly for the second assumption) they found that various latitude zones approached their equilibrium responses for a given CO_2 increase at different rates. For example, 60°S, which is all ocean, approached its equilibrium value about one-half as fast as the equator approached its equilibrium response. These results imply that different regions of the earth will have different transient responses to CO_2 increases. Therefore, perturbations to the horizontal surface temperature gradients for the actual time-dependent CO_2 increases are likely to differ from those that would occur in equilibrium. Consequently, regional climatic anomalies predicted from the equilibrium response of a climatic model driven by a doubling of CO_2 are likely to be significantly different from those given by the transient response which would occur from a more realistic time-dependent, exponential increase in CO_2. The study suggests that considerably more attention must be paid to the characteristics of the atmosphere/ocean/ice system which governs the transient response of the surface temperature to external forcings over decadal time scales.

Schneider, Thompson, and Nuzhet Dalfes (Rice University) applied a stochastic forcing parameterization of transient eddies to the Thompson/Schneider zonal energy balance model to test the sensitivity of the statistical response of the model to variations in several of its physical parameterizations. A principal conclusion from these experiments is that much of the larger noise levels noted (in the model simulations and in observations) in high latitudes compared to lower latitudes can be ascribed to two factors: (1) ice/albedo/temperature feedback, which amplifies local temperature changes; and (2) the low effective thermal capacity of the high latitudes due to extensive ice-covered oceans (or the Antarctic land mass), which results in relatively small heat storage and thus a larger surface temperature response to fluctuations in horizontal energy flux convergences.

Schneider, Thompson, and Eric Barron (University of Miami) applied the Thompson/Schneider zonal energy balance model to boundary conditions typical of Cretaceous times (about 100 million years ago), when the relative amount of oceanic area in the northern hemisphere was considerably larger than now. This was simulated in two ways: (1) a decrease in zonal albedo due to more oceans and (2) a change in zonal thermal inertia coefficients due to altered land/sea fraction. The first factor warmed the climate slightly (about 1°C, but considerably less than the 10°C warming believed appropriate to Cretaceous times). The increased thermal inertia associated with more oceanic areas roughly halved the amplitude of the seasonal cycle of temperature in the northern hemisphere, thereby reducing the extent of winter snow cover, thus decreasing the albedo. This feedback contributed several degrees Celsius of warming to the simulated temperatures. However, the simulated climate was too warm in the tropics and too cold at the poles. Changes in ocean circulation and cloud-top altitude were considered to improve the simulations. The results show that raising the altitude of cloud tops in polar regions several kilometers above present values and increasing oceanic heat flux from tropics to poles can produce more realistic Cretaceous simulations. It remains, however, for more physical models which explicitly compute cloudiness and oceanic motions to be applied to this problem.

Thompson and Stephen Warren (Brandeis University) adapted a version of Ramanathan's radiative/convective model to the problem of the parameterization of outgoing infrared flux to space as a function of surface temperature. Such a parameterization is important for energy balance models. They found that water vapor amount played an important role in the humid tropics, and its neglect could lead to considerable errors for surface air temperatures near 300 K. They devised several simple expressions which fit the output of the radiative/convective model. These expressions can be used in energy balance models and are more accurate than the usual linear forms (even those with a cloudiness factor) currently used in most energy balance models.

Response of Arctic Ocean Ice Cover to a Climatic Warming. Kellogg collaborated with Claire Parkinson (Goddard Space Flight Center) in a theoretical study of how the Arctic Ocean ice pack would respond to the kind of warming that would accompany a doubling of carbon dioxide. The sea ice model used was that developed by Parkinson and Washington (updated last year), a large-scale time-dependent model that takes into account four layers and their interfaces (ice, snow, ocean, and atmosphere) and includes seasonal effects of both thermodynamic and dynamic processes. The result was that a 5°C increase in mean atmosphere temperature was sufficient to eliminate the model's ice pack in summer, a condition that could exist early in the next century. However, the ice pack returned in winter in the central part of the ocean even when the upward flux of heat from the ocean was assumed to increase by an order of magnitude more than its present value. It was noted that paleoclimatic evidence indicates that the Arctic Ocean has not been ice-free for a million or more years.

Cloud/radiation Feedbacks. Ramanathan has devoted considerable effort to improving our understanding of the nature of feedbacks arising from cloud/radiative interactions. The first step is, of course, to develop realistic treatment of these processes in the GCM, based on available observational and model studies. This development process, initiated last year, was completed this year in that a new treatment of clouds and their radiative interactions has been incorporated and tested in the GCM. The new model adopts a relatively self-consistent approach to the problem by relating the cloud parameters (such as cloud optical properties; cloud tops and bottom) to the large-scale fields generated by the GCM. For example, the albedo and emissivities of clouds formed by grid-scale saturation are calculated from their liquid or ice-water content by using the theoretical radiative transfer calculations of Graeme Stephens and Warren Wiscombe. The model also forms subgrid-scale clouds of convective and boundary-layer types. The tops of convective clouds (of deep cumulus and cb types) are determined by the vertical profile of equivalent potential temperature. The subgrid-scale boundary-layer clouds (stratus and fog) are consistent with the static stability of the lowest layer. Preliminary results with the GCM indicate that the new scheme simulates reasonably well the regional locations of the stratus clouds.

Coakley and Wielicki have developed algorithms for determining cloud amounts and heights from a combination of radiances measured with satellite-borne infrared sounders and operational analyses of temperature and humidity profiles. By testing the algorithms with synthetic data, Coakley and Wielicki have found that, whereas fairly accurate information should be obtainable for middle- and upper-level clouds ($p < 500$ mb), measurement noise and errors in the temperature and humidity profiles prohibit the recovery of information on low-level clouds ($p > 700$ mb). Some improvement in the retrieved cloud properties appears possible through reducing the impact of temperature and humidity error on the estimated clear-sky radiances. To overcome these errors, Coakley has begun to explore a new approach for obtaining clear-sky radiances for partially cloud-covered fields. Even with reduced errors, however, the remaining measurement noise makes impossible the recovery of properties for low-level clouds. To obtain these properties, it will be necessary to rely on radiances in the visible spectrum from high-resolution scanning radiometers. The development of retrieval algorithms for the high-resolution scanner data is planned for the coming year. Such algorithms, in addition to those developed for the infrared sounder, are to be used to characterize the cloud fields observed during the Earth Radiation Budget Experiment (ERBE) in 1983-1984. A proposal prepared by Ramanathan and Coakley to participate on the ERBE science team was recently approved by the National Aeronautics and Space Administration. Ramanathan's focus will be on the use of the data to validate GCM cloud-radiation parameterizations.

Other Physical Processes. Wiscombe and Warren have developed a detailed radiative transfer model for the spectral albedo of snow. This model provides a description of the variations of albedo with solar zenith, snow depth, and grain size. Snow grains increase in size with time, depending on temperature and other physical conditions. It was found in this study that it was impossible to match calculated snow albedos in the visible to measurements in the northern hemisphere unless small carbon-like particles were added to the snow crystals. This suggests that industrial activities may already have significantly decreased albedos in the Arctic from their natural values.

Societal Impacts. Schneider spent considerable time in 1979 on a number of projects related to climatic impact assessments. As a United States delegate to the World Climate Conference in Geneva, he was assigned to the working group on climatic impacts and helped to draft the report of that group. He served as cochairman (with Elise Boulding, Dartmouth College) of the panel on Social and Institutional Responses of the Department of Energy (DOE)/American Association for the Advancement of Science Workshop on the Impacts of a CO_2-induced Climate Change. He and Boulding are leading a subgroup of that panel in preparing a research plan for the DOE in the area of social responses to possible CO_2-induced climatic changes.

Schneider, with Robert Chen (National Academy of Sciences), completed a climatic impact assessment of the physical, economic, social, and policy implications of a hypothetical 5-8 m sea-level rise associated with a long-term CO_2-induced warming. Schneider also participated in the CO_2 and the Climatic Impacts Groups of the Climate Research Board's summer review of the U.S. National Climate Plan. He also became a working member of the Committee on Social

Indicators of the Social Science Research Council, whose work is connected with problems of measurement and quantification in the social sciences. He has been asked to assess methods to measure and quantify indices dealing with environmental quality.

Kellogg has been working with the Aspen Institute to develop a plan for the climate impact component of DOE's CO_2 Climate Change Program. Earlier in the year Kellogg served on the Secretariat of the World Meteorological Organization in Geneva, where he was responsible for preparing the plan for the World Climate Programme and assisted in organizing and conducting the World Climate Conferences.

Empirical Studies Group

The ESG continued studies on global and regional scales to identify physical processes at work in the observed atmosphere, the natural variability of climate, and interrelations among physiographical regions.

In particular, Harry van Loon continued a study of the association between horizontal eddy transfer of sensible heat by the quasi-stationary eddies and various features of the general circulation in winter. Since the poleward heat flux on the west side of the Pacific trough is nearly as large as that in all three other preferred areas of poleward heat flux, it seemed likely that changes in the flux in the Pacific trough would be compensated by changes of the opposite sign elsewhere, everything else being equal. This turned out to be so in the sense that the stationary-eddy flux over the Atlantic Ocean is negatively correlated (-0.7 for 31 winters) with that over eastern Asia. In addition, for winters as a whole, strong poleward heat flux in the quasi-stationary eddy over easternmost Asia tended to be accompanied by anomalously high pressure over the Arctic in the Atlantic sector and by low pressure over the subtropical Atlantic and central and southern Europe, and conversely when the flux over Asia was weak.

Circulation statistics for the southern hemisphere were being computed by van Loon from the six years of daily analyses made in the Australian Meteorological Service. The results show that the objective analysis scheme used is flawed, and that the data set cannot be used, for example, for energy balance calculations. It seems, however, good enough for resolving features of large time and space scales, such as seasonal means of wavenumber 1. The investigations are being extended to include the operational GWE analyses to see if the same flaws appear in these, and a comparison is being made with the NMC operational analyses of the southern hemisphere for the same period.

Madden continued studies comparing variations of daily temperatures with those of time-averaged temperature. The work (earlier done to establish these variations at individual stations and grid points) was extended to large-scale patterns by computing the eigenvectors of both daily and monthly mean temperatures over the United States. The expected sampling variability of monthly means estimated earlier by Madden and Shea was extended to seasonal means for comparison with seasonal forecasts made by the Climate Section at Scripps Institution of Oceanography.

Madden completed a review paper of the observational evidence for large-scale, traveling Rossby waves. During a visit to the Freie Universität in Berlin, he began diagnosing a wave present during January 1979 to establish its horizontal and vertical structures and to determine its effect on the large-scale circulation. Madden also contributed to work on determining the geographical variations in the vertical structure of geopotential height fluctuations shown in studies by John Wallace and David Gutzler (University of Washington) and Maurice Blackmon (ASP).

Newton, with Stanley Barnes (NOAA/Environmental Research Laboratory--ERL), completed a review on thunderstorm-environment interactions in relation to synoptic-scale systems and regional climatology.

Julian and Shea continued their analysis of the Tropical Wind Energy Conversion and Reference Level Experiment data. They have participated in the GWE dropwindsonde and Constant Level Balloon (CLB) programs for GWE SOP I and II. The data processing is continuing on the dropwindsonde data and has been completed for the CLB data.

Global Climate Modeling

A Coupled Atmosphere and Ocean GCM Experiment. A coupled three-dimensional GCM of the atmosphere and ocean has been constructed by Washington, Albert Semtner (Oceanography Section), Gerald Meehl, David Knight, and Mayer. With this model, it is possible to perform a wide variety of climate sensitivity experiments, including an assessment of the possible climatic consequences of increased atmospheric CO_2. The components of the model are an eight-layer, five-degree horizontal resolution, third-generation GCM; a four-layer, five-degree horizontal resolution, primitive-equation model; and a simplified sea-ice model. Because the atmosphere and ocean have such different time scales, a coupling strategy is being tested that allows for nonsynchronous coupling of the atmosphere and ocean. The atmosphere is run for four different seasons and used to force the ocean over several years. The ocean requires wind stress, precipitation, and some components of surface energy balance from the atmosphere. In turn, the atmosphere requires surface temperature and sea-ice distribution from the ocean.

The first long-term simulation of the coupled system yielded zonal atmospheric temperatures and wind patterns similar to those of observed climatological ocean temperatures, realistic seasonal ocean surface temperature patterns, the major ocean gyres and current systems, and horizontal oceanic heat-flux values. The vertical velocity at the base of the top layer of the ocean model (50 m) was close to that deduced from observed wind stress. The seasonal distribution of Arctic sea ice is well simulated; however, the Antarctic sea ice is not. The reasons for this and other failures of the coupled model are being explored.

In support of research on the most effective means of coupling atmosphere and ocean models, Washington and Robert Chervin have studied the time response of an atmospheric GCM to an altered ocean surface temperature. They found a general estimate of atmospheric response time of 30 days for a new equilibrium to be established, but in atmospheric layers near the ocean surface and in the tropics the response time was of the order 10 days or less. This result suggests that in a nonsynchronous coupling strategy the atmospheric part of the interaction should be at least 10 days to allow the near-surface atmospheric variables to adjust to the changed ocean temperatures.

General Circulation Model Statistical Analysis and Sensitivity. Chervin completed the development of the sampled climate ensemble concept for providing a more complete description of the climate, whether produced naturally in the real atmosphere or simulated by an atmospheric GCM. In this way, the consideration of various ensemble and time statistics for sets of independent, finite time-span realizations permits an objective evaluation of climate change and the extent to which observed and simulated climate ensembles agree or differ.

Within this sampled climate ensemble context, Chervin, Houghton, and John Kutzbach (University of Wisconsin) analyzed the vertically averaged meridional transports of momentum, heat, and moisture in a previous version of the NCAR GCM (for which different horizontal resolutions were considered) and an observed data set from Abraham Oort (NOAA/ERL). The analysis clearly demonstrated the advantage of evaluating the full horizontal distribution of these flux quantities instead of just the traditional zonal average measures. Important correspondences and deficiencies of the GCM simulations with respect to the observations, as well as some effects of model truncation error, were noted.

Chervin, Kutzbach, and Robert Gallimore (University of Wisconsin) completed the analysis of the sensitivity of a previous version of the NCAR GCM to a variety of idealized, very large amplitude, mid-latitude and subtropical North Pacific Ocean surface temperature anomalies. In the Pacific sector, the model exhibited a differential sensitivity depending on the latitudinal position of the imposed anomaly. Typically, the model response was a combination of a relative direct thermal circulation, an alteration in the pattern of cyclonic activity, and a preferential wave response dependent on the planetary waves present in the unmodified control case.

OCEANOGRAPHY SECTION

The research of the Oceanography Section in 1979 can be divided into three sections according to overall method of research: eddy-resolving numerical studies, analytical models of local eddy processes, and the analysis of field data.

Eddy-resolving Numerical Studies

During the last several years, Holland has carried out a large number of numerical experiments with eddy-resolving models, examining the role of the eddies in the large-scale circulation in midlatitude, closed gyres. These studies have been carried out with a highly efficient quasi-geostrophic model, whose adequacy for midlatitude applications has been demonstrated by Semtner and Holland through intercomparison with a primitive-equation model.

It is now quite clear that mesoscale eddies can limit the growth of large-scale current systems and can alter their characteristics in ways not consistent with homogeneous friction. The eddy and mean circulations are so intimately coupled that an understanding of the oceans' role in climate will require an understanding of the role of eddies in the oceanic general circulation.

Current work on this problem is aimed at increased understanding of local dynamical behavior in these complex situations, exploring the relevant parameter space, isolating special problems, and carrying out studies of the North American Basin. In particular, Holland is examining (1) the problem of Gulf Stream separation from the western boundary, (2) the role of Gulf Stream Rings in the general circulation, (3) the role of thermal forcing on basin scale circulation, and (4) the problem of advection-diffusion of passive tracers by mesoscale eddies . In collaboration with Dale Haidvogel (Woods Hole Oceanographic Institution--WHOI), he has carried out several linear stability analyses designed to give insight into the origin of mesoscale eddies, and he has begun a study of vacillation (long time-scale) behavior in eddy models. With Edward Harrison (MIT) and Peter Rhines (WHOI), he is carrying out analyses of potential vorticity, energy, and heat budgets occurring in model studies to get at the complex interactions which give rise to the oceanic general circulation.

A number of primitive-equation experiments on the general circulation of equatorial oceans have recently been completed (Semtner and Holland). A first study examines the natural variability of a steadily forced ocean and shows that baroclinic instability occurs in the westward currents to the north and south of the equator and barotropic instability occurs in the equatorial undercurrent. The transient phenomena are similar to those observed in nature, and their structures have some similarity to equatorially trapped, free waves in a resting ocean as calculated by linear theory. A second study examines the spinup phase, the onset of instability, the response to anomalous forcing, and the effects of parametric changes. Considerable attention is paid to the breakdown of linear theory whenever forced waves (as opposed to free waves) are important. Planned studies of equatorial ocean dynamics include experiments on the propagation of free waves in a turbulent ocean and on the influence of periodic forcing and nonsymmetric winds on the general circulation (Semtner and Holland). By using a stepwise progression toward greater realism in terms of model formulation and physical forcing, we hope to isolate the mechanisms responsible for maintaining the mean currents and the variability in this climatically active part of the world ocean.

A study has been made of the special equatorially trapped standing modes which exist for definite values of ocean width and frequency (Peter Gent and Semtner). This work tests Gent's previous theoretical results for oceans without meridional boundaries in the numerically calculable situation of totally bounded basins where the modes are slightly modified. The modes are found to be "robust" and to be easily excited by atmospheric forcing or by arbitrary initial conditions. These results have an important bearing on the design of the extensive observational programs in the equatorial oceans which are planned for the next decade.

Analytical/Numerical Models of Local Eddy Processes

James McWilliams and Glenn Flierl (MIT) have studied isolated, highly nonlinear vortices, with applications to Gulf Stream Rings. The nonlinearity, as well as the more familiar large-scale, baroclinic nondispersion, can indeed provide a "glue" which gives these isolated vortices great persistence (as observed in Rings). The basic theory for barotropic and baroclinic, quasi-geostrophic, uniformly propagating, permanent-form solitary-eddy solutions (modons) has been completed by McWilliams in collaboration with Flierl, Vitali Larichev (USSR), and Grisha Reznik (USSR). A further numerical study, with a particular focus on questions of modon stability and robustness is currently in progress [McWilliams, Flierl, and Norman Zabusky (University of Pittsburgh)]. Modons have also been examined as an idealized model for the persistence of midlatitude atmospheric blocking (McWilliams).

Analysis of Field Data and the Design of Future Experiments

McWilliams and Colin Shen (University of Washington) have completed a study of observed modal coupling between the barotropic and first baroclinic modes for mesoscale eddies using observations from the Mid-Ocean Dynamics Experiment. The coupling is such as to yield substantial correlations between the modes (largest at spatial lags on the order of 50 km), primarily due to the lowest frequency component of the resolved mesoscale field. This occurs in an equilibrium where there is very little energy transfer between the modes, yet is maintained, most plausibly, by an exterior influence such as radiation from the Gulf Stream gyre (n.b., local equilibrium models rapidly destroy the observed coupling in forecasts from observed initial states).

Francis Bretherton and McWilliams have completed a study on the theory of estimations from irregular data arrays. The general framework is optimal linear estimators. Topics treated are estimations of the mean, the variance, the degree of spatial inhomogeneity in the processes, and the spectrum. Also treated is the theory of optimal array design for spectral estimation.

AAP DIVISION STAFF AND VISITORS

DIVISION OFFICE

Staff

Meg Carr
Jackson Herring
Barbara Hill
Holly Howard
Cecil Leith (Director)
John Masterson (to 1 October 1979)
Ann Modahl
Philip Thompson

Visitors

RAINER BLECK, University of Miami: June to August 1979

JAMES CURRY, Massachusetts Institute of Technology: June to August 1979

URIEL FRISCH, Observatoire de Nice: August 1979 and December 1979 to January 1980

RICHARD GROTJAHN, Florida State University: January to June 1979

RAYMOND HIDE, Meteorological Office, Bracknell: June to July 1979

MAURICE MENEGUZZI, Centre d'Etudes Nucleaires de Saclay: December 1979 to February 1980

DAVID MONTGOMERY, College of William and Mary: August 1979

GARTH PALTRIDGE, CSIRO, Australia: April to June 1979

JEAN-PIERRE POYET, Columbia University: July to August 1979

DANIEL SCHERTZER, Direction de la Météorologie, Cedex, France: December 1979 to January 1980

ERIC SIGGIA, Cornell University: May to August 1979

NORMAN ZABUSKY, University of Pittsburgh: June to August 1979

LARGE-SCALE DYNAMICS SECTION

Staff

David Baumhefner
Thomas Bettge
Grant Branstator
Mary Chambers (to 30 June 1979)
Roger Daley
Patrick Downey (to 30 June 1979)
Akira Kasahara (Section Head)
Thomas Mayer
Mary Niemczewski
Nadine Perkey (to 12 January 1979)
Thomas Schlatter
Richard Somerville
Joseph Tribbia (long-term visitor)
Joseph Wakefield
Stephen Whitaker (to 13 April 1979)
David Williamson

Visitors

G. C. ASNANI, University of Nairobi, Kenya: August to September 1979

JAMES KOERMER, University of Utah: September and November to December 1979

KAMAL PURI, Australian Numerical Meteorological Research Centre, Melbourne: January to March 1979

JAMES SETHIAN, University of California, Berkeley: July to September 1979

JEAN-PIERRE VOLMER, French Meteorological Office, Paris: January to July 1979

ROBERT WALKO, University of Arizona: June to August 1979

MESOSCALE RESEARCH SECTION

Staff

William Bergen (to 6 January 1979)
Raymond Bovet
Richard Brost
John Brown
Chia-Bo Chang (long-term visitor)
Robert Enk (long-term visitor)
Tzvi Gal-Chen (long term visitor)
Dorene Howard
Patricia Jones (to 4 September 1979)
Jean Kelley (to 26 June 1979)
Joseph Klemp
Margaret LeMone
Donald Lenschow
Douglas Lilly (Section Head)
José Meitín (to 22 June 1979)
Rebecca Meitín
Alan Miller (to 10 March 1979)
Dennis Miller (long-term visitor)
Katsuyuki (Vic) Ooyama
Yunn Pann (to 30 June 1979)
Donald Perkey
Nadine Perkey (long-term visitor)
Gary Rasmussen (long-term visitor)
Herbert Riehl (to 30 November 1979)
Anthony Rockwood (to 26 January 1979)
Doyne Sartor
Clark Smith (to 29 April 1979)
Borislava Stankov

Robert Ubelmesser (to 27 September 1979)
Henry van de Boogaard (to 17 September 1979)
Patricia Waukau
Morris Weisman
John Wyngaard
Edward Zipser

Visitors

CHING-SEN CHEN, University of Illinois at Urbana-Champaign: June through August 1979.

DONG LEE, University of Wisconsin: November and December 1979.

JEAN-LUC REDELSPERGER, Central National pour Recherche Scientifique, Paris: March and April 1979.

ANTHONY ROCKWOOD, Metropolitan State College: June and July 1979.

ROBERT WILHELMSON, University of Illinois at Urbana-Champaign: June through August 1979.

CLIMATE SECTION

Staff

Eileen Boettner
Julius Chang (to 26 July 1979)
Robert Dickinson (Section Head)
Christine Kingsland
Eric Pitcher (long-term visitor)
Richard Wolski

Climate Sensitivity Group (CSG)

Bruce Briegleb
James Coakley
Richard Johnson (long-term visitor)
Laurence Goldberg
William Kellogg (Group Leader)
Randi Londer (to 24 August 1979)
Veerabhadran Ramanathan
Mary Rickel
Stephen Schneider
Robert Schware (long-term visitor)
Bruce Wielicki
Warren Wiscombe

Empirical Studies Group (ESG)

Paul Julian
Christine Kingsland
Roland Madden
Chester Newton (Group Leader)
Dennis Shea
Harry van Loon

Global Climate Modeling Group (GCMG)

Robert Chervin
Ann Gayton
Edward Gerety
Yen-Huei Lee
Gerald Meehl
Lynda Verplank
Warren Washington (Group Leader)

Visitors

ERIC BARRON, University of Miami: CSG, June to August and December 1979

ROBERT CESS, State University of New York at Stony Brook: CSG, January and July to August 1979

PETR CHÝLEK, Harvard University: CSG, June to August 1979

H. NÜZHET DALFES, Rice University: CSG, May to August and December 1979

WESLEY EBISUZAKI, University of Toronto: CSG, July to September 1979

JEFFREY KIEHL, Harvard University: CSG, June to August 1979

VERNON KOUSKY, The Institute of Space Sciences, São Paulo, Brazil: ESG, July to October 1979

TAMARA LEDLEY, Massachusetts Institute of Technology: CSG, July to August 1979

H. MOYSÉS NUSSENZVEIG, University of São Paulo, Brazil: CSG, December 1979

V. RAMASWAMY, Harvard University: CSG, June to August 1979

STARLEY THOMPSON, University of Washington: CSG, June to September and December 1979

STEPHEN WARREN, Brandeis University: CSG, January to December 1979

RONALD WELCH, Johannes Guttenberg-Universität, Federal Republic of Germany: CSG, June to July 1979

OCEANOGRAPHY SECTION

Staff

Julianna Chow
Bernard Durney (to 30 June 1979)
Peter Gent
William Holland (Section Head)
Christine Kingsland
James McWilliams
Albert Semtner

ATMOSPHERIC QUALITY DIVISION

INTRODUCTION

The major goals of the Atmospheric Quality Division (AQD) program may be summarized as follows:

- To derive and explain the chemical composition of the earth's atmosphere, with particular concern for such constituents as have global and regional significance because of their effects on the biosphere, climate, and the stratospheric ozone layer. This research implies the quantization of the sources and sinks of atmospheric gases and especially of the effects of biospheric and industrial emissions.
- To determine the atmosphere's composition (including the products of chemical conversions) and dynamical features (including their interactions with chemistry) from global observations. This will be accomplished through satellite programs; global in-situ sampling measurements from aircraft, balloons, and rockets; and various global chemical field programs.
- To design photochemical-meteorological models for the analysis and interpretation of global atmospheric data and to predict future trends in the earth's chemical, physical, and biological environment.
- To determine the important chemical, physical, and biological mechanisms that maintain and perturb chemical balances within the earth's atmosphere.

Our investigations in the upper atmosphere continue to contribute substantially to knowledge of its composition and dynamic structure through the employment of a variety of observational techniques on balloons, aircraft, and satellites. Along with the observational work we have actively pursued photochemical and dynamical modeling efforts, so that theoretical and observational activities have supported each other. We have also called attention to the important role of CO, NO_x, CH_4, and nonmethane hydrocarbons in the tropospheric ozone budget. Our work has again emphasized the importance of biospheric processes in determining the composition of the atmosphere. We have identified biomass burning as an important source of the atmospheric trace gases CO, H_2, N_2O, NO_x, and COS. An extensive field program in the cerrado and tropical forest regions of Brazil has convinced us that tropical regions during the dry season are heavily polluted and must be a source of many important atmospheric trace gases.

The Acid Precipitation Experiment (APEX), which is aimed at studying the cause of acid rain in North America, has provided new knowledge of the physical and chemical processes leading to the acidification of rainwater.

Another important aspect of AQD work has been the interpretation of chemical observations and the design of field experiments within the context of meteorological phenomena. As an example, stratospheric-tropospheric exchange processes were investigated through the development of meteorological models of tropopause folding. Chemical and optical instrument development in a number of projects has been directed at supporting this effort. Sensitive chemical equipment for measurements of constituents characteristic of stratospheric-tropospheric exchange, such as H_2O, O_3, and Aitken particles, were successfully flown on the Sabreliner and correlated with turbulence observations to define the chemical exchange near tropopause folds.

As an essential aspect of our responsibilities as a group at NCAR, many of the activities in AQD are taking place or are evolving through strong interactions with university scientists or colleagues from other research institutions. Our study of global chemistry encompasses a broad span of research activities and encourages most groups in AQD to collaborate closely with scientists outside of NCAR, to the advantage of all. For more details on research achievements during the past year the reader is referred to the project descriptions which follow and to the attached literature list.

IN-SITU MEASUREMENTS AND PHOTOCHEMICAL MODELING PROJECT

Brazil Brushfire Experiment

The In-Situ Measurements and Photochemical Modeling (ISPHOM) Project undertook a major field experiment in the late summer of 1979. The activity, titled the "Brazilian Brushfire Experiment," involved a team effort with participants from ISPHOM and its subprojects and from the U.S. and Brazilian university communities. NCAR field staff included Paul Crutzen as leader, Anthony Delany, William Mankin, Michael Coffey, Leroy Heidt, Patrick Zimmerman, Arthur Wartburg, and Richard Lueb. Florida State University was represented by Alistair Leslie and Luiz Carlos Boueres (who acted as a liaison with Brazilian participants). Brazilian colleagues included Oyanarte Portilho of the University of Brasilia and Celso Orsini of the University of Sao Paulo.

Earlier sampling and analysis of forest and agricultural burning, coupled with theoretical considerations, had indicated that combustion of vegetation is significant in the global balance of atmospheric trace gases, especially as such combustion results from shifting agriculture in the tropics (South America, Southeast Asia, and Africa) and the burning of vegetation in the course of clearing land for agriculture. Furthermore, tropical emissions occur in a photochemically and dynamically important region influenced by the Hadley circulation, which to a considerable extent is responsible for transferring tropospheric air into the stratosphere. There remains a distinct possibility that the land areas of the tropics may suffer from pollution equivalent in intensity to that of the industrial midlatitudes of the Northern Hemisphere. The Brushfire Experiment proposed to acquire basic data on the composition of the products of combustion within this source region through direct sampling. The effort was highly successful.

Gas chromatographs were shipped to Brazil and set up at the University of Brasilia by Heidt and Lueb. Samples collected both at the surface and with the NCAR Sabreliner aircraft were analyzed at this temporary laboratory. Gases measured included CO_2, CO, CH_4, N_2O, OCS, and CH_3Cl. Because of the large number of samples collected, data reduction is being completed at NCAR. Emphasis was placed on these gases because of their importance to the earth's radiation budget and ozone balance.

Chemical Modeling

Work has been completed to include all photochemistry of the coupled O_x-HX-NX-ClX chemical constituents in the two-dimensional model. At the same time a separate model which emphasizes tropospheric chemistry was developed. This work was done by Paul Crutzen in collaboration with Jack Fishman and Louis Gidel (Colorado State University). A series of theoretical and observational studies by Crutzen, Wolfgang Seiler (AQD visitor), Fishman, and Susan Solomon (Advanced Studies Program graduate assistant) have emphasized that tropospheric ozone is affected to a substantial degree by tropospheric photochemical processes. This leads to the possibility that ozone may be increasing in the Northern Hemisphere troposphere. The important climatological effects of such an increase were discussed in a paper co-authored by Fishman, Ramanathan (Atmospheric Analysis and Prediction [AAP] Division), Crutzen, and S. Liu (former visitor, AAP).

Adjustments of transport parameterization in the tropical troposphere were necessary in the two-dimensional models in order to describe the measured interhemispheric gradients of CCl_3F and CCl_2F_2. After this change was introduced it was found that the calculated gradients of CH_3CCl_3 were also in excellent agreement with observations, giving good confidence in the meridional OH distributions as calculated with the model. The model is now being used for studies of the atmospheric budgets of such gases as CH_4, CH_3Cl, and CO. In this way it was found that atmospheric sources of CO other than industrial processes and methane oxidation were necessary during the summer in both the Northern and the Southern hemispheres, as well as during the entire year in the tropics. In earlier work we had identified the emissions of hydrocarbons from vegetation and from biomass burning as important additional sources of CO.

The two-dimensional model has additionally been used to calculate expected ozone depletions due to the continued use of the industrial chlorocarbon gases $CFCl_3$, CF_2Cl_2, and CH_3CCl_3 and to subsonic and supersonic aircraft emissions of NO_x.

The two-dimensional model is now being extended to higher altitudes to study the effects of thermospheric and mesospheric processes on stratospheric photochemistry via the downward transport and diffusion of NO_x, especially during polar night conditions. In the course of these studies, which will result in a Ph.D. thesis by Susan Solomon of the University of California (Berkeley), the effects of the intense ionization events (PCAs) of August 1972 and of relativistic electron precipitation events have been explored. An interesting result is that during such events at high altitudes ($\gtrsim$75 km) the intensive ionization leads to a strong dissociation and a near disappearance of water vapor by its conversion to molecular hydrogen. After the events, therefore, we expect an increase in ozone and atomic oxygen at these heights. The extended two-dimensional models will be of substantial value in the interpretation of data to be obtained on the future Solar Mesosphere Explorer (SME) and the Halogen Occultation Experiment (HALOE) satellite experiments.

As part of the AQD studies on the atmospheric effects of biomass burning, Seiler and Crutzen have conducted a detailed study of gross biomass burning rates and worldwide forest clearing rates. This study led to estimates of emission rates of such important gases as CO, H_2, N_2O, COS, NO_x, and CH_3Cl. The study also addressed the issue of the net release of CO_2 to the atmosphere from a variety of human activities, including land clearing and shifting agriculture. As an important outcome of this study, production of charcoal in fires has been identified as a totally neglected and potentially very important sink of atmospheric CO_2 (as well as a source of O_2).

Stratosphere-Mesosphere Measurements

The principal objective of the Stratosphere-Mesosphere Measurements component of ISPHOM is to contribute to knowledge of the temporal and spatial distribution of a number of atmospheric gases through observational techniques. As a part of this long-range goal, Lueb, Pollock, and Joseph Krasnec successfully completed two balloon profiles from Juazeiro do Norte, Ceara, Brazil (6.5°S), in December. Samples were collected cryogenically and returned to the laboratory, where measurements are being performed for H_2O, H_2, CH_4, CO, CO_2, N_2O, CF_2Cl_2, $CFCl_3$, CH_3Cl, and OCS. The balloon flights were a continuation of the global measurements being partially supported by the High Altitude Pollution Program (HAPP) of the Federal Aviation Administration (FAA).

A substantial addition to the laboratory early in 1979 was a gas chromatograph-mass spectrometer (GC/MS). After its installation, Pollock, Heidt, and Lueb attended training sessions at Hewlett-Packard. The rest of 1979 was spent in developing operational confidence and sample handling techniques for the instrument. Pollock is now sufficiently proficient in the GC/MS operation to begin measurements of hydrocarbons (C_3-C_{18}) and other organics in both the troposphere and stratosphere.

Volcanic Emissions

Major explosive eruptions inject material into the stratosphere that affects its radiation balance and its chemistry, often worldwide. During February 1978, Richard Cadle, physical chemist, AQD, and William Rose, volcanologist, an Advanced Study Program appointee and professor of petrology at Michigan Technological University, spent 3 1/2 weeks in Guatemala sampling the eruption clouds from three volcanoes from an NCAR Queen Air aircraft. Several articles have resulted from this work. Important questions still remain concerning the composition of the fume from explosive eruptions. One is the relative concentration of hydrogen sulfide in the fume, and another is the concentration of carbonyl sulfide. We need to know the amounts of hydrogen sulfide injected into the stratosphere by highly explosive eruptions in order to judge the rate at which sulfur-containing particles are formed in the stratosphere following such eruptions, and thus the manner in which the eruptions affect the radiation balance. Results already obtained suggest that volcanoes may be a not inconsequential source of carbonyl sulfide in the atmosphere. Crutzen has suggested that, in the absence of major explosive eruptions, carbonyl sulfide is responsible for most of the particulate material in the stratosphere being converted to sulphuric acid droplets photochemically. Therefore, two objectives of a Queen Air flight in Central America in February 1980 were to determine the H_2S/SO_2 ratios and to obtain better estimates of carbonyl sulfide concentrations (calculated from COS/CO_2 and COS/SO_2 ratios) in the eruption clouds from the explosive volcanoes.

To complement the Brazilian Brushfire Experiment observations discussed, we measured carbon monoxide, hydrogen, methane, nitrous oxide, NO_x ($NO + NO_2$), sulfur dioxide, hydrogen sulfide, and carbonyl sulfide in smoke from burning vegetation in Central America using the same techniques as was used in the determination of the composition of the eruption clouds. Other groups were invited to participate in these activities.

Total Chlorine

Research efforts have continued within ISPHOM to measure the total volume mixing ratio of chlorine in the stratosphere. The procedures and techniques developed for high-altitude balloon sampling during the previous year's chlorine program were adapted last year to aircraft. Special nose-mounted total halogen sampling units were designed, built, and tested by Walter Berg for use aboard a NASA WB-57F aircraft. Six stratospheric flights were flown by this aircraft from April through November 1979 using the NCAR-built sampling system. These flights ranged from the Yucatan Penninsula (16°N) to the Arctic circle (75°N) and yielded consistent total chlorine values (Cl_x) of about 3.0 ± 0.5 ppbv at 18.0 km. Values for the total volume mixing ratio for bromine were determined for the first time anywhere. The latitudinal, seasonal, altitudinal, and diurnal variability of total stratospheric chlorine and bromine will be carefully examined in the coming year with a combined series of six balloon and six aircraft sampling missions.

BIOSPHERE-ATMOSPHERE INTERACTIONS SUBPROJECT

The vacant position of project leader in the Biosphere-Atmosphere Interactions (BAI) Project was filled when Patrick Zimmerman joined NCAR in June 1979. He has assumed a leadership role in BAI activities from that date. Before coming to NCAR he held a faculty position at Washington State University, where he was involved in research into biogenic hydrocarbon emissions.

The BAI group is greatly expanding its sampling and analytical capabilities. By mid-1980 the group will have a series of gas chromatographs and a high pressure liquid chromatograph in operation. These instruments will be equipped with detectors and columns that will give the laboratory the capability to detect trace levels of hydrocarbons, halocarbons, sulfur compounds, and other gases, including N_2O, CO_2, and CO. In addition, the BAI has improved laboratory methods and developed new equipment with which biogenic and fire emission samples can be collected and quantified.

These facilities will not only be used by NCAR scientists but will also provide a foundation for cooperative research as well. Plans are being completed for Bernard Bonsang from the Centre des Faibles Radioactivities, Laboratoire Mixte, Centre National pour l'Exploitation des Oceans (CNEXO), France; Takashi Yasuoka from Tokai University, Japan, and Michel Marchand, CNEXO, France, to spend one year each in residence at NCAR working on different aspects of the BAI programs. The BAI project team is also developing cooperative research programs with scientists in West Germany and the United States.

The BAI project played a major role in the experimental biomass burning program which was conducted in Brazil in the fall of 1979. Samples were acquired and analyzed to determine the concentrations of hydrocarbons C_2 through C_{15} as combustion by-products. Data analysis and compilation will continue during 1980.

In 1980 the BAI group will participate in field programs to be conducted at the Pawnee Grasslands Research Site, near Greeley, Colorado; biomass burning research in South America and in Guatemala, and in a Meteor cruise from Hamburg, West Germany, to Montevideo, Uruguay. This research will be focussed primarily upon emissions of hydrocarbons to the atmosphere from biogenic and biomass combustion sources.

GAS AND AEROSOL MEASUREMENTS SUBPROJECT

In response to recent emphasis on reactive gas measurements, a calibration system for our aircraft ozone and nitric oxide/nitrogen dioxide detector systems has been developed. A long-path ultraviolet absorption cell serves as the primary standard against which the Dasibi ultraviolet absorption ozone monitors and the CSI chemiluminescence ozone detectors are calibrated. A gas titration system that utilizes the reaction of nitric oxide with ozone allows the nitric oxide detectors' calibration to be referred back to the ozone standard. Efficiencies for NO_2 to NO conversion may then be defined. The Dasibi itself provides a means of secondary calibration for ozone, and a mass flow-controlled dilution system serves for nitric oxide and nitrogen dioxide.

Two types of aircraft-compatible nitric oxide detectors have been fabricated. The first is a high sensitivity device that is designed to detect concentrations of 10^{-11} for NO. This instrument and its associated converters will be operational in early 1980. The second instrument, capable of measuring concentrations of 3×10^{-10} for NO has already been successfully operated aboard the Sabreliner jet aircraft during the Brazilian Brushfire Experiment as an NO/NO_x detector. The research flights in central Brazil indicated that the concentrations of NO and NO_x in the continental background boundary layer were typically 1 and 3 ppb, respectively, and even in the middle troposphere values of 300 and 600 ppt, respectively, were observed. These values, which are supported by ground-based measurements, indicate that in spite of the general dry-season subsidence a mechanism exists for extensive vertical mixing and that despite the nonindustrial character of central Brazil its air quality may, in fact, be comparable to the eastern industrial regions of North America.

A cooperative research effort involving Donald Stedman, University of Michigan, Donald Lenschow, NCAR Research Aviation Facility, and Richard Pearson, University of Michigan, was devoted to establishing an aircraft system capable of defining the ozone destructive flux to the ground and measuring that flux over a wide range of different surfaces. The correlation measurements between ozone flux and vertical air motion parameters were repeated in September 1979 aboard the NCAR Queen Air over the same area as the previous year using a fast chemiluminescence instrument fabricated by Pearson. Noise and interference were much lower than for the previous experiment, and values of $\sim -3.1 \pm 0.6 \times 10^{11}$ mol cm^{-2} sec^{-1} were measured over the dry grasslands with very small flux divergence between altitudes of 15 m and 150 m above ground level. The same system will be used in the upcoming 1980 ground-truth intercomparisons to be carried out during the AQD Pawnee Grasslands tower experiment and will be used for extended ozone destruction flux survey flights next summer.

Russell Dickerson (University of Michigan/UCAR graduate assistant with AQD) completed his work on the determination of $J(NO_2)$ and $J(O_3)$ using chemical photometers. Thomas Kelly (University of Michigan/student visitor to AQD) likewise has completed his work on NO_2, HNO_3, and NO determinations. Both graduate students are expected to complete their Ph.D. dissertations in the coming year.

The specially constructed aircraft-compatible integrating nephelometer, which was supplied by Robert Charlson and Alan Waggoner (University of Washington), was mounted on the Electra aircraft for use during the summer MONEX program. Because of difficulties involved with the operation of the device during altitude changes, the instrument will be modified before further deployment, possibly as a component of the second phase of the Brazilian Brushfire Experiment to take place in 1980.

A cloud-water collector effective in the nonprecipitable size range was completed during the year. Its design is based on the principle of a spinning disk, radial slot, multiplate impactor. The disk spins at 5,000 rpm. Volker Mohnen of the State University of New York at Albany is cooperating in the operational flight testing to define its efficiency. Further wind tunnel tests at NASA Langley by Irvin Miller are planned.

GLOBAL OBSERVATIONS, MODELING, AND OPTICAL TECHNIQUES PROJECT

The goals of the Global Observations, Modeling, and Optical Techniques (GOMOT) Project are to study and understand the global interactions of chemical composition, radiation, and dynamics in the middle atmosphere, including sources, sinks, transports, and anthropogenic and natural perturbations. The project's activities include data acquisition, analysis, modeling, and instrument development.

Global Data Acquisition

Activity has centered on the reduction of data from the Limb Infrared Monitor of the Stratosphere (LIMS) experiment onboard the Nimbus 7 spacecraft. John Gille is co-leader of the science team, which has responsibility for the development of calibration, inversion, and mapping algorithms. Other members are co-team leader James Russell III (NASA Langley Research Center), and S. Roland Drayson (University of Michigan), Herbert Fischer (University of Munich), Andre Girard (Office National d'Etudes et de Recherches Aeronautiques, Paris), John Harries (National Physical Laboratory, England), Frederick House (Drexel University), Conway Leovy (University of Washington), Walter Planet (National Oceanic and Atmospheric Administration [NOAA]), and Ellis Remsberg (NASA Langley Research Center).

Paul Bailey, Douglas Roewe, and Raja Tallamraju, have developed algorithms to produce calibrated radiances, vertical profiles, and global maps. Bailey, Stanley Nolte, and Verrill Rinehart have implemented these and other algorithms on a SEL 32/35 minicomputer.

The LIMS operated very well from its launch on 24 October 1978 until its supply of solid cryogen was expended on 4 June 1979. The data appear to be of excellent quality with very low noise levels. During the conversion of raw signals from the spacecraft to calibrated, located radiances, the usual minor problems arose. These have now been solved, and the production of radiance data is nearly complete.

In comparing the results of the initial inversion algorithm to corroborative radiosonde and rocketsonde data, we discovered a systematic temperature error which, though small, was sufficient to affect retrievals of trace gases H_2O, NO_2, O_3, and HNO_3. Corrections are now being tested.

Similar independent tests of trace gas retrievals are being studied and show good agreement. The algorithm developments discussed earlier should be completed by the summer of 1980, and production of the inverted data is scheduled to begin by late summer.

Gille presented preliminary results from the LIMS sounder at scientific meetings in Boulder, and at the International Union of Geodesy and Geophysics.

In other activities, Gille, Bailey, Michael Coffey, and William Mankin have been working with University of Colorado (CU) and Laboratory for Atmospheric and Space Physics (LASP) scientists on the design of a limb scanning infrared radiometer for the Solar Mesosphere Explorer (SME) satellite, scheduled for launch in fall of 1981. This instrument will measure pressure, temperature, ozone, and water vapor in the stratosphere and mesosphere. The principal investigator for SME is Charles Barth (LASP); co-investigators include Julius London (CU), Ian Stewart and Gary Thomas (LASP), Paul Crutzen and Robert Dickinson (NCAR), Shaw Liu and John Noxon (NOAA), and C. Bernard Farmer (Jet Propulsion Laboratory).

Gille is team leader for the instrument definition team for the Cryogenic Limbscanning Interferometer and Radiometer (CLIR), a multi-user instrument designed for flight on the Space Shuttle. Team members include Coffey and Mankin, Farmer, Paul Feldman (Johns Hopkins University), Virgil Kunde (NASA Goddard Space Flight Center), David Murcray (University of Denver), and A. T. Stair Jr. (Air Force Geophysical Laboratory).

Gille and colleagues submitted proposals for consideration for the Upper Atmosphere Research Satellite (UARS) at the end of 1978. NASA has postponed an announcement of its decision until 1980.

Analysis and Interpretation of Global Data

Global data analysis has primarily involved the reduction and interpretation of the Nimbus 6 Limb Radiance Inversion Radiometer (LRIR) data. Since this was the first satellite-borne limb scanner, new algorithms were required to invert, analyze, and use the data.

Bailey developed a fast, accurate inversion routine for temperature and ozone which was applied to all seven months of LRIR data. It produced profiles which extend from 100 mb (about 15 km) to 0.08 mb (about 67 km).

The LRIR retrievals of temperature and ozone mixing ratio were evaluated simultaneously for precision (1-2 K and 0.3 ppmv, respectively) and accuracy (<1 K and <0.3 ppmv above 30 km and ∿1 ppmv lower below 30 km). The accuracy was determined by comparison with rocket soundings and the precision by internal comparisons of the LRIR measurements. Work to achieve an understanding of the differences in the ozone values continues.

Measurements of equatorial mesospheric ozone obtained by both an OAO-3 satellite experiment and LRIR (about 1 day apart near 2300 h local time) show a major discrepancy. The LRIR data agree with theoretical models and with most other observations, while OAO-3 is a factor of three to six high. Thus the deficiency in understanding of mesospheric chemistry implied by OAO-3 measurements is not supported by the LRIR results.

Gail Anderson has done a preliminary study of terminator crossing data (evolution of day/night ozone differences) above 2 mb, which should prove useful for checking photochemical theory.

To maximize the use of LRIR data for dynamical studies, a synoptic mapping routine was developed by William Kohri (UCAR graduate assistant from Drexel University) and has been implemented. Quantities mapped from the LRIR data set will include temperature, ozone, and geopotential height. Kohri, as part of his Ph.D. dissertation, is using the temperature and geopotential height data to study the propagation of planetary waves in the stratosphere. The purpose of his study is to determine the extent to which theoretical predictions of planetary wave structure agree with the stratospheric observations made by the LRIR instrument.

A preliminary LRIR ozone climatology for the winter of 1975, including zonal cross sections and monthly means, shows interesting variability of detail. The inverse correlation between ozone and temperature in the upper stratosphere is clearly apparent. The onset of this inverse correlation, as detected by the LRIR wave number 1 phase analysis, may be used to locate the pressure levels at which chemistry begins to dominate dynamics (i.e., 4 mb at 44°N, 0.7 mb at 72°N). This observation is supported by a preliminary mechanistic model of Hartmann and Garcia (discussed later) and is in qualitative agreement with some current chemical models.

Co-investigator on the LRIR experiment is Frederick House (Drexel University); the late Richard Craig (Florida State University) was a co-investigator until his death in 1978.

Modeling

Rolando Garcia collaborated with Dennis Hartmann (University of Washington) to develop a new mechanistic model in which planetary waves are allowed to interact with the zonally averaged wind and ozone fields. Garcia and Hartmann found that steady planetary waves can produce significant departures from photochemical equilibrium above 30 km, in middle and high latitudes. When the model is used to simulate a sudden warming, the ozone distribution undergoes even larger changes; the changes extend to altitudes as low as 20 km.

A model to compute infrared heating and cooling in the stratosphere and lower mesosphere (completed and tested by Garcia) produced a maximum CO_2 cooling rate of about 10 K day^{-1} at the stratopause. The magnitude and altitude agreed with accepted values, but the shape of the cooling profile appeared too narrow when compared with the results of other studies. Inadequacies in the transmittance parameterization may require that a theoretical band-transmittance formulation be used with the radiation model.

An accurate model for computing infrared cooling rates is important in determining the mean meridional circulation of the stratosphere from satellite observations. In particular, it should be possible to use satellite observations to estimate the contribution of wave transience and dissipation to the Lagrangian circulation of the stratosphere.

Initial steps were taken toward the collaborative (with AAP) use of a three-dimensional model to study the coupling among chemical composition, radiation, and dynamics.

Optical Techniques

The principal goal of the Optical Techniques group is the development and application of optical and spectroscopic methods for the measurement of trace gases in the atmosphere. Problems of current interest in AQD require measurements of atmospheric species with high sensitivity and reasonably high spatial and temporal resolution.

Mankin and Coffey have developed a long-path absorption cell for use on the NCAR Sabreliner in conjunction with a high-resolution Fourier transform spectrometer that measures the absorption spectrum of gas in the cell. In use, air from outside the aircraft flows continuously through the cell. By multiple reflections, an optical path of up to 160 m may be obtained. This allows measuring concentrations of gases with a sensitivitiy around 30 ppb. A complete spectrum is obtained in 6 s.

The system has been used in the investigation of grass and forest fires in Brazil. The smoke plumes from these fires are typically a few hundred meters in dimension. Enhancements of CO concentration by as much as a factor of ten were observed in the plumes on these spatial scales.

Analysis of stratospheric absorption spectra previously acquired has continued. These data, taken with a high-resolution Fourier transform spectrometer viewing the sun from an aircraft at 12 km in altitude, yield the total overburden of many stratospheric species. The most significant result obtained recently is the latitudinal and seasonal distribution of carbonyl sulfide in the lower stratosphere. This work was done by Mankin, Coffey, David Griffith (visitor from CSIRO, Australia), and S. Roland Drayson (University of Michigan). Carbonyl sulfide is believed to be the most important precursor of the stratospheric aerosol layer; it had not previously been detected spectroscopically in the stratosphere. Aaron Goldman (visitor from University of Denver) has also participated in analysis of these spectra, searching for previously undetected molecules.

Mankin and Coffey have also made additional measurements of NO, NO_2, and HNO_3 in the stratosphere to elucidate the relationship between atmospheric chemistry and the wintertime stratospheric circulation.

New techniques are being developed to increase the sensitivity and applicability of optical measurements of trace gases. Griffith has been developing matrix isolation spectroscopy in which species of interest are frozen in a matrix of the more abundant CO_2 or N_2O in the sample and examined spectroscopically at low temperature. The spectra are usually simpler than in the gas phase, and reactive or unstable species can be preserved. Several species have been detected at mixing ratios around 10^{-10}.

Griffith has also studied the theory of nondispersive infrared analyzers for CO_2; his work improved the accuracy of derived CO_2 concentrations by enabling better interpretation of the data.

Work has begun on the application of tunable infrared lasers to fast, sensitive measurement of trace gases, a technique which holds much promise. An airborne tunable laser system has been designed and should be in operation within a year.

REACTIVE GASES AND PARTICLES PROJECT

Tropospheric Research

During 1979, Allan Lazrus and the Reactive Gases and Particles (RGP) Project personnel completed two successful flight programs as activities of the Acid Precipitation Experiment (APEX). APEX, which is coordinated at NCAR and uses NCAR's Research Aviation Facility, is primarily a university research project directed at understanding the chemical and meteorological processes underlying the problem of acid rain.

Participants in APEX during 1979 included Volker Mohnen and Eugene McLaren (State University of New York at Albany); Eugene Likens and John Eaton (Cornell University); John Winchester (Florida State University); Gregory Kok (Harvey Mudd College); Barry Huebert (Colorado College); Donald Stedman (University of Michigan); C. S. Kiang (Georgia Institute of Technology); and Allan Lazrus, Paulette Middleton, Phillip Haagenson, Ronald Ferek, Paul Sperry, Bruce Gandrud, and Anthony Delany of NCAR.

During the spring 1979, a series of flights between Colorado and New York State was completed. New insights were obtained into a number of basic problems: e.g., the relative contributions of nitric acid vapor and sulfuric acid aerosol to the acidity of air in this region, the rate of conversion of precursors to acids in dry air, the relative contributions of in-cloud and below-cloud scavenging of acids in warm frontal precipitation, the relative contributions of existing acids and acids produced in cloud droplets to total rain acidity, the role of hydrogen peroxide in cloud chemistry, and the distributions of hydrogen peroxide vapor and of hydrogen chloride vapor.

During 1979, the research emphasis changed from a survey of atmospheric acids and their distributions to case studies of precipitation events. The spring flight series dealt intensively with precipitation associated with a warm front. A complete inventory of acids, acid precursors, and oxidizing agents was made in the warm overriding air feeding off the cloud and also in the air below the cloud. Analogous measurements were made in both the cloud water and the rainwater collected at the surface.

A similar approach was taken during a mission flown in autumn. During this period, two cases of warm frontal precipitation were studied. The results, which have not yet been analyzed, are expected to provide confirmation of the patterns which emerged from the spring study. In addition, several cases of cold frontal precipitation and of orographic precipitation were investigated in order to see how storm types may affect the processes which produce acidity. Similarly, both warm and supercooled clouds were studied.

The RGP group participated in the Field Intercomparison Study during the summer in Claremont, California, designed to test various techniques for measuring tropospheric nitric acid. In cooperation with Barry Huebert of Colorado College, the RGP group made measurements of nitric acid and hydrochloric acid vapors using techniques developed at NCAR.

Instrumentation was designed and tested to make measurements similar to those of APEX in remote regions. The first such experiment will be performed cooperatively with Kenneth Rahn Rhode Island University, who is studying long-range transport of pollutants to the North Slope of Alaska.

Stratospheric Research

Stratospheric research was somewhat de-emphasized during 1979. Four balloon flights were made with a recently developed instrument for stratospheric chemisorption sampling of stratospheric trace constituents. The new sampler is of greatly improved precision and is capable of obtaining an entire concentration profile up to 37 km in a single flight. Two flights, winter and spring, were made to provide nitric acid profiles as ground truth for the Limb Infrared Monitor of the Stratosphere instrumentation on the Nimbus G satellite, which is designed by the Global Observations, Modeling, and Optical Techniques Project. These profiles are in excellent agreement with the average of four seasonal midlatitude profiles obtained during 1976.

Two additional balloon flights were successfully made in summer and fall to test a new instrument for halogen compound sampling. The new sampler will be especially important for stratospheric bromine measurements, since no other technique is presently available and the precision of earlier measurements was less than required. Bromine has recently been reported to significantly influence the efficiency of ozone decomposition by chlorine catalysis.

A similar instrument designed for a U-2 aircraft was operated in a series of summer flights at Poker Flats, Alaska. This instrument is being used, along with many other simultaneous measurements, to evaluate the climatic effect of stratospheric aerosols, and to provide ground truth for satellite measurements.

THERMOSPHERIC DYNAMICS AND AERONOMY PROJECT

The primary goals of the Thermospheric Dynamics and Aeronomy (TDA) Project are to understand the global structure and circulation of the atmosphere above about 80 km; to examine the interactions among upper and lower atmospheric physical, chemical and dynamic processes; and to understand the interaction of the aurora with the earth's atmosphere. To accomplish these goals the project emphasizes numerical modeling. Close collaboration is, however, maintained with university, government, and foreign scientists to obtain the necessary guidance for the numerical efforts and interpretation of the measurements.

Long-range work toward the goals of this project progressed in four separate but interconnected areas: (1) thermospheric dynamics, (2) ionospheric dynamics and auroral processes, (3) electrical coupling between the upper and lower atmospheres, and (4) the study of minor and major neutral constituents in the upper mesosphere and lower thermosphere.

In studies of thermospheric dynamics, NCAR's thermospheric general circulation model (TGCM) was used to study global temperature structure and circulation for equinox and solstice conditions during solar cycle maximum and minimum conditions. This work is a collaborative effort between Raymond Roble, Robert Dickinson (AAP), and Cicely Ridley of the Atmospheric Technology Division (ATD). The global model is on a grid of 5° in latitude and longitude with 24 constant pressure levels in the vertical covering the altitude range from 90 to 500 km. The energy sources that drive the circulation and establish the temperature and compositional structure include heating by the absorption of solar EUV and UV radiation, upward-propagating tidal and planetary waves from the lower atmosphere, and high-latitude heat and momentum sources associated with auroral processes. The model has been used to examine the steady diurnal variation for both equinox and solstice conditions. Starting from rest the model reaches a diurnal reproducible circulation and temperature structure within 5-10 days with no inherent instabilities, such as the barotropic and baroclinic instabilities that NCAR general circulation model (GCM) develops in the lower atmosphere. The results show that it is necessary to include a high-latitude heat and momentum source from the aurora in order to bring the calculations into agreement with observations. During the past year the model has been used to identify the important processes responsible for maintaining the temperature and circulation structure of the thermosphere and also to compare the zonally averaged structure calculated by the TGCM with results obtained by a model of the zonally symmetric thermosphere developed earlier. Good agreement was obtained between the two models. The TGCM model is now being used to examine the effectiveness of the high latitude heat in drag momentum source and joule heating associated with magnetospheric convection in affecting the global structure.

To obtain data to verify model predictions, collaborative efforts are being maintained with Gonzalo Hernandez (NOAA), Paul Hays and John Meriwether (University of Michigan), Manfred Rees (University of Alaska), Manfred Biondi (University of Pittsburgh), John Evans (Massachusetts

Institute of Technology), James Walker (Arecibo Observatory), and Vincent Wickwar (Stanford University). These investigators determine thermospheric winds and temperatures from ground-based optical observatories and incoherent scatter radars for a variety of geophysical conditions.

In ionospheric modeling, work is under way to construct a global ionosphere to interact with the thermospheric general circulation model. Currently the TGCM uses an empirical model of ion drag that provides a drag on the neutral atmosphere without interactive feedback. To adequately model the large-scale neutral plasma interactions between the thermosphere and ionosphere it is necessary to incorporate a global ionospheric model that interacts at each time step and accounts for large-scale plasma motions driven by magnetospheric electric fields.

The auroral model was used to investigate the neutral gas heating efficiency due to particle bombardment of different fluxes and mean energy levels. The results are parameterized to specify the global distribution of neutral gas heating due to auroral particle bombardment for modeling the thermospheric energy input for the TGCM. The auroral model is also being used in collaboration with Barbara Emery (AQD) and Knut Stamnes and Manfred Rees (University of Alaska) to model specific auroral events for which both satellite data and ground-based optical measurements are available for comparison with model predictions. Studies have been conducted using data from the Atmospheric Explorer satellite, the German Aeros satellite, and various rocket flights into auroral forms. These studies examine our current understanding of time-dependent physical and chemical processes operating within auroral arcs.

A new numerical model of global atmospheric electricity has been developed to replace the analytic model that used Tesseral harmonic expansions. The results obtained from the analytic model guided the development of the new model. The numerical model allows more realistic electrical conductivity profiles to be used in the calculation of global distribution of currents and fields. In addition, a more realistic ionospheric model is coupled with the model that allows day-night conductivity variations and also conductivity changes due to solar-terrestrial perturbations. The current model has the same grid as the NCAR general circulation model, so many of the GCM fields such as global cloudiness, thunderstorm distribution, and precipitation are used to determine the electrical properties of tropospheric phenomena and their effect on the global electrical circuit.

In addition to the global electrical model two- and three-dimensional regional models of atmospheric electricity have been developed to examine small-scale phenomena, such as the electrical structure around individual thunderstorms, mountains, and clouds. The global and regional models are coupled through appropriate boundary conditions. These models are being used to assess the global redistribution of currents and fields caused by solar-terrestrial perturbations, such as solar flares, auroral activity, PCA's, and electron bombardment. Work on the new global electrical model is continuing in collaboration with Paul Hays (University of Michigan), George Reid (NOAA), Israel Tzur (University of Michigan), and Roger Williamson (Utah State University).

A two-dimensional chemical-dynamic transport model has been recently developed in collaboration with John Gary (University of Colorado) to study the distribution of minor neutral constituents in the thermosphere and upper mesosphere. This model has been used to demonstrate and examine the importance of winds in affecting the nitric oxide (NO) distribution in the vicinity of auroral arcs near 100 km. Horizontal winds blowing through auroral arcs develop a downwind plume of NO from the arc. The magnitude of the NO build-up was found to depend upon the wind speed, temperature, and compositional structure of the neutral atmosphere and the particle flux and mean energy of the auroral bombarding beam.

The model is currently being extended to examine the global distribution of NO, $N(^4S)$ and $N(^2D)$ in the lower thermosphere for various seasons during both geomagnetically quiet and disturbed conditions. This work is being done in collaboration with Dave Rusch and A. Ian Stewart of the University of Colorado and Jean-Claude Gerard from the University of Leige, Belgium.

The two-dimensional model is also being used to examine the global atomic and molecular oxygen distribution in the lower thermosphere. This work is being done in collaboration with James Kastings (ASP post-doctoral fellow, University of Michigan).

STRATOSPHERIC-TROPOSPHERIC EXCHANGE PROJECT

The Stratospheric-Tropospheric Exchange Project (STEP) acts to coordinate the AQD investigations of the meteorological and chemical aspects of the exchange of air and constituents between the stratosphere and the troposphere. For the past year, the project has continued to focus its research efforts upon the exchange processes which take place in the vicinity of upper level jet stream systems and their associated folding across the tropopause. In addition, the project has continued to pursue its research interests in the theoretical and diagnostic aspects of upper level jet stream-frontal zone systems.

Melvyn Shapiro (AQD) and John Adams (Computing Facility) developed a two-dimensional secondary circulation model based upon the geostrophic momentum approximation which was used to determine vertical mass circulations about front-jet systems. This diagnostic numerical model will be used by Shapiro and Roland Madden (AAP) to study the meridional mass circulations forced by stationary and transient eddy heat and momentum fluxes within the stratosphere. Shapiro has extended the geostrophic momentum secondary circulation equation to three dimensions and derived the less physically restrictive nondivergent momentum form of the equations. These newly derived equations illustrate the first-order importance of the acceleration of the nondivergent component of the ageostrophic velocity in forcing secondary circulations about sharply curved upper level jet-front systems.

A collaborative effort between Shapiro, Louis Gidel (Colorado State University), and David Williamson (AAP) is the study of the differences between quasi-geostrophic, semigeostrophic, and nonlinear normal mode initialization of Gidel and Shapiro's isentropic coordinate, primitive equation model of upper level frontal development and tropopause folding.

Shapiro, James McWilliams (AAP), and Gidel have initiated an atmospheric predictability study to assess the effect of mesoscale potential vorticity features near the tropopause upon the evolution of downstream synoptic scale cyclones and upper level waves. The experimentation is being carried out using the McWilliams three level, quasi-geostrophic, cyclic channel model. Initial results reveal major differences in synoptic scale wave amplitude, phase velocity, and energy conversions as a result of incorporating changes in mesoscale potential vorticity at the tropopause. Earlier aircraft observations with the NCAR Sabreliner by Shapiro were the first to reveal the existence of these mesoscale potential vorticity anomalies near the tropopause.

Shapiro has completed a new set of equations for describing frontogenesis. Frontal forcing processes are partitioned into their geostrophic and ageostrophic components. These equations were used to diagnose the frontogenetic evolutions of the Gidel and Shapiro frontal simulation model as well as real-data cases of upper level frontal formation.

Philip Haagenson (AQD) and Shapiro have continued development of a three-dimensional, objective isentropic trajectory analysis computer code originally designed to study real cases of exchange between the stratosphere and the troposphere and the motions of low-level air parcels. The routine is currently being used to diagnose the geostrophic, ageostrophic nondivergent, and ageostrophic irrotational components of the total velocity acceleration following the Lagrangian motions of air parcel trajectories as they meander through the synoptic waves and frontal zone jet stream systems of extratropical latitudes.

During the past year, STEP researchers and their collaborators have focused their efforts on preparing articles describing the results from previous years' field programs. These articles, which are either accepted for publication or in review to appear in 1980, are summarized below.

Shapiro has shown the first-order importance of turbulent mixing within tropopause folds as a mechanism for the exchange of chemical constituents between the stratosphere and the troposphere.

Kennedy and Shapiro discussed results from NCAR Sabreliner research aircraft measurements of clear-air turbulence within upper level jet stream-frontal zone systems.

Shapiro, Elmar Reiter (Colorado State University), Richard Cadle (AQD), and William Sedlacek (Los Alamos Scientific Laboratory) presented their results from the NCAR Sabreliner and NASA RB-57/F aircraft studies of vertical mass and trace constituent transport in the vicinity of jet streams.

Gidel and Shapiro utilized the NCAR GCM to address the question of asymmetries in stratospheric-tropospheric exchange processes between the Northern and Southern hemispheres. The resulting article presents evidence for large downward ozone and potential vorticity transports from the stratosphere into the troposphere in the Northern Hemisphere. The additional Northern Hemispheric transports were not of sufficient magnitude to explain the observed overabundance of tropospheric ozone in the Northern Hemisphere.

APPENDIX

RADIOACTIVE AEROSOLS AND EFFECTS PROJECT

In the recent past the Radioactive Aerosols and Effects (RAEF) Project has studied the atmospheric distribution of radon and its long-lived radioactive daughter products, their atmospheric interactions and effects, and their use as tracers for assessment of atmospheric aerosol transport and residence times. During 1979 research studies were directed principally toward the short-lived radioactive daughter products of airborne radon, their remarkable concentration on biological surfaces, and their possible mutagenic and carcinogenic effects. The two short-lived radon progeny which emit alpha radiation, RaA and RaC' (polonium-218 and polonium-214) are now clearly implicated as agents of skin cancer as well as lung cancer in man. These same two alpha emitters, highly concentrated on all biological surfaces by the deposition of airborne radon progeny, also may contribute significantly to the incidence of natural mutations in organisms. Preliminary RAEF studies of the role of these two alpha emitters as agents of sex-linked recessive lethal mutations in *Drosophila* and as agents of human skin cancer are now being completed.

During 1980 the RAEF Project will concentrate its attention more specifically on the atmosphere-biosphere interactions and the aerosol physics properties of the short-lived radon progeny. The Office of Radiation Programs, U.S. Environmental Protection Agency (EPA), is now initiating an expanded research effort into the indoor radon progeny problem, now recognized as a serious public health problem. Arrangements are being made to carry out the RAEF studies at NCAR in cooperation with and with the support of the EPA Office of Radiation Programs.

Objectives of the NCAR research effort on this problem are as follows:

(1) To assess the nature and magnitude of the influences of various meteorological parameters on radon emanation rates and on the concentrations of indoor radon and its progeny.

(2) To evaluate the aerosol physics properties of radon progeny, the influence of humidity, condensation nucleus concentration, and other factors on such properties, and the mechanisms of accumulation of radon progeny on charged and neutral surfaces.

(3) To determine the accumulation of radon progeny on biological surfaces and the mechanisms of deposition, at controlled and/or known levels of airborne radon and its progeny.

The experimental approach to be used in NCAR studies in the pursuit of these objectives is twofold: (1) the use of environmental chambers and emanation chambers in laboratory studies, at elevated levels of radon and its progeny under controlled conditions and (2) specific site studies, both occupational and residential, with above average levels of radon and its progeny. These studies will include an assessment of the unattached fraction of radon daughter ions; the fraction attached to condensation nuclei; and the influence of charge distribution, size distribution, humidity, condensation nucleus concentration, and other factors relating to their accumulation on conducting and nonconducting surfaces, including biological surfaces.

The results of these experimental studies should provide new insights, fundamental to an understanding of the radon progeny problem and to an assessment of the efficacy of various possible courses of remedial action. The results also will yield information on alpha radiation doses on biological surfaces and provide a basis for modeling multiple-alpha interaction mechanisms of human skin cancer induction. The studies also should provide new insights into basic mechanisms applicable in cloud physics as well as in atmosphere-biosphere interactions of ions and condensation nuclei.

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Roger Dennett, University of Michigan, April 1978 to Present, GAME

Ronald Ferek, Florida State University, September 1978 to Present, RGP

Jack Fishman, Colorado State University, April 1978 to December 1979, ISPHOM

Alan Fried, University of Michigan, April 1978 to May 1979, GAME

Louis Gidel, Colorado State University, April 1978 to Present, ISPHOM

Aaron Goldman, University of Denver, September 1979 to February 1980, GOMOT

John Harries, National Physical Laboratory, United Kingdom, February 1979 to June 1979, GOMOT

VISITORS (cont')

Thomas Kelly, University of Michigan, April 1978 to December 1979, GAME

C.S. Kiang, Georgia Institute of Technology, July 1979 to September 1979, ISPHOM

Zev Levin, Tel Aviv University, Israel, July 1979 to September 1979, TDA

Francoise Millier, LASP(CNRS), France, August 1979 to October 1979, TDA

A. P. Mitra, National Physical Laboratory, India, April 1979 to May 1979 and August 1979 to September 1979, ISPHOM

Howard Moore, Florida International University, June 1979 to August 1979, ISPHOM/RAE

William Sedlacek, Los Alamos Scientific Laboratory, November 1978 to September 1979, ISPHOM

Anne Smith, University of Washington, July 1979 to September 1979, GOMOT

Susan Solomon, University of California, June 1979 to Present, ISPHOM

Israel Tzur, University of Michigan, August 1979 to August 1980, TDA

Stacy Walters, University of California, March 1979 to Present, ISPHOM

John Winchester, Florida State University, August 1979 to January 1980, ISPHOM

HIGH ALTITUDE OBSERVATORY

INTRODUCTION AND OVERVIEW

The High Altitude Observatory focuses its research in the area of solar-terrestrial physics--the physics of the sun and its influence on the earth. Within this broad arena, the past year's research efforts range from an examination of the nature of the solar interior and its relation to stellar evolution, to a determination of an agent for the modulation of galactic cosmic rays incident upon the earth.

These and many other studies (described in more detail in the remainder of this report) are being carried out within a newly reorganized scientific framework consisting of three sections: Solar Variability, Solar Atmosphere and Magnetic Fields; and Coronal-Interplanetary Physics. Within each section, and across sectional boundaries, scientific work has been carried out through an extensive range of experimental and theoretical studies.

In the former category a number of experimental hardware programs have been brought to fruition, emphasizing the Observatory's commitment to diverse observational programs which use both ground-based and space-borne techniques. For example, the past year has seen the completion and initial operation of the long-awaited successor to the K-coronameter at our Mauna Loa station. Following a major effort extending over several years, the new instruments--the Mark III K-coronameter and the prominence monitor--began to provide initial data in December 1979, prior to the launch of the NASA Solar Maximum Mission (SMM) satellite containing another HAO instrument, the coronagraph-polarimeter. The latter instrument, a more advanced version of the highly productive Skylab coronagraph, successfully completed integration and test procedures during 1979, and was launched on 14 February 1980.

Also successfully completed during the past year was an upgraded version of the Stokes polarimeter, incorporating a new linear array detector and polarization scrambler. These modifications permit Stokes observations a greatly increased temporal resolution and accuracy of calibration. New measurements were obtained in the fall of 1979 and are now undergoing study.

Another new instrument made initial observations during 1979: a rocket coronagraph constructed as one element of a dual instrument, in collaboration with the Harvard College Observatory. The first flight of the dual coronagraph system was carried out in April 1979, and successfully demonstrated the principle of concomitant ultraviolet and white-light measurements. A second rocket flight was carried out near the time of the 16 February 1980 total solar eclipse, and it appears that this flight will yield valuable knowledge of the temperature, density and velocity structure of the solar corona. This principle of joint visible and far-ultraviolet observations can best be implemented from an orbiting vehicle, and NASA has recognized this by accepting a jointly proposed effort to make similar observations from a future Spacelab flight.

Theoretical and interpretive research has long been a mainstay of Observatory efforts, and the past year has seen no diminution in these areas. As noted above, the importance of such studies may indeed be broad, as evidenced, for example, by the potential application of recent work on models of the solar global circulation and dynamo to other stars. These models build upon earlier observations of stellar cycles by permitting general deductions concerning stellar evolution (particularly of the stellar convection zone) along with predictions of the rotational properties of the stars. As the solar models become more sophisticated--although always guided by detailed observational evidence--we may expect a substantially improved understanding of the nature of stellar evolution to emerge.

Another example serves to illustrate the nature of recent interpretive work. It has long been difficult to explain the agents or processes responsible for the modulation of the flux of galactic cosmic rays incident upon the earth. One feature of the behavior of this flux with time has been the rather steep increase following the period of maximum solar activity. The abruptness of the increase seemed to mimic the rebirth of polar coronal holes, and detailed examination of this correlation suggests, in fact, that the flux is modulated by the presence and extent of polar holes, at least during solar cycle 20. It may be suggested that this new _physical_ correlation will permit important new progress to be made on the physics of the transport of cosmic rays in the solar system--an unsolved problem for several decades.

The above examples are discussed in more detail within the description of work in HAO's newest section, Solar Variability. Different examples from other sections would equally suffice have to demonstrate the span of the Observatory's solar research program. However, efforts within the variability section deserve special mention, as we seek to establish a "critical mass" in this area. Without deemphasizing the importance of research in the other scientific sections, the establishment of a viable program in solar variability remains the Observatory's highest priority, and we anticipate its continued growth over the next several years.

Finally, it is appropriate to note that during the past year HAO has responded to its role as a division in a national center in both collective and individual ways. The results from the highly successful Skylab Workshop series, sponsored by NASA, are nearing completion with the appearance of a second volume, _Solar Flares_, edited by Peter Sturrock (Stanford University), and the preparation of the final volume _Solar Active Regions_ (now in progress), edited by Frank Orrall (Hawii). Also, the Observatory cosponsored (with NASA) a seminar on "The Ancient Sun" during the fall, which brought close to 100 participants to Boulder. On an individual basis, a dozen HAO scientists have participated in meaningful ways in the affairs of the International Astronomical Union, the National Academy of Science, NSF, NASA and other such groups, through service as officers and members of advisory panels, committees, and working groups. Continued requests for this participation remain one of the most visible tributes to the scientific vitality of the Observatory staff.

SOLAR VARIABILITY SECTION

As stated in the 1978 Annual Scientific Report, the broad goal of the solar variability effort is to describe and understand the fundamental operation of the solar cycle over a broad range of time scales, from weeks and months to tens of thousands of years. This goal includes study of the ways in which the sun's outputs that reach the earth--radiation, magnetic fields, and particles--are influenced and organized by the cycle of solar activity.

Research in solar variability is closely related to efforts by NASA and the National Oceanic and Atmospheric Administration (NOAA) to monitor solar luminosity and other radiative outputs with the satellites OSO-8, Nimbus 6 and 7, and the SMM, and to monitor the solar wind and magnetospheric and ionospheric variations. Parallel, and in some cases collaborative, studies are also being carried out at Sacramento Peak Observatory (SPNO), Kitt Peak National Observatory (KPNO), Hale Observatories, the University of Arizona, and observatories elsewhere in the world. Related dendrochronological, geochemical, and climatological research is also being conducted at a variety of institutions.

The research goals in solar variability are central to one NCAR objective, namely the understanding of solar processes and their influence on the interplanetary medium. They are also an important element in attaining a second objective: understanding climatic trends and their causes.

The complex nature of solar variability research has dictated that we pursue several lines of research in parallel. Solar variability research conducted in 1979 may conveniently be described in full interrelated areas:

(1) Modeling and observations of global circulation and the dynamo

(2) Documentation and diagnosis of solar radiative variability

(3) Observations and theory of measurements of long-term solar variability

(4) Understanding of the long-term evolution of the corona and the solar wind

(5) Understanding of the geomagnetic response to solar variability

Modeling of Global Circulation and Dynamo

In the global circulation and dynamo modeling effort, progress has been made in several areas, principally by Peter Gilman and collaborators. Earlier calculations had shown that a deep convecting spherical shell sustains equatorial acceleration if the influence of rotation on the convection is strong, and deceleration if this influence is weak. Also, deep convecting layers have equatorial acceleration that is broad in latitude, while shallow ones have a narrower jet near the equator. Gilman has shown that if these results are applied in a qualitative way to other stars, some estimates of the anticipated differential rotation can be made. Main sequence stars occurring later than the sun, particularly late G and K stars thought to have deep convection zones, are likely to have broad equatorial acceleration like the sun's. F stars, with shallower convection zones and weaker influence of rotation, should have either narrow equatorial acceleration or broad equatorial deceleration, despite the fact that they generally rotate much faster than the sun. Such deductions should help us to estimate the kinds of dynamos various classes of stars should have, and to build a broader theoretical picture of stellar cycles and variability for comparison with observations of stellar cycles such as those made by Olin Wilson (Hale Observatories).

Extrapolations of present global circulation models to the sun or other stars are of uncertain validity, since the model physics is much simpler than the real stellar physics. Gilman and graduate assistant Gary Glatzmaier have moved closer to the real physics during 1979 with continuing calculations of solutions to a linear version of the equations for convection of a compressible fluid in a deep rotating spherical shell. This effort constitutes the substance of Glatzmaier's Ph.D. thesis for the University of Colorado. New results indicate that the convectively unstable patterns all propagate prograde in longitude relative to a reference frame in which there is no net angular momentum, by as much as 20% of the rotation rate. This effect depends upon a coupling of rotation with a large radial density decrease, and can be explained as a consequence of the conservation of potential vorticity. These rotational or vorticity waves bear some resemblance to the classical Rossby waves of dynamic meteorology and oceanography, but are nevertheless distinctly different. Their basic properties have been captured by Glatzmaier and Gilman in a second, very simple mathematical model. Such waves are expected to be present in the convection zones of most rotating stars. In the case of the sun, such waves may be related to the occurrence of long-lived coronal holes, which often rotate without much shearing due to differential rotation.

Gilman's calculations, using a hydromagnetic dynamo model with incompressible rotating spherical shells, are revealing not only relatively few similarities to the sun, but actually several substantial differences. These differences suggest that much previous "success" in simulating the solar dynamo is illusory, depending critically upon assumed parameterizations of certain interactions between velocity and magnetic fields which apparently do not hold when more detailed calculations are done.

Another interesting effect seen in the dynamo results is the large role played by time changes in the velocity fields in determining the rate at which the magnetic field is dissipated. Gilman has found that the threshold level of induction required for dynamo action to occur can be more than doubled by time-dependent velocity fields. The physical reason for this effect is that, as the magnetic field begins to adopt a pattern optimum for growth with a given velocity field, the velocity changes to a new pattern that is not optimum. In the process, magnetic energy is cascaded out to the smallest physical scales present in the model, where it is dissipated more quickly. This effect apparently has not been seen in dynamo studies before because the models virtually always have been based on steady velocity fields.

In a related study, David Galloway (visitor from the University of Sussex, England) has collaborated with Nigel Weiss (visitor to SPNO) in examining the whole question of the role of magnetic flux tubes in the evolution of the sun's magnetic field. Several lines of argument lead them to the conclusion that all through the solar convection zone the sun's magnetic field is concentrated into flux tubes by the action of different scales of convective motion. Furthermore, they argue that flux tubes which originate within the convection zone will be highly disordered, and that they may not be the primary contributors to the rather regular progression of the zone of sunspot occurrence toward the equator as a solar cycle progresses. Instead, they propose that the most regular aspect of the sun's magnetic field derives from a shallow layer just beneath the convection zone where the motions and the magnetic field are much better organized. The details of this proposal remain to be worked out, but, along with the calculations by Gilman described above, they should present a serious challenge to currently accepted solar dynamo theory.

One of the ways in which the global fluid models described above oversimplify the physics is to represent small-scale turbulent processes by linear functions with constant coefficients. Hendrik Spruit (visitor from Space Research Laboratory, Utrecht, The Netherlands) and Bernard Durney (now at SPNO) have been collaborating on a formalism that holds promise for a better parameterization of the turbulent transport of heat and momentum. Starting from assumptions concerning the dominant size and shape of the flow pattern (partly predicted from linear theory) they have calculated tensor functions of position and rotation rate for the turbulent pressure, viscosity, and temperature conductivity. These functions will be used in a global circulation model to estimate the differential rotation and meridian. The formulation can also be compared with explicit model calculations carried out with Gilman's model.

In trying to understand how the global circulation of the sun operates, it is valuable to carry out parallel theoretical studies motivated by global circulation of other celestial bodies, in particular of the planet Jupiter. Jupiter's atmosphere is not only heated from below like the solar convection zone, but also from above (differentially) by the sun. Jupiter also has an equatorial acceleration, although it is much narrower in latitude than on the sun. David Hathaway (visitor from the NCAR Study Program, ASP), together with Gilman and Juri Toomre (University of Colorado), have been modeling the circulation of the Jovian atmosphere by means of convective stability calculations, in which convection in a rotating fluid is driven by both a radial and a latitudinal temperature gradient. Rather than solving a full spherical shell model, they consider a local region in latitude, with a fixed angle between the rotation vector and gravity. They confirm that without a latitudinal temperature gradient, convective rolls with axes aligned north-south are preferred, as has been predicted for the sun by several scientists previously. However, as the latitudinal temperature gradient is increased, a point is reached at which east-west rolls are favored, particularly in low and middle latitudes. Moreover, the rolls are broader near the equator than in middle latitudes. Such broad belts are seen on Jupiter and have this same characteristic.

Observations of Global Circulation

During 1979, Timothy Brown has continued his development of the Fourier tachometer for measuring global velocity fields on the sun. The current prototype instrument was built at SPO, with Brown, Jacques Beckers (now at the Multiple Mirror Telescope Observatory, University of Arizona and Smithsonian Astrophysical Observatory), Jack Evans (SPNO), and others contributing. All of the instrumental hardware and most of the software for data handling have been tested, and solar velocity fields have been seen through the instrument. The first operational run with the Fourier tachometer was scheduled for February 1980, from which we will attempt to determine what really can be seen with it in detail, and what level of accuracy is being achieved. Discussions are under way concerning a second-generation instrument that could be dedicated to a long-term program of measuring global velocity fields to accuracies of a few meters per second through most of a solar cycle.

In parallel efforts Brown, Gilman, and Glatzmaier have been examining the relationship between a velocity field on the sun and that part of it which would be present in a line-of-sight measurement such as the Doppler shift. Brown has been developing a formalism relating spherical harmonics on the sun to corollary functions that would form a complete orthogonal set on the solar disk, which is what is seen at any given time. This formalism will be helpful for the inverse problem, i.e., going back from the observed signal to what is actually happening on the sun. The formalism will be tested on initial data from the Fourier tachometer when it becomes available during 1980.

Gilman and Glatzmaier have been simulating the data reduction process employed by Robert Howard and his colleagues at Hale Observatories on their long record of global velocities. Howard concluded that they were unable to find evidence of global patterns, other than differential rotation with an upper limit of about 10 m/s. However, starting from simple periodic east-west flow patterns, Gilman and Glatzmaier have shown that Howard's data reduction technique can severely attenuate the signal, sometimes by a factor of 10 or more, so that quite substantial global velocities could have been present but were lost in the reduction process. Two effects conspire to produce this result: (1) the least-squares three-parameter fit to the data used by Howard to take out certain unwanted effects also removes much of the largest spatial scales of velocity; and (2) if the velocity patterns move across the sun in longitude with even slightly variable rotational speed, as suggested by model calculations, internal cancellation in the reduction process is greatly enhanced. It seems clear from this work that other data reduction techniques will need to be tried if we hope to find global velocities other than differential rotation.

Global oscillatory velocities on the sun can be used to diagnose many properties of the solar atmosphere. Brown and Robert Harrison (University of New Mexico) have now been able to observe bands of power in frequency wave number space, of the local continuum intensity of the solar photosphere. The oscillations, with frequencies between a few minutes and one hour, may be the result of gravity waves trapped in the photosphere and chromosphere. For almost a decade such waves had been predicted, but never observed. In principle, they can be used to diagnose details concerning the structure of the photosphere and chromosphere. On the other hand, these waves have very little extension into the convection zone, and so cannot be used to diagnose properties of that region. Therefore, they represent a quite different tool from the pressure oscillations (so called p-modes) so widely studied recently.

Diagnostic Measures of Solar Radiative Variability

The 1977 and 1978 Annual Scientific Reports discussed baseline measurements of chromospheric Ca II K emission for the sun at solar minimum, carried out by Oran White and William Livingston (KPNO). At that time, solar activity had not increased enough to estimate the rate of change of the K index for the sun in the present solar cycle (solar cycle 21). Now, however, White and Livingston have observed a very clear and steady increase in the chromospheric intensities from 1976 through 1979. In 1967, Neil Sheeley (Naval Research Laboratory) predicted that the change could be as much as 40% over a single solar cycle, but this had never been checked by quantitative measurement of the solar line profile. Livingston and White have now recorded a 43% rise in the line core. The present measurement, then, will set the range of variation of the so-called K index for the sun, and this can be compared with the measurements made for other stars previously by Olin Wilson and now by George Preston and Arthur Vaughan (Hale Observatories). Thus far, White and Livingston detect variation only in the central part of the line, which is formed in the chromosphere. They have not yet seen changes in the line wings, formed deeper in the solar atmosphere, which would signal a photospheric variation and perhaps a related variation in the solar constant.

For better comparison with K line changes in other stars, the center of the solar K line needs to be monitored regularly, although, perhaps as infrequently as two or three times per month. It may be possible to do this using a narrow-band birefringent filter mounted on a relatively small telescope. Discussions have begun with Alan Title (Lockheed Solar Observatory) on the design of such an instrument. Daily measurements of the solar K line make it much easier to interpret the daily changes of stellar K lines in terms of rotational modulation. Preston and Vaughn have started working on the stellar problem in collaboration with Dimitri Mihalas (on leave at SPNO).

Measures of Solar Variability: Observations & Theory

In the 1978 Annual Scientific Report we reported on the work of Jack Eddy and Aaron Boornazian (Stan Ross and Company) to re-analyze the Greenwich Observatory transit telescope measurements of the apparent solar diameter. Over the period from 1836 to 1953, and particularly for the last 75 years of that record, the data show a statistically significant secular decrease in solar diameter beyond that likely to result from either observer error or bias. The same trend has been noted before by others who examined all or part of the Greenwich data set, and has been attributed to secular atmospheric effects or to personal equation. The trend is not so obvious in the less continuous series of meridian transit measurements made at the U.S. Naval Observatory between 1862 and 1945, and it does not appear in the less precise measurements made at Campidoglio and Monte Mario in Italy between 1874 and 1937.

The Greenwich decrease is a nearly monotonic feature of both horizontal and vertical diameters (D_H and D_V), and a least-squares fit gives 2.25 seconds of arc per century in D_H and 0.75 seconds of arc per century in D_V. If this measure of the change in solar diameter is real, it amounts to about 0.1% per century, which is two orders of magnitude more than the rate originally proposed by Helmholtz in 1854 to explain the total solar luminosity by gravitational contraction. It could result, however, from a temporal contraction of only the photospheric and convection layers of the sun, and not of layers throughout the solar volume.

On the other hand, the apparent contraction could result from a secular change in the atmospheric conditions at Greenwich, through changes in the effect of irradiation. Such an irradiation effect appears as an annual change in the Greenwich data and makes it possible to compensate for long-term variations in atmospheric transparency and its effect on apparent solar diameter. Monthly averages of the transit data over the last 75 years show that after subtracting out the diameter change due to the annual variations in the distance between the sun and the earth, the apparent diameter of the sun is larger in summer than in winter, following a smooth, annual curve that fits the annual change in the zenith distance of the sun. The winter-to-summer increase is about 1 arc second in both horizontal and vertical coordinates. First noted by Richard Cullen in 1926, the effect is easily explained as the result of the change in sun-to-sky contrast through the physiological phenomenon of irradiation: in summer, when the sun is higher in the sky at noon, the contrast between sun and sky is greatest, leading to an appearance of a slightly larger sun; in the winter, with a low sun and a longer path length through the atmosphere, the sun-to-sky contrast decreases, and with it the apparent size of the sun.

By the same token, a long-term decrease in the sky transparency at Greenwich might produce an apparent long-term decrease in the size of the sun seen from there. This can be identified by examining the trend of the amplitude of the annual summer-to-winter (Cullen) effect for long-term changes. Such an effect is apparent in the last 75 years of Greenwich data; that is, the amplitude of the Cullen effect systematically increases during that time. This leads to a secular correction for irradiation of 0.5 seconds of arc per century in both horizontal and vertical measurements of the solar diameter. When this correction is applied to the apparent decrease we obtain a rate of:

D_H : -1.9 ± 0.3 arc sec/century
D_V : -0.2 ± 0.2 arc sec/century

The change in vertical diameter is therefore negligible, to one standard deviation in uncertainty. Thus, if the horizontal change is a real solar change, then during the last 75 years the sun has been becoming more prolate, or trending from oblate to circular in figure. Such an unbalanced change seems incompatible with the low limits on oblateness set by Hill and his colleagues in the modern period and, more fundamentally, with anticipated effects on the orbits of the planets.

Several related studies by colleagues elsewhere have added new information to the question. Irwin Shapiro of the Massachusetts Institute of Technology has now re-examined historical timings of the transits of Mercury across the face of the sun to see if they can help in distinguishing between change or constancy in the solar diameter. As with the Greenwich meridian transit measurements, individual transit timings of contact times at the solar limb are subject to difficulty of definition of the limb and personal error, yet they constitute an independent data set that should be free of some of the systematic Greenwich errors. Shapiro examined observations of 23 transits of Mercury between 1736 and 1973 and finds no evidence of any significant long-term change in the diameter of the sun. Unfortunately they cannot be used to test whether shorter-term changes occur; moreover, the 20th century Mercury transit data seem least reliable.

In another study, David Dunham (International Occultation Timing Association), Sabatino Sofia (NASA Goddard Space Flight Center), Alan Fiala (U.S. Naval Observatory), David Herald (Woden, Australia), and Paul Muller (Anglo-American Computers, Ltd., of England), have combined precise observations of timings of two modern total solar eclipses (1976 and 1979) with historical observations compiled by Edmund Halley of the 1715 solar eclipse in England to arrive at another independent measure of possible solar diameter change. Their result, which refers to the vertical diameter of the sun, indicates a contraction of 0.5 ± 0.2 seconds of arc per century. This would seem to agree with the corrected value for the vertical diameter in the Greenwich data, although at this point the agreement is more likely to be merely fortuitous.

Because of the obvious importance of an accurate knowledge of the solar-diameter and its possible variations, HAO has decided to build its own instrument and begin a long-term independent program of solar diameter measurements, in order to verify or refute the rates of change being estimated from historical data. Timothy Brown will be the principal scientist involved. Ours will still be a transit instrument, capable of measuring both the horizontal and vertical diameters of the sun on a daily basis from the NCAR Mesa Laboratory. By using linear diode array detectors and a precise, objective definition of the limb of the sun, we expect to be able to achieve an accuracy in an individual measurement much superior to that obtained by visual techniques; we anticipate an rms error in daily measurements of about 0.06 seconds of arc. With errors of this size, a change in the diameter of the sun at a rate of 2 seconds of arc per century should be apparent with 3-sigma confidence in about only three years. The basic design for the instrument is now complete, and it should be ready for daily observations when the HAO addition to the NCAR Mesa Laboratory is completed in early 1981.

Motivated partly by the recent estimates of solar diameter change, some researchers have made several theoretical attempts to estimate how much diameter change would accompany a given solar luminosity change such as that due, for example, to fluctuations in convective efficiency. Ronald Gilliland (visitor from ASP) has recently used his own stellar evolution computer code to demonstrate that this ratio is highly model-dependent, and that previous estimates of diameter change are probably too large, by a factor of between 10 and 100. If his estimates are correct, then the observed diameter changes would correspond to luminosity changes of as much as 12% per century, much larger than the observed upper limits. He concludes that meaningful estimates coupling diameter and luminosity changes must await fully compressible, physically reasonable calculations of solar convection which demonstrate the cause, location, and magnitude of convective efficiency variations.

The best known long-term record of solar activity is, of course, the classical Wolf sunspot number. Richard Bogart (visitor from Cornell University, Ithaca, New York), in consultation with White, has been reexamining this record, particularly to find out what evidence of recurrence of solar activity it contains. The principal technique is simply to compute the autocorrelation function for the sunspot number record. This is done for the time period 1850 to 1977, for which this number is best defined. While not finding any true periodicities, Bogart has found strong evidence for the existence and persistence of active longitudes for periods of up to a year. He also finds that the rotation period of active longitudes in different solar cycles can vary by as much as two days, or about 7%. Active longitudes are seen to be more pronounced in some cycles than in others, although the strength of active longitudes in a cycle is not clearly related to the amplitude of the cycle. Finally, he also sees that in some cycles active longitudes have recurred at intervals of from 250 to 400 days.

At least two kinds of solar variability could be initiated by nuclear evolution effects, and Gilliland has been building a stellar model to study them. First, global gravity waves can be excited in the solar interior as a result of instabilities in the layer of helium 3 (3He) built up just outside the core due to nuclear burning. The result would be an apparent nonradial pulsation of the sun with periods of one to a few hours. But, in addition, the presence of many such oscillations could lead to intermittent mixing of 3He into the core, which could lead to changes in solar luminosity on time scales of 10^5 to 10^8 years. The basic mechanism was proposed in the literature earlier by others, and Gilliland is testing its validity with a model which allows finite-amplitude short time scale pulsations to be present. Part of this work is being done in collaboration with Douglas Keeley (Science Applications, Inc.).

Gordon Newkirk has also been examining the long-term variability of the sun, using a variety of astrophysical data. He concludes that the present slow rotation of the sun can only be accounted for by the loss of solar angular momentum through the solar wind. Consequently, both the solar wind speed and the solar magnetic field strength must have been significantly higher in past eons. By inference, then, solar flare activity must also have been higher in the past, and therefore solar cosmic-ray flux was also higher. However, galactic cosmic-ray flux in the inner solar system was probably lower than at present, because the higher solar wind speed and magnetic-field strength deflected more of these particles. These conclusions are generally consistent with fossil cosmic-ray evidence preserved in the moon and in meteorites. However, to establish these conclusions more firmly, we need both increased temporal resolution in the fossil record, and more physically sophisticated models of the ancient sun and interplanetary medium.

Long-Term Evolution of the Corona

The flux of galactic cosmic rays measured near the earth's orbit shows a well-known 11-year modulation that is correlated with--but 180° out of phase with--sunspot number. However, the cosmic-ray flux observed during solar cycle 20 showed an abrupt change from the low value characteristic of sunspot maximum to a high value characteristic of sunspot minimum in 1970-71. In contrast, the decline in sunspot number took six more years. Arthur Hundhausen, Richard and Shirley Hansen, and David Sime noticed that the rebirth of the polar coronal holes occurs at this same time and with similar abruptness. In fact, the area index for polar holes calculated for all of cycle 20 cited above shows a far better correspondence to the observed cosmic ray intensities than the familiar sunspot number. This correspondence suggests cosmic- rays have easy access into the solar system via the open-field configuration of the polar coronal holes, subsequently diffusing and drifting in the general dipole-like interplanetary magnetic field thought to exist when polar holes are prominent. Refinement of the hole area index and further comparison with observations and theoretical models is now under way.

By comparing the general pattern of changes in the solar wind with those of the corona, Hundhausen has extended his synthesis of coronal and interplanetary evolution further. From this synthesis it has become clear that long-lived solar wind streams were the dominant structure in interplanetary space throughout cycle 20. The major excursions in long-term averages of solar wind speed or geomagnetic activity are clearly produced by such streams. In contrast, Hundhausen cannot find any such excursions that can be traced to the solar-flare interplanetary-shock-wave phenomenon so often invoked in earlier discussions of solar-terrestrial physics. Comparison with geomagnetic records from earlier solar cycles gives some indication of a similar character in cycles 16 and 18; it is clear, however, that sunspot cycle 19 was of a diametrically opposite character, with flare-associated, rapidly changing phenomena dominant near sunspot maximum. Thus, the relative importance of short- and long-term changes in the corona in determining changes in the solar wind and geomagnetic response can be quite different in different solar cycles.

Xue-Pu Zhao (visitor from the Department of Geophysics, Beijing University) has been working with Hundhausen on the three-dimensional structure of interplanetary space. He has shown that the suggestion (based on coronal observations) that interplanetary structure in 1974 was organized about a magnetic neutral sheet tilted at 30° to the solar equator is confirmed by a detailed examination of solar wind data (see the description in the coronal-interplanetary physics section of this report). This work is being extended to other epochs in the past solar cycle and will hopefully yield information on the evolution of interplanetary spatial structure on this time scale, as well as on its relationship to the coronal structure observed with white-light coronagraphs.

Geomagnetic Response to Solar Variability

Sadami Matsushita and Yohsuke Kamide (University of Kyoto) have now extended their mathematical model for ionospheric electric currents to study geomagnetic events of short duration. The model begins with forcing due to an assumed interplanetary magnetic or solar wind, including temporal variations, and calculates ionospheric currents and electric fields. Matsushita and Kamide have condensed their results into a color movie, which allows one to follow in detail the rapid changes in electric potential and electric currents which take place during a typical magnetospheric substorm lifetime of five hours. Among the observed effects they have been able to capture are the rapid, large-scale interactions between the auroral zone and low and middle latitudes. Detailed studies are under way to examine these effects further.

Matsushita previously demonstrated that interplanetary magnetic field (IMF) sector structures, such as those occurring "toward" the sun and "away" from the sun, can be estimated objectively from daily and monthly mean values of the horizontal component of the geomagnetic variation field at Godhavn in the northern polar region. This technique has now been applied by Wen-Yao Xu (visitor from the Chinese Academy of Science, Beijing) and Matsushita to geomagnetic data at the South Pole during the period from 1959 to 1970. The agreement between the estimation and actual satellite observations of the sector structures for the interval 1964 to 1970 is 87, 63, and 50% in local summer, equinox, and winter, respectively (those from Godhavn data were 88, 79, and 58%). A remarkable agreement (more than 90%) is obtained for the summers of 1964, 1966, and 1969. Since local winter at Godhavn corresponds to local summer at the South Pole, data from both stations provide a very good chance for agreement throughout the year. The physical behavior estimated from the South Pole data supports the behavior obtained from the Godhavn data.

Paul McKenna (graduate assistant) and Matsushita have been studying how various correlations between properties of the interplanetary medium (solar wind velocity, magnetic field magnitude, and southward component) on the one hand, and various geomagnetic indices on the other, change according to the time scale of the fluctuation. McKenna and Matsushita have been focusing primarily on correlations of daily average values, and have found high correlations for all three interplanetary parameters for all seasons and at high and low sunspot number. However, correlations of most geomagnetic indices with solar wind velocity fall off rapidly for time scales shorter than one day, and remain strong for all time scales longer than one day. By contrast, correlations with interplanetary magnetic field parameters show the opposite behavior. McKenna and Matsushita infer from these results that individual magnetospheric substorms are influenced mostly by short time scale variations in the interplanetary magnetic field, while the general level of geomagnetic activity on time scales longer than one day is controlled much more by changes in the solar wind.

McKenna and Matsushita's results also affect the methods used to estimate the interplanetary magnetic sector polarities mentioned above. In particular, geomagnetic indices can be sensitive to magnetospheric ring current enhancements, produced during the passage of high-speed streams past the earth. These streams produce an additional geomagnetic signature which may counteract the signature of an interplanetary magnetic sector passage. Thus, the wrong interplanetary magnetic field polarity could be inferred.

SOLAR ATMOSPHERE AND MAGNETIC FIELDS SECTION

Research carried out within the Solar Atmosphere and Magnetic Fields Section of HAO centers around problems related to the energy balance and structure of the solar atmosphere from the photosphere at 6000 K, through the chromosphere and transition region, to the corona, with its temperature of several million K. It is in these highly structured and complex domains that energy generated deep in the solar interior is converted to radiation, mass flows, and wave motions which then propagate into the outer solar corona, the solar wind, and eventually interplanetary space. Both quasi-steady and violently active events such as flares and eruptions characterize these regions, with a variety of complex interactions occurring between the solar plasma and the radiative and magnetic fields. As part of its research effort, the Section actively engages in the study of stellar atmospheres as a means of broadening the basis from which the multifaceted phenomena of the solar atmosphere can be understood. The approach to both the solar and stellar problems includes four general categories of effort: observational programs from ground-based and orbiting observatories; interpretive analysis of observational data; development of diagnostic techniques, and theoretical modeling.

During the past year, the primary data base for the Section was provided by the Stokes and KELP instruments operated by HAO at SPNO, by the data archive obtained from HAO participation in Orbiting Solar Observatory (OSO-8) experiments, and by collaborative observing programs with the large solar instruments at SPNO and KPNO. Theoretical modeling has concentrated on problems related to energy balance and energy propagation in magnetic field and plasma topologies similar to those found in the sun. Substantial efforts have been devoted to planning future observing programs for an ultraviolet spectrometer-polarimeter on the SMM satellite. Also, plans for collaborative programs have been initiated with a number of stellar astronomers.

Solar Activity

Several factors are combining to cause a greater concentration on the phenomena of solar activity: first, the Stokes and KELP instruments, which obtain their best data from regions of stronger magnetic fields such as active regions; second, the SMM, which represents the major space effort in solar physics during the early 1980's, and which is dedicated to the study of flares and related activity; third, the OSO-8 data archive, which contains substantial new data on active region phenomena; and finally, improved opportunities for detecting solar-type variability in other stars. Direct efforts within the Section this past year included participation in the Skylab Workshop on active regions, in analysis of OSO-8 active region data, and in the design and organization of observing programs which use instruments on SMM and at collaborative ground-based observatories.

Both Grant Athay and Joseph Hollweg contributed chapters to the proceedings of the active regions workshop, which summarized the current state of knowledge concerning mass motions in active regions and theories of coronal heating with particular emphasis on contributions in the post-Skylab era. The book on solar active regions will be the third book resulting from the series of Skylab workshops administered by HAO with NASA sponsorship.

In the OSO-8 program, Andrew Skumanich completed data reduction and initiated analysis of spectral line data for Mg II and Lyman-alpha for a flare observed with the French instrument on 19 April 1977. H-alpha, radio, and X-ray data obtained by other observatories will be integrated with the OSO-8 data in order to investigate the physical state of the solar plasma during the flare and pre-flare stages. The combined data represent one of the most complete sets of flare observations on record.

Bruce Lites, who joined HAO in late 1979, is working with Skumanich on the reduction and analysis of a large sunspot observed extensively with both the French and University of Colorado instruments on OSO-8. The spot was long-lived and of simple structure, and was studied at a number of ground-based observatories, including SPNO, where Lewis House obtained good Stokes observations of the spot and surrounding regions. The Stokes data will provide valuable information on the magnetic field topology for comparison with plasma parameters and mass motions derived from the OSO data. Contrary to previous results from ground-based observations, where scattering in the terrestrial atmosphere is a major problem, the OSO results show reversed emission cores in the CaII H and K lines even in the spot umbra. The core reversals are important because the cores of the lines are formed higher in the solar atmosphere than the wings of the lines, and hence this data adds greatly to the diagnostic potential for the lines.

Athay, White, Lites, and E.C. Bruner, Jr. (Lockheed, Palo Alto Research Labs) completed their study of active region bright bursts observed in the transition region lines from OSO-8. A few such bursts were studied with Skylab instruments, but the Skylab data lacked any information on Doppler shifts. The OSO-8 analysis included 51 bursts and demonstrated that the bursts are associated closely with fast-moving material similar to that expected for small surges and in falling condensations. Bursts occur at a rate of several per hour in some active regions, and are indicative of a surprisingly high level of activity at transition region levels.

Considerable effort has been directed by Athay, White, Charles Querfeld, and Egidio Landi Degl'Innocenti (visitor, from Osservatorio di Arcetri, Italy) to the planning of observing sequences with the SMM satellite and the coordination with ground-based observations, including Stokes and KELP observations. Athay and White are co-investigators on the ultraviolet spectrometer polarimeter (UVSP) developed by the Marshall and Goddard Space Flight Centers (Huntsville, Alabama, and Greenbelt, Maryland) and Querfeld is a co-investigator on HAO's coronagraph-polarimeter.

Stellar Atmospheres

Although it has long been believed that the sun is an "unusual star" in that the chromosphere and corona represent remarkably large departures from classical radiative equilibrium models, it is now clear that most stars, in fact, have chromospheres and coronae. It is becoming increasingly important, therefore, to attempt to understand chromospheres and coronae as products of a physical system that persists through a wide range of states, rather than as phenomena peculiar to some singular characteristic of the sun. The stars permit us to study the "system" through such a broad range of physical states, whereas the sun complements the stellar studies by providing a very detailed picture of the system for a particular state.

It is clear from studies of the sun that the system of mechanical energy generation, propagation, and dissipation that gives rise to chromospheres and coronae involves phenomena on large scales (convection, rotation) and small scales (magnetic flux tubes, coronal loops, spicules, etc). Modern observing techniques are capable of providing information on stellar rotation, convection, winds and activity, which, in turn, can be correlated with evidence of chromospheres and coronae. Such information will provide valuable guidance in understanding the mechanisms leading to the solar chromosphere and corona.

From a study of spectroscopic binary stars which had evolved away from the main sequence, Skumanich found that the ratio of CaII chromospheric luminosity to visual luminosity is bounded by an upper envelope that he interprets as being close to synchronization between the orbital and rotational periods of the stars. In close binary systems, tidal forces eventually bring about synchronization of the two rotation periods as well as synchronization of the orbital and rotational periods. Thus, the orbital period, which can be accurately measured, is also the rotational period. Using these rotational periods Skumanich finds that the CaII (chromospheric) luminosity scales in proportion to $P^{2/3}$, and the X-ray (coronal) luminosity scales as $P^{4/3}$. For stars near the main sequence, however, the CaII luminosity scales as P^{-1} and the X-ray luminosity as P^{-2}. Thus, in both cases the coronal X-ray luminosity is proportional to the square of the chromospheric CaII luminosity, but the older, evolved stars show increased chromospheric and coronal luminosity with increasing periods, whereas main sequence stars (which include the sun), show just the opposite.

Chromospheric and coronal emission in the sun is closely associated with magnetic fields, the CaII brightness being roughly proportional to the magnetic field strength (as described in the 1971 and 1972 Annual Scientific Reports). If the same is true of the spectroscopic binaries, then the magnetic flux appears to increase as $P^{2/3}$. However, since dynamo action involves convection and differential rotation as well as the average rotation rate, the apparent dependence of magnetic flux on $P^{2/3}$ may result indirectly from a dependence of convection and differential rotation on the rotation period.

Mihalas continued his study of line formation in expanding, rotating atmospheres and demonstrated that some of the classical diagnostic schemes fail badly for such atmospheres. In particular, he found that velocity gradients in the atmosphere, which are necessitated by mass conservation (continuity), lead to an effect on the curve-of-growth that mimics the effect normally ascribed to microturbulence. He also found that the line-profile characteristics assumed in Fourier methods of profile analysis are invalid in expanding, rotating atmospheres. At the same time, he demonstrated that a more thorough analysis using line asymmetry in combination with Doppler shift and line width could yield reliable diagnostics for expansion, rotation, and microturbulance.

In collaboration with Peter Conti (University of Colorado), Mihalas has pointed out that certain line profiles observed in early-type stars could be interpreted as indicating co-rotation of the stellar corona out to a significant distance from the stellar surface. Such co-rotation, possibly induced by a modest magnetic flux, would be important to the braking of rotation in these stars.

The second in a series of workshops between solar and stellar astronomers, designed to foster cooperative work in the study of solar and stellar cycles and related chromospheric structure, was organized by Mihalas, White, and Gilman and held in Tucson in early October. One of the problems of immediate interest is to observe the sun as a star, i.e., to observe the spectrum from the integrated solar disk. White and William Livingston of KPNO started such a program a few years ago and are recording the shapes and depths of selected Fraunhofer lines as a function of the solar cycle. As described in more detail in the Solar Variability Section discussion, their results show marked changes in the chromospheric emission cores of CaII H and K lines from 1977 to 1979 as the level of solar activity increases. Such data will be essential to solar-stellar studies. Other collaborative programs have developed from the Tucson meeting and will probably lead to future extensions of HAO's involvement in studying both solar and stellar activity cycles.

Solar Fluctuations

The sun's surface is highly structured in terms of its brightness in individual spectral lines. Structure exists on scales from less than one second of arc up to the solar radius. On all scales less than the solar radius, the brightness fluctuates in time. Typical fluctuation times vary from a few minutes for some small-scale features, up to a day or more for some larger scale features such as sunspots.

Widths of spectral lines are customarily assumed to be more or less steady in time and space except for the larger and more violent features of solar activity and for the gradual changes from disk center to the limb. High spatial resolution rocket data (Guenter Bruechner, NRL) have shown, however, that the widths of chromospheric and transition region lines vary substantially from point to point on the solar disk. Studies of OSO-8 data by Athay and White also demonstrate that line widths undergo large temporal fluctuations. For transition region lines, the temporal fluctuations in line width have characteristic times and scale sizes comparable to those of the structural features distinguished by brightness. In particular, the fluctuations appear to be dominated by the small-scale features. For chromospheric lines that are optically thick, however, the characteristic fluctuation times are considerably longer and the scale sizes are more typical of the larger structures of supergranules, network, and active regions. Apparently, the effects of depth integration in these lines washes out the fluctuations associated with small-scale structure.

One of the surprises from the OSO-8 data is that accurate "average profiles" for individual features such as supergranules or network require averages either over many such features or over long time periods. Data obtained for supergranules, network and plages, combining double averaging over an area of 2 x 20 arc seconds and for 30 min of time, still show moderately large variations in line widths. Future observations and analysis will have to make proper allowances for both the spatial and temporal fluctuations.

Stokes II

The Stokes II polarimeter, now being managed by Querfeld, became fully operational in September 1979. Relative to that of Stokes I, its speed is increased by a factor of 50 for active region observations on the solar disk. Collaborative observing projects completed with Stokes II include sunspot observations in the Mg b lines (with David Rees, University of Sydney), polarization in CN bands (with Reiner Illing, Laboratory for Atmospheric and Space Physics, University of Colorado) and Stokes profiles for large areas of the solar disk (with Peter Foukal, Atmospheric and Environmental Research, Inc.). Collaborative observations of limb prominences in D_3 and 10830 (with Ray Smartt, SPNO) are still in progress. Also, detailed plans for collaborative studies with SMM experiments are being formulated.

Theoretical Modeling

Hendrik Spruit (visitor from the Astronomical Institute, Utrecht, The Netherlands) has recently reviewed the general status of theoretical models of magnetic flux tubes in a chapter written for The Sun as a Star, edited by Stuart Jordan (Goddard Space Flight Center). His review addresses the broad category of flux tubes (including coronal loops, photospheric magnetic knots, sunspots, etc.) and presents an up-to-date discussion of the formation, topology, and stability of such magnetic structures.

Hollweg has extended his work on Alfven waves in the solar atmosphere to include torsional waves propagating along open and closed flux tubes. The two magnetic configurations show markedly different propagation characteristics. Along open flux tubes sufficient wave energy is possible that long period waves could be effective in driving the solar wind, and short period waves (, 1 min) could be effective in heating the chromosphere and corona. In closed flux tubes, most of the energy propagates at a few well-defined resonant periods. Waves at these resonant periods penetrate the transition region and could provide appreciable heating. Outside the resonances the wave energy is low.

Steepening of Alfven waves to form fast shocks in the chromosphere is under investigation by Hollweg in collaboration with Galloway (visitor from the University of Sussex, currently at the Max Planck Institute). The Alfven shocks transfer both energy and momentum to the material in the flux tubes. Momentum input is greatest in the transition region and may be a possible cause of spicule eruptions as well as chromospheric heating. In a collaboration with Alan Nye (University of Rochester), Hollweg has shown that the upwardly propagating Alfven waves from sunspots could carry enough energy to provide the required heating of the corona above active regions but could not carry sufficient energy to cool the sunspots to their observed state.

A study of the thermal stability for a plasma heated by fast-mode Alfven waves and cooled by radiation has been carried out by Ellen Zweibel, who concluded that one of the main damping mechanisms for the waves is thermal conduction by electrons, which is proportional to $T^{7/2}$. As a result, local perturbations (in which temperature is increased) are heated even faster than normal, leading to an instability. The fastest growing instabilities are those whose major axes are perpendicular to the magnetic field lines.

Edward Shoub (visitor from the University of Colorado) completed a theoretical study of the energy distribution of electrons in the steep temperature gradients found in static models of the transition region. Electrons in the high-energy tail of the Maxwellian distribution penetrate into layers of much lower temperature, producing an excess of high-energy electrons in the lower temperature portion of the transition region. These high-energy electrons, in turn, produce enhanced states of ionization that differ markedly from the levels obtained with an assumed Maxwellian distribution. Plasma flow in the transition region would, of course, alter the results. Nevertheless, the effects would still tend to be present and could significantly influence the ionization equilibrium.

Diagnostics

The problem of treating the transfer of polarized radiation with sufficient care to ensure that reliable inferences about magnetic field structures can be drawn from Stokes data is still under development. Landi Degl'Innocenti has worked with House to develop a suitable computer code for interpreting linear polarization in the helium D_3 line observed in prominences when the magnetic field strength is low (, 5 gauss). In the case of linear polarization observed in sunspots, Landi Degl'Innocenti has shown that magneto-optical effects produce a spiral pattern in the direction of polarization even when the magnetic field is axially symmetric. Such an effect has been observed with the vector magnetograph at Marshall Space Flight Center.

In addition, Landi Degl'Innocenti has developed a general quantum-mechanical technique for treating the transfer of polarized radiation self consistently with atomic level populations. The method includes all of the known polarization and depolarization phenomena, including the Hanle and magneto-optical effects.

Two-dimensional effects in the transfer of unpolarized radiation in the wings of the CaII and MgII lines were investigated by Stanley Owocki (graduate student) and Lawrence Auer. They found that features in the solar atmosphere as small as 100 km are not strongly influenced by lateral photon diffusion in the CaII line wings, whereas the same features would be influenced markedly by lateral diffusion in the MgII line wings. Thus, they conclude that the CaII lines are better suited for the study of fine structure in the solar atmosphere.

Finally, Mihalas extended his work on the transfer problem in a co-moving frame to include relativistic flows. The equations are now exact for relativistic velocities, and a method of solution for the full-angle and frequency dependent problem has been outlined. Relativistic problems are encountered in a variety of astrophysical contexts, including radiation-driven flows in the high-velocity regime.

CORONAL-INTERPLANETARY PHYSICS SECTION

The broad goal of the Coronal-Interplanetary Physics Section is that of understanding the physical conditions and processes determining the state of the solar corona and its extension into interplanetary space, the solar wind. Areas of emphasis in our present efforts to achieve this goal include the acceleration of the corona and solar wind, the role of magnetic fields both in determining coronal structure and in "modulating" the outflow of plasma; the role of transient disturbances in changing the balance of magnetic flux and the flow of coronal material; the propagation of the solar wind (especially "disturbances" of solar origin) through interplanetary space; and the interactions of the solar wind with the earth, cosmic rays, and the interstellar medium. Our approaches to these problems range from an observing program using both ground-based and space-borne instrumentation, through extensive efforts to interpret coronal and interplanetary data, to theoretical research aimed at the development of basic models of the corona and solar wind. Many of these efforts are carried out in close coordination with the other two scientific sections of HAO and in collaboration with scientists from other institutions. Our goals are clearly central to the NCAR theme of understanding solar processes and their influence on the interplanetary medium.

Observing Programs

Since the inception of HAO, the development and application of new techniques to observe the solar corona have been cornerstones of the Observatory research program. In the past decade the construction and successful flight of a white-light coronagraph on NASA's Skylab mission has added tremendously to the data base provided by earlier eclipse expeditions and by the long-term operation of coronagraphs at the Climax and Mauna Loa observing stations. Our present program of coronal observations emphasizes a coordinated attack on problems of coronal physics based on complementary ground-based, space-borne, and rocket observations.

A major effort within the section in 1979 involved final preparations for the launch of an orbiting coronagraph-polarimeter on SMM. This instrument is one of a complement of instruments designed to function as a sophisticated observatory dedicated to the study of solar activity--with particular emphasis on solar flares and related phenomena--near the maximum of the current sunspot cycle. The coronagraph-polarimeter is designed to observe coronal manifestations of solar activity, including the "coronal transients" that aroused great interest when observed during the declining phase of the past sunspot cycle with the Skylab coronagraph. The HAO scientific team of Lewis House, Ernest Hildner, Constance Sawyer, and William Wagner has moved to field assignment at NASA's Goddard Space Flight Center for the period of intensive SMM observations and study conducted in direct coordination with other SMM investigators and collaborators.

At the Mauna Loa observing site a series of K-coronameters has been operated by HAO since 1965 and has already yielded a synoptic record of the low and middle corona that is unparalleled in its length and continuity. In 1979 a new K-coronameter (designated the Mark III) has been readied at the Mauna Loa station for operation in conjunction with the SMM mission. The Mark III program, headed by Richard Fisher, engaged nearly the entire engineering and technical staff of the Observatory over the past few years and has been the largest in-house experimental effort ever undertaken by HAO. The instrument is designed to complement the SMM coronagraph-polarimeter by observing the effects of solar activity at the low solar altitudes which are inaccessible to the spacecraft instrument. Its ability to scan and record coronal conditions more rapidly than earlier generations of K-coronameters make it ideal for the study of transient phenomena. The first coronal data from the new instrument were obtained in late 1979. With software for data processing and reduction completed, the Mark III K-coronameter is ready for intensive operation during the entire SMM mission and beyond.

The Stokes and KELP instruments, which are located at SPNO, have been developed to expand our ability to observe vector magnetic fields in the lower solar atmosphere (Stokes) and the magnetic field direction in the inner corona (KELP). In October 1979 KELP observed a surge, its first detection of a coronal transient; this event is currently under study. Upgraded versions of both the Stokes and the KELP instruments have been readied by Querfeld and collaborators for closely coordinated observations with SMM. Several analyses of data from these instruments are discussed elsewhere in this report.

1979 also saw the first rocket flight of a joint HAO-Harvard College Observatory (HCO) "dual-coronagraph" package. An HAO white-light coronagraph has been designed, under the supervision of Richard Munro as principal investigator, to observe the corona in conjunction with an HCO instrument that measures the intensity and profile of the coronal Lyman-alpha spectral line. This combination of observations provides a direct measurement of the coronal temperature and expansion speed. Although both instruments operated as planned during their initial flight in early 1979, a pointing error for the package produced a high scattered light background on the coronagraph images that seriously compromised the signal at the positions where the Lyman-alpha instrument obtained its data. In the absence of the desired overlap, the planned reduction of combined data cannot be accomplished. However, the flight did succeed in establishing the feasibility of the technique. A second flight of this package occurred on 16 February at the time of the total solar eclipse and we once again look forward to a new source of information on the corona. 1979 also saw the acceptance of a similar joint Smithsonian Astrophysical Observatory/HCO/HAO instrument package by NASA for flight on Spacelab. The HAO white-light coronagraph for this package will be constructed in-house with Munro and Robert MacQueen leading the effort.

Finally, a group of HAO scientists--MacQueen (principal investigator) Thomas Holzer, Hundhausen, Querfeld, and David Sime--have joined with scientists from American Science and Engineering (Alan Krieger and John Davis), the Naval Research Laboratory (Martin Koomen, Don Michels, Russell Howard, and Neil Sheeley), Stanford University (Arthur Walker and James Underwood), and the Observatoire de Paris (Bernard Fort and

Jean-Pierre Picat) in developing a white-light coronagraph and X-ray/XUV telescope package for the International Solar Polar Mission (ISPM). This mission will provide the first opportunity for such instruments to view the corona and solar chromosphere from a vantage point well away from the ecliptic plane. The coronagraph/X-ray/XUV telescope package is intended for observations of the three-dimensional structure and evolution of the low corona and chromosphere, and for examinations of the differential rotation of the sun by following the motions of chromospheric tracers. Current plans call for launch in 1983 and an initial passage over one pole of the sun in 1986; passage over the other pole will follow about six months later. The HAO group, with Sime as the experiment scientist, is currently involved in the detailed definition of the instruments--which must be considerably smaller and lighter than any yet flown in space--and in the development of scientific goals and observational programs for the mission.

Interpretive Studies

The interpretation of coronal and interplanetary data--involving the identification of interesting features or phenomena, the deduction of physical parameters from observed quantities, and the comparison and correlation of results with those obtained from other sources--continues to be a major undertaking of the Coronal-Interplanetary Physics Section. The coronal data produced by earlier and ongoing HAO observing programs, including eclipse expeditions, the Mauna Loa K-coronameters, and the Skylab white-light coronagraph, remain a rich source of information on the physical state and temporal evolution of the corona, for which this institution bears a major responsibility. Both coronal and interplanetary data from other sources have been used to complement the HAO data base in all phases of this interpretive work. We will concentrate here on some highlights of our interpretive studies performed or published during 1979.

The collection of Skylab images of the white-light corona constitutes the largest coronal data set ever obtained, and efforts at interpretation of this 1973-74 data base continue. One area of interest within the past year has been the bright, dense coronal structures seen over active regions in the lower solar atmosphere.

Monique Pick and Gerard Trottet (Observatoire de Paris) and MacQueen have found that large structural and density variations occur on time scales of hours in the bright corona above an active region that produced Type III radio bursts. The use of simple, time-independent density models in the study of radio burst generation in such structures is thus poorly justified. In a recent study, Arthur Poland and MacQueen have examined the longer-term evolution of a bright streamer in the outer corona (at 3 solar radii) and attempted to correlate this evolution with changes in the underlying photospheric magnetic field and in lower coronal (observed in X-rays) and chromospheric (observed in H-alpha) structures. During the epoch under study no identifiable features could be associated with the streamer and the <u>increase</u> in streamer brightness (or electron density), while the strength of the underlying magnetic field was observed to <u>decrease</u>. This result suggests that such large-scale coronal features are related, not to the details of local structure lying beneath them, but to the large-scale or global characteristics of the solar magnetic field.

Research interest in the many coronal transients observed with the Skylab coronagraph has also continued, and the question of the geometric configuration of transients still remains open. Does the loop-like appearance of these features in the Skylab coronagraph images truly indicate a loop-like structure, or is this merely the effect of looking through the bright front of a spherical shell of dense material? Sime has completed a careful analysis of the observed polarizations for a number of coronal transients. He has concluded that the events are usually best described as loops rather than as spherical "bubbles." This result has wide implications for some of the theoretical models of coronal transients described below.

The extensive synoptic record produced by the Mauna Loa K-coronameters has proven a valuable storehouse of information about the long-term evolution of the corona. Work has been completed or published in 1979 on the evolution of coronal holes during sunspot cycle 20 described in earlier reports(R. Hansen, S. Hansen, and Hundhausen); on the temporal variation of polar hole areas and its relationship to the modulation of galactic cosmic rays (Hundhausen, the Hansens, and Sime); and on the correlation of structures observed in the low corona with potential field models of the coronal magnetic field (the Hansens and Gerry Pneuman) and with the global pattern of solar wind speeds inferred from radio scintillations (Sime). A new study by Zhao and Hundhausen, noted earlier, throws further light on the three-dimensional structure of interplanetary space in 1974, when the K-coronameter observations suggest that the corona is organized about a magnetic neutral sheet tilted at 30° to the solar equator. Zhao and Hundhausen have tested the ability of a similar "tilted magnetic" coordinate system to organize the variations in solar wind speed and density observed by spacecraft near the orbit of earth. They find that a choice of tilt of 30° 5° in the coordinates (and selection of a "phase" consistent with the observed interplanetary magnetic structure) does yield a high degree of organization. The solar wind speed is close to 400 km sec^{-1} near the magnetic neutral sheet and increases approximately as the square of the sine of the angular displacement from the sheet to 700 km sec^{-1} at 35° "magnitude latitude." The solar wind density shows a small but consistent maximum near the neutral sheet, and falls off smoothly with increasing magnetic latitude.

Finally, the direct observations of coronal magnetic field direction made with the KELP instrument have been used to search for Alfven waves that are sometimes invoked to accelerate the solar wind (described below). Such waves would produce measurable fluctuations in the coronal magnetic field lines; thus a determination of the level of variation in the field line directions observed by KELP can be used to estimate the Alfven wave energy flux in the corona, given assumptions concerning the field intensity and the number of independent fluctuating elements along the line of sight. Querfeld and Hollweg have obtained and analyzed several time series of magnetic field directions. The detected variances in field direction yields Alfvenic energy fluxes of 2 x 10^{2} to 7 x 10^{3} ergs cm^{-2} sec^{-1} for periods between .5 and 3.5 h. These fluxes are considerably lower than those invoked in most models of solar wind acceleration by such waves.

Theoretical Studies

Theoretical research in the Physics Section has been focused on attempts to construct quantitative models of coronal and interplanetary structures or phenomena from basic physical principles. In 1979 work of this nature was pursued in a number of the areas of emphasis listed in our introduction; we will again describe several highlights of this research here.

The acceleration of coronal plasma to form the solar wind is a process central to much of the research in this Section. While the basic nature of this process has been discussed for more than a decade, the discovery of the source of fast solar wind in coronal holes and the recognition that solar wind speeds occur as high as 700 km sec^{-1} have raised new questions about the precise mechanism and location of the acceleration, as well as about the source of energy that drives the coronal expansion. One possible mechanism for producing the large accelerations implied by the observation of high-speed wind emanating from coronal holes, where the magnetic field lines (and hence the flow lines) diverge rapidly, involves the dissipation of, and momentum transfer from, Alfven or other hydromagnetic waves propagating outward through the solar corona and solar wind. In the recent past, numerous theoretical studies of this possibility have been conducted at HAO. For example, Shaddia Habbal (visitor from the University of Cincinnati), Egil Leer (visitor from the University of Tromso, Norway), and Holzer have studied the dumping of fast-mode waves in both closed and open coronal magnetic geometries, while Hollweg and Paul Dusenbery (visitor from the ASP) have continued to study the acceleration of minor ion species by Alfven waves in interplanetary space. Most recently, Holzer and Leer undertook a more general study of the effects of momentum and energy addition to the expanding corona that has important implications with respect to magnetohydrodynamic waves. They considered several different electron heat conduction laws and diverging flow geometries, and used observed values of the solar wind mass flux density at 1 AU and the electron pressure at the base of the corona as boundary conditions. For reasonable coronal temperatures, their model gives an upper limit on the amount of momentum that can be directly added to the solar wind by waves. They also argued that the production of high-speed solar wind streams requires a significant addition of energy in the outer corona, where the flow is supersonic; addition of energy in the lower region of subsonic flow raises the mass flux so efficiently that the energy per unit mass, or the speed of the solar wind, actually decreases.

Another area of long-term research interest in this section of HAO has been the differential acceleration of ion species under the forces giving rise to the coronal expansion, and the resulting variations in chemical composition and ionization states in the corona and solar wind. In the recent past, Joann Joselyn (NOAA), Munro, and Holzer have completed a study of the effects of mass motion in the solar transition region and the lower corona on the ionization state of that region. In 1979 Holzer has worked with Hundhausen on the rates of flow of different ion species through the same regions. They were able to show that if the plasma flow in the transition region is sufficiently "laminar," i.e., if both flow and diffusion are largely in the vertical direction, then the force balance equation in the transition region will be dominated by the "thermal force" term, describing both the tendency for minor ion species to be dragged to regions of high temperature by the abundant species (protons and electrons) in the corona, and also the frictional drag produced by the motion of the species relative to hydrogen. In this case, the flux of the minor species, relative to that of the major ionic constituent--the ionized hydrogen--is completely fixed by the thermal structure of the transition region. This result provides a very simple mechanism for stratification of chemical abundances in a transition region and corona not dominated by turbulent or chaotic motions.

Theoretical studies of a number of coronal phenomena related to solar-activity-related coronal phenomena were carried out by Pneuman. In particular, Pneuman has examined the role of magnetic reconnection both on the energetics of flare loops observed in X-rays, and also on the outward propulsion of the coronal transients observed with white-light coronagraphs. He suggests that the bright, loop-like structures observed in the corona after solar flares occur stem from the continuous magnetic reconnection of field lines that were forced open earlier in the flare event. This process would then lead to a system of "detached" loops above the bright structures; the net magnetic force on the upper loop system is outward and these structures should thus propagate outward through the corona. A crude calculation of the outward velocity profile shows general agreement with the speed vs. height curves of observed coronal transients.

Finally, the difficulty of observing the three-dimensional magnetic structure in the corona has led to many attempts to compute these structures from observed photospheric magnetic fields. Such models can be constructed with complete geometric generality if electric currents are assumed to be zero in the corona (the so-called potential magnetic fields) or to be aligned with the magnetic field (the so-called force-free assumption). Ellen Zweibel and Hundhausen have used a formalism applicable to two-dimensional magnetic fields (long arcades of closed loops, for example) to deduce magnetic structures that are in magnetostatic equilibrium in an isothermal atmosphere and hence free of any restrictive assumptions concerning the electric current. A family of analytic solutions to this problem has been found that shows how potential fields (now a special case of the more general solutions) are distorted when a non-uniform particle pressure is prescribed at the base of closed magnetic loops. Such solutions include closed loops detached from the solar surface with a region of dense material held up by the magnetic force. The further examination of the stability of such structures should now be highly interesting and may be simplified by starting from these completely self-consistent equilibrium states.

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David Galloway
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July - Sept. 1979

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CONVECTIVE STORMS DIVISION

INTRODUCTION

The Convective Storms Division (CSD) is an outgrowth of the National Hail Research Experiment (NHRE), for which the topic of central interest was hail. As is well known, microphysical and dynamical developments must cooperate to produce large hail. For this reason, it was essential to take account of both aspects in the research program of NHRE. Consequently, a primary task was to organize large-scale field programs in which comprehensive and coordinated measurements could be gathered.

Such a "whole cloud" approach was possible only with extensive participation of the scientific community. The techniques, skills, and cooperative relationships required to carry out field operations represent valuable resources, and we plan to apply them to the study of convective storms in general, the core topic now being broadened to include all precipitation. This mode of operation is appropriate not only to the topic under study, but also to the mission of NCAR, which specifically includes the conduct of large cooperative projects.

The major difficulty in making progress in understanding precipitation from convective storms is that so many different kinds of phenomena interact in ways that are important. The formation of precipitation is obviously influenced by the size and duration of the parent cloud; these in turn are determined by such factors as the properties of the boundary layer, the environmental sounding and wind field, and sometimes downdrafts associated with earlier rain showers. The important question of the origin of ice within the cloud is obscured not only by basic uncertainties concerning the modes of nucleation and possible ice multiplication but also by lack of knowledge of the sources of the air parcels that mix together to constitute any given portion of a convective cloud. As an ice particle grows, its fall speed increases so that its trajectory within the cloud is more and more determined by its size as well as by the velocity of the air. Its further growth depends on the liquid water content of the surrounding cloudy air, which in turn is influenced by mixing and depletion due to competing ice particles.

The scientific challenge is to unravel the most important of the many interactions. A variety of approaches is required for this endeavor, ranging from laboratory studies through field investigations to numerical modeling. Our program centers on the interactions between microphysics and dynamics. In the field, we deploy multiple in situ and remote probes in a coordinated manner. Such studies may be expected to contribute to our ability to predict the nature and amount of precipitation from convective clouds, evaluate the possibilities of intentional modification, and estimate the magnitude of man's impact on weather and climate through inadvertent modification of convective clouds.

CSD maintains close relations with the scientific community; in November 1978, a representative group of atmospheric scientists met at Winter Park, Colorado, to discuss various possible scenarios for our future work. Following this, the decision was made to collocate the next field program with the High Plains Experiment (HIPLEX) in Montana in 1981. The name "Cooperative Convective Precipitation Experiment" (CCOPE) was adopted for the project, and initial plans for a fully integrated research project addressing the major problems of precipitation physics were made by the Water and Power Resources Service (WPRS; formerly the U.S. Bureau of Reclamation) and NCAR, with assistance from scientists at the University of Wyoming and the South Dakota School of Mines and Technology. These plans are described in A Program Prospectus for a Cooperative High Plains Experiment on Convective Precipitation, NCAR/TN-145+PPR. A CCOPE workshop held in Denver on 10, 11, and 12 December 1979 was planned as the first general meeting of scientists who expect to participate in CCOPE. Some 45 scientists from universities and elsewhere attended and took part in discussions which identified core problems and outlined the experiments needed to study them, as described in a report of the workshop available from CSD.

Apart from preparing for CCOPE, our chief task has been continued analysis of data collected in NHRE field seasons. This work has led to a large number of papers, but we also plan to assemble in book form a final report on the research carried out in NHRE. Progress with this report has been slower than planned; the case studies which are central to our analysis of data from NHRE field programs have proven to be more complex and time consuming than was expected. It is now planned to terminate the analysis of this data this summer and to complete writing and editing by the fall. This experience points to a dilemma facing the "whole cloud" approach: the more successful a field program is in gathering comprehensive, reliable, and coordinated measurements, the longer will be the time required to analyze them, particularly when the analysis includes a comparison of the observed storm with a model. At present we have planned to mount field programs at intervals of three years as a compromise between the time required for analysis and the need to maintain a viable field capability. It seems possible that a longer period would be preferable, provided that field-oriented staff members could spend some time with other field programs, as indeed happened last summer when some of our staff collaborated with the Severe Environmental Storms and Mesoscale Experiment (SESAME) and the Thunderstorm Research International Program (TRIP).

In the following sections, some research findings of the past year are discussed briefly. More extensive documentation of some of the case studies has been published in the NCAR Technical Note series.

Dual-Wavelength Detection of Graupel and Hail

An important goal of hail research is that of understanding the temporal and spectral evolution of hail embryos into hailstones. One of the major drawbacks in studies to date has been the lack of a remote technique that can successfully discriminate between and identify hail locations within clouds. Atlas and Ludlam as early as 1961 proposed that the peculiar scattering properties of hailstones provided a means of detecting hailstones from radar. The back-scatter cross sections of hailstones with differing water coat thickness were fairly well known from both laboratory measurements and theoretical considerations. Calculations for 10 and 3 cm wavelength radars, for example, showed that homogeneous, spherical hailstones between 1 and 4 cm in diameter should produce equivalent radar reflectivity factors which are greater at the 10 cm wavelength than at 3 cm. They concluded that the difference in returned power from the two wavelengths (Y') should produce a "positive" hail signal $\geq$ 3 dB when particles $\geq$ 1 cm are present in the radar beam volume. The first validation of the technique was recently achieved in one of the Convective Storms Division's case studies, involving a cooperative effort between Arthur Jameson of the Illinois State Water Survey (ISWS) and Andrew Heymsfield of NCAR. In this study, dual-wavelength measurements were integrated with the aircraft measurements, data from hailpads, and hailcubes at surface locations and Doppler radar measurements. The comparison between dual-wavelength measurements and those provided from the supporting data provided the basis for the verification of the technique.

One of the main data bases used in the interpretation of the dual-wavelength signals for the 22 July 1976 CSD study in northeastern Colorado was observations of hail at the ground. The locations of hail at the surface predicted from the criteria of Y' $\geq$ 3 dB are compared to the hailpad and hailcube impacts for particles larger than 0.7 cm in Fig. 1. The outer contour in the figure corresponds to predicted locations of hail of 1.1 cm diameter. Figure 1 shows that, with only one exception, whenever a hailcube was located within the contour, the hailcube was impacted. Likewise, hailcubes located at distances greater than 1 km outside of the edge of the contour were never hit. Some hailcubes situated within 1 km from the edge of the contour were struck. With only one exception, the sides of the hailcubes that were impacted point toward a Y' contour. The hail detected at these sites was likely to have been carried horizontally by the divergent outflow from the storm. Time-resolved hail samples and partial mapping of surface hail locations (Fig. 1) by ground crews also provided verification of the dual-wavelength technique.

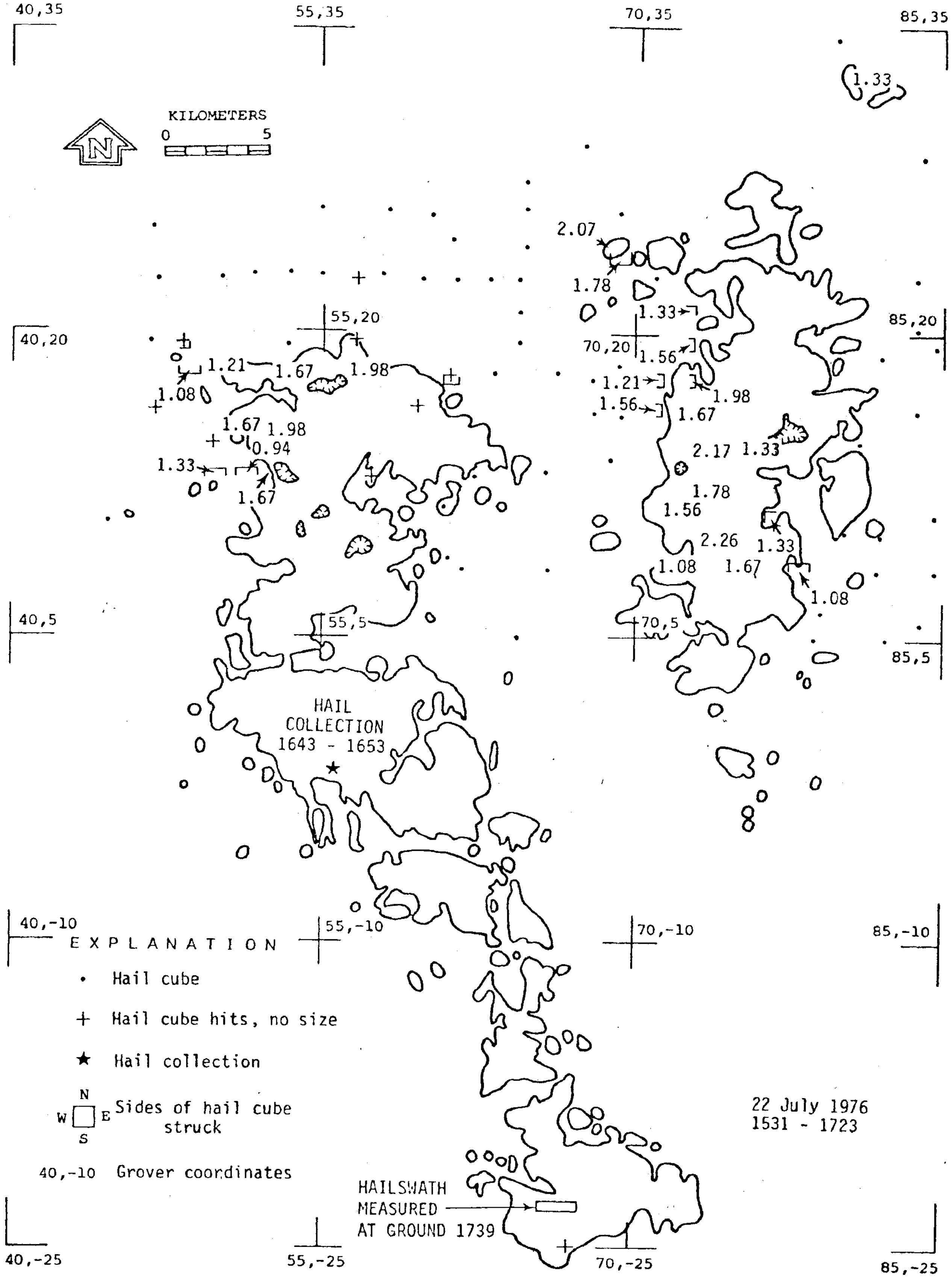

Figure 1. Radar hailswath defined from the dual-wavelength signal (Y' ≥3 dB) appears as outer contour. Numbers associated with hail cube sites are the maximum measured hail diameter (cm). Coordinates are shown in km with respect to the Grover field headquarters (positive to east and north). Arrows indicate apparent predominant directions of wind during hailfall.

The strongest verification of the techniques came from in situ measurements by the South Dakota School of Mines and Technology T-28 aircraft. There were five penetrations in which the T-28 particle size spectra measurements were compared with the dual-wavelength data. In all five cases where the aircraft encountered hail, there was an associated "hail signal." Of the ten beginning and terminating points of aircraft detection of hail, seven occurred within 300 m of the boundary of the radar-detected hail region and the rest fell within 800 m.

The dual-wavelength measurements also showed the unexpected observation of extensive regions of negative hail signal in which $Y' < -3$ dB. Negative hail signals were found primarily within the updraft region at levels above the melting level and in downwind regions. The T-28 measurements indicated that these negative hail signals were due to graupel particles of about 7 mm maximum dimension. While negative hail signals have been predicted theoretically for wet particles of about 7 mm diameter, the data indicated that particles at most locations of negative hail signals could not have been wet, and so a satisfactory theoretical explanation for the correspondence of graupel and negative hail signals does not yet exist.

The above results show that by using the dual-wavelength hail signal it may be possible to discriminate two sizes of particles. This is an extremely important finding because it provides a possible approach for remotely identifying the primary embryo source regions and for investigating the evolution of graupel into hail.

Case Study of a Hailstorm

This summary reports highlights from the intensive analysis of a hailstorm observed during our 1976 field season. The general goal of the research effort was to improve our understanding of the mechanisms responsible for rain and hail formation and to more fully understand the processes responsible for the observed structure and evolution of the intense convective elements. Because of the many important interactions that occur in storms it is difficult to isolate individual mechanisms for study. Rather, it is thought that progress will be most rapid if processes such as air motion and hydrometeor growth are examined simultaneously. Indeed, in many such cases it is the interactions themselves which prove to be the most exciting part of the study. This is, them, the rationale for the intensive case study: To bring together a wide variety of measurements in order to provide a comprehensive description of storm phenomena. The study here is a cooperative effort by Brant Foote, Andrew Heymsfield, Charles Wade, and Harold Frank of NCAR, Arthur Jameson of the Illinois State Water Survey, and Dennis Musil of the South Dakota School of Mines and Technology.

The storm under investigation occurred on 22 July 1976 in northeastern Colorado and produced hail over a period of several hours with sizes ranging up to about 2 cm. Observations by high-resolution conventional radar, dual-wavelength radar, a network of scanning Doppler radars, cloud-penetrating aircraft and aircraft flying in the subcloud region, and networks of surface and upper air stations contributed to the unusually broad data base for such a study.

Scans of the storm by an S-band radar with high resolution (1° beamwidth) provided detailed measurements of the storm's reflectivity structure. An analysis by Wade and Foote indicated that the storm was sustained during its lifetime by a series of convective impulses which were evident in both the magnitude of the reflectivity and the maximum height of the echo. Examination of horizontal and vertical cross sections showed the cellular structure and evolution as revealed by conventional analysis. However, detailed examination showed such a wide spectrum of scales and lifetimes associated with the storm's substructure that use of the term "cell" as representing a well-defined concept, has now been brought into question. While in the past, and particularly with radars of low resolution, the larger elements have been emphasized, role of smaller, shorter-lived convective updrafts clearly now deserves more consideration. Such motions are not resolved by present multiple-Doppler radar systems.

Wade and Foote analyzed the reflectivity history of the storm in three phases with the intent of documenting the manner in which the evolution took place. Only in the third phase was a variety of other data available, though, and this latter period is emphasized here.

During the early phases of the storm, new cells tended to form on the right flank of existing cells. The evolution took place in terms of discrete turrets forming in clear air adjacent to the mature cell in a manner previously described for multicell storms. However, during the third phase the evolution had changed dramatically and the storm had assumed a nearly steady configuration, much like that described previously for supercell storms. It was during this period that the T-28 aircraft was making storm penetrations and the Doppler radars were scanning the storm. Though the overall echo structure was quite steady, the detailed 90 s radar scan sequences showed that interesting oscillations in the storm strength were occurring in the forward flank of the storm at intervals of about 15 min. Associated with these oscillations were weakly developed and transient vaults that formed in the underside of the forward overhang.

The fact that the vault development preceded slightly the increase in the echo top height suggested that the updraft intensity was being modulated through the whole depth of the storm, though apparently starting in the lower regions and perhaps reflecting a boundary-layer influence. Such behavior has not previously been reported in the literature, and its cause is not obvious. Unsteadiness of this kind could tend to promote mixing of particles into the updraft core, and it may have implications for hail growth aside from the changes in updraft speed.

A dense surface mesonet combined with measurements from the subcloud research aircraft provided information on the evolving structure of the storm's subcloud environment. Initially new cell development was on the storm's southwest flank, resulting in an overall storm motion toward the south-southwest. During the later period, cold outflow from an adjacent storm to the east spread westward toward the primary storm system. According to Wade's analysis the intersection of this outflow air with that of the primary storm resulted in the development of a region of enhanced low-level convergence on the storm's southeast flank. This in turn resulted in a shift in the region of cell development and the turning of the storm to a more southeasterly direction. Updrafts monitored at cloud base show a good relationship between the area of maximum convergence at the surface, the region of intense updraft at cloud base, and the location of the transient weak-echo vault. The influence of such boundary-layer phenomena on storm evolution has been long suspected but never well documented. If results such as these prove to be common, then prediction of storm behavior might prove more tractable as surface measurements might be adequate for the task, and these are by far the easiest to make.

Doppler radar observations of the 22 July 1976 hailstorm were made over a 90 min period, during which time 13 4-min volume scans of the storm were accomplished by at least three radars. Triple-Doppler radar data have been analyzed by Frank for six of these scans, using the radial velocity measurements to establish horizontal components of the flow and calculating vertical air motion, w, assuming mass continuity with the boundary condition $w = 0$ near the echo top. Examples of results from volume scans around 1626, 1635, and 1640 are shown in Fig. 2. On the left side of these north-south cross sections is shown radar reflectivity factor (dBZ) as observed by the CP-2 radar, in the center is vertical air speed (in meters per second), and on the right is the storm-relative vector velocity field. The figures show the development with the time of an intense updraft and the weak, transitory vault associated with it. Although the updraft appears to be fairly erect, the slope in the middle levels is enough to strongly limit the residence time of hailstones growing there.

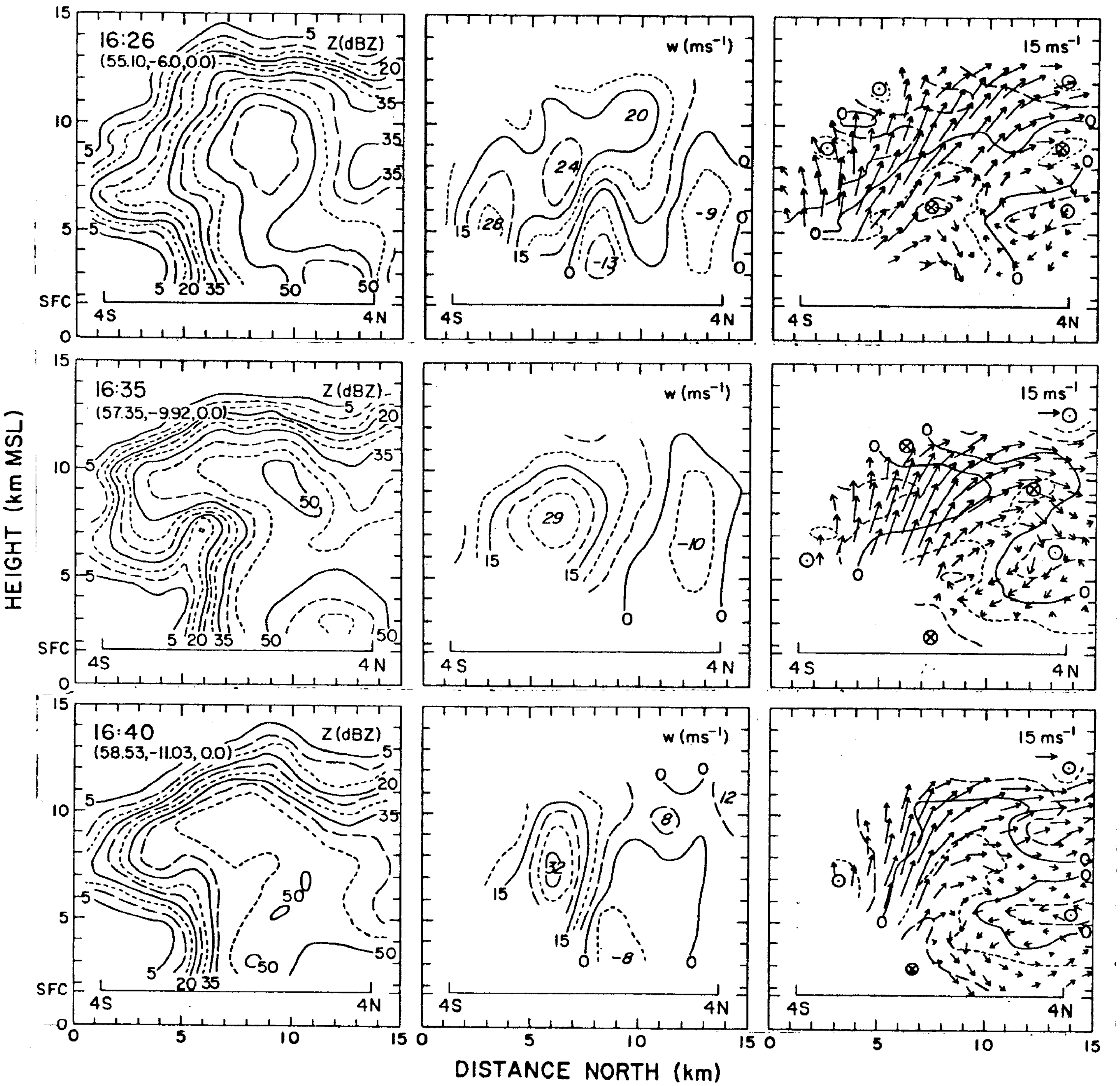

Figure 2. Vertical cross sections from south to north through the region of maximum updraft are shown for three consecutive triple-Doppler radar volume scans of the 22 July 1976 hailstorm at 1626 (top row), 1635 (center row) and 1640 (bottom row). The coordinate system translates with the mean overall storm motion; absolute coordinates of the origin relative to Grover are indicated for each scan. *Left:* Radar reflectivity factor as measured by the CP-2 S-band radar at Grover. *Center:* Vertical air velocity contoured at 5 m s^{-1} intervals. Local maxima and minima in the plane of the figure are noted. *Right:* Arrows (scale at upper right) denote air-velocity vectors appropriate at the tails of the arrows, projected onto the plane of the figure. The velocity component normal to the plane is contoured at 5 m s^{-1} intervals; regions of motion toward the viewer are denoted by ⊙ and away from the viewer by ⊗.

The basic dynamic configuration evident in the 22 July storm is similar to that inferred by other investigators for storms that formed under similar conditions. It agrees with principles outlined by Moncrieff and Miller (1976; Quar. J. of Roy. Met. Soc.) that relate the behavior of storms to the wind shear and potential instability in their immediate environment. The underlying mechanism for maintenance of the storm was the convergence that occurred where inflowing moist air encountered the leading edge of the cool air "dome" associated with the precipitating region. The cool air dome was maintained by downflow in the precipitation region driven both by the weight of the precipitation and by evaporation cooling of relatively dry air that entered from the environment. Because the environmental winds relative to the storm impinged from the front side at all heights, the downdraft air had little horizontal momentum relative to the inflow. Potentially cold (dry) air that composed most of the downdraft was diverted around both sides of the updraft region before entering the precipitation region to the north and to the east of the updraft, on its leeward side.

The updraft branch of the flow entered from the front side and veered to exit toward the left rear, maintaining an overall backward tilt throughout its depth. There was often little or no tilt where the updraft was strongest. Environmental flow around the storm imparted westerly momentum to the exposed portion of the updraft region, so that air ascended along cyclonically curved paths around the right-forward side of the strongest updraft.

The above comments apply to the basic storm-scale characteristics of the flow that persisted for 1 hr or more during the steadiest phase of the storm. The history of reflectivity for the storm establishes that precipitation production, and therefore the updraft, was not steady over this long a period. Such fluctuations can be described in terms of the life cycle of updraft cells that are evident in the vertical velocity field, as in Fig. 2. The velocity structure of these cells closely resembles that of the buoyant ring vortex, or "thermal," that has been studied in the laboratory and has often been used as a model for cloudy convection. The updraft structure changed continually as convective cells reinforced or inhibited each other, and the greatest increases of reflectivity were associated with convective cells of relatively large scale such as the one depicted in the figure at 1635.

While the convective cells resolved by Doppler radar measurements are of interest in themselves, it is equally valuable to consider the more general implications of their presence. The circulation within these convective cells impacts the trajectories of growing precipitation particles suspended in the updraft region, and, as we shall see later, transport of particles from one cell to another is even possible.

Convective cells are of further interest in assessing the way surrounding air is mixed into the cloud. The laboratory experiments show that mixing is most pronounced in the top of a buoyant convective cell and that mixed fluid is drawn downward in the outer portion of the ring vortex and then inward to enter the updraft. In cloud convection, mixed air at the top can be negatively buoyant through a substantial depth in the cloud as shown recently by Ilga Paluch of CSD, thus reinforcing the downward penetration of mixed air. This process was evident on a large scale on the east side of the updraft of the storm discussed here.

Measurements inside the storm were made by the armored T-28 aircraft in a joint effort with the South Dakota School of Mines and Technology. The T-28 observations in the 22 July 1976 case study are some of the most complete measurements obtained in a thunderstorm to date, and they have been analyzed by Heymsfield (CSD) and Musil (South Dakota School of Mines and Technology; SDSMT). Six penetrations were made through the storm at an altitude of 6-7 km MSL. Three of these were through the region of strong updraft. The measurements indicate that the updraft core was diluted throughout, with 25-50% of the air within the updraft core originating from the environment above cloud base. Intense mixing of updraft and downdraft air was noted along the eastern side (downwind) of the updraft region. The downdraft in this region initiated through mixing with dry environmental air on the upwind and forward side of the storm.

The T-28 measurements indicate that the particles were relatively small within the updraft core, and this is also suggested by the weak radar reflectivity there. Particles encountered were largest along the eastern (downwind) side of the downdraft region and were largely unrimed aggregates of ice particles and small single crystals along the western side of the updraft region.

Depletion of liquid water by the growing ice particles within the updraft core was primarily by particles of small sizes. The lack of depletion by large particles within the updraft core suggests that the hail formation was quite inefficient and that most depletion was by particles which would have later melted to form rain at the surface. This topic is discussed further in a later section.

The T-28 measurements also indicate that a potential source region of hail embryos existed in a quiescent region which extended around the forward edge of the storm. Particles in this region of the "forward overhang" were primarily large aggregates of ice particles (up to 1-2 mm). Examples are shown in Fig. 3. The particles originated in decaying cumulus congestus turrets upwind of the mature storm and grew largely through aggregation as they were advected around the forward side of the storm. Such particles should be capable of serving as embryos for hailstones grown in the strong updraft, a matter which we now consider in more detail through a discussion of deduced hail trajectories.

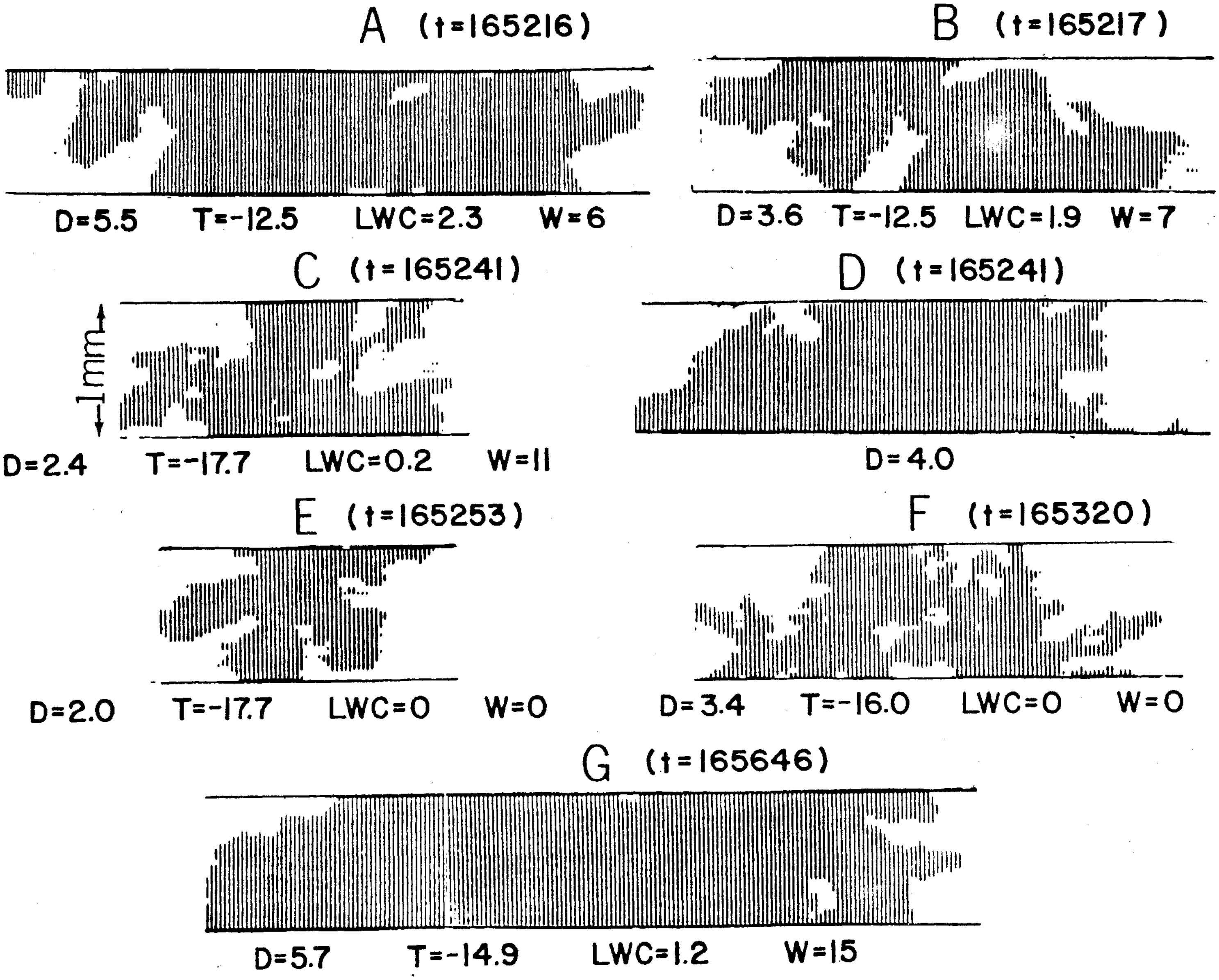

Figure 3. Two-dimensional images of particles sampled in the 22 July 1976 storm with the T-28 aircraft in the forward overhang region. The following parameters are indicated with each particle: t = time (MDT); D = maximum dimension (millimeters); T = temperature (°C); LWC = liquid water content (grams per cubic meter); W = vertical velocity (meters per second). A and B: rimed aggregates sampled in a feeder cell. C and D: unrimed dendrite and aggregate of dendrites sampled in feeder cell. E and F: unrimed dendrite and aggregate of dendrites sampled in forward overhang. G: rimed aggregate of dendrites sampled in feeder cell.

Hailstone growth trajectories have been estimated in two different ways: by theoretical calculation using the measured wind field and by tracking the dual-wavelength hail signal using the Doppler data only for qualitative guidance. In the first approach Foote and Frank calculated possible hail trajectories through the storm using the time-resolved Doppler wind fields and the hailstone growth equations and assuming an arbitrary grid of initial embryo locations. A number of additional assumptions are necessary, such as initial particle size and density, and a particle drag law, but variations of these parameters over reasonable ranges do not affect the general conclusions. The calculations assume a spatial distribution of liquid water as measured by the T-28 aircraft, with the maximum liquid water content being only about 60% of the adiabatic value.

Starting with embryos in the size range of 1 to 4 mm the calculations show that hail of the observed size, 1 to 2 cm, can be grown in 15-25 min. Such times correspond reasonably well with the lifetimes of individual cells, though cell decay may limit the growth of some of the hail according to these calculations. The trajectories are consistent with the observed reflectivity field in that the hail tends to fall out where the low level echo is a maximum. As in other case studies carried out by the Division, these results show that there is no need to resort to superadiabatic water contents to explain hail growth. Nor is there a need for up-and-down recycling of stones in the updraft. The calculations indicate that the hail grows in a single pass through the tilted updraft of the storm.

There is a reasonably strong sensitivity found to embryo size, with much less hail being produced with the 1 mm embryos than with 3 mm embryos, for example, though there are still starting locations that will produce about 2 cm hail from 1 mm embryos. There is also some sensitivity to initial embryo location, which, if real, would help to explain the patchiness of hail as well as its general scarcity.

The realism of the above calculations is limited by, among other things, the assumed existence of suitable embryos and by the extent to which the Doppler flow field is representative of the actual air motion. Of particular concern in the latter case are the affects of scales of motion smaller than those resolved by the multiple-Doppler approach (less than 3 km or so in this case) and the accuracy of the Doppler measurements of updrafts. Also, some assumptions have to be made about the growth to embryo size, which is not accounted for in the computations. The effect of such uncertainties on hail trajectories is sidestepped by using the dual-wavelength technique previously described, in which the hail position and to some extent its size are measured rather than calculated, and assumptions about early hailstone history are not necessary.

Using the dual-wavelength approach, Heymsfield and Frank, along with Jameson (Illinois State Water Survey), were able to document more fully the apparent two-stage nature of hail growth in this storm: Initial growth of embryos in upwind congestus towers, or sometimes in well-developed storm cells located upwind, followed by transport downwind into a second and vigorous updraft where the final growth to hail size takes place. Figure 4 shows the position of hail growing in the updraft as derived from the dual-wavelength and Doppler data.

Heymsfield and Jameson examined the hail production process further by computing as a function of time the volume of cloud that contained hail. During a period of 1 hr they noted three distinct cycles of hail production. By combining the dual-wavelength radar data with the derived wind fields for the six time periods of triple-Doppler radar scans, they found that the processes leading to the pulsation became more apparent. The data suggested that the pulsating hail production was a result of variations in the supply of suitable hail embryos rather than variations in the magnitude of the vertical velocities or the size of the updraft region. When hail production was at a maximum, graupel particles and hailstones which initiated earlier in feeder cells were being advected into the main updraft region where they grew into small and large hail. Hail production was at a minimum when feeder cells were weak in intensity and particle growth was confined to the main updraft regions.

Internal Storm Motion from a Single Conventional Radar

Radar has been used to track storms almost from its very invention about 40 years ago. The initial emphasis was on tracking storms for forecasting purposes, a primary use of meteorological radar even today. Radar provides much more information than just a storm's overall movement, however, and numerous investigators have used quantitative echo information in studies of storm structure, evolution, and precipitation. Doppler radar, with its ability to measure directly the radial component of velocity inside storms, has been used over the past decade as the primary tool for detecting internal storm motions, as in the case study just presented. Because of the straight forward advantages Doppler radar in motion detection, conventional (i.e., non-Doppler) radar has been little used for studying motion within storms.

Ronald Rinehart, Ellen Garvey, and John Tuttle of CSD have recently developed a pattern-recognition technique which can track features in the reflectivity field within storms to determine their motion. This technique called TREC (<u>t</u>racking <u>r</u>adar <u>e</u>choes by <u>c</u>orrelation) uses correlation analysis with arrays of digitized radar reflectivity data collected at consecutive range gates and azimuth rays. By comparing data in a specified initial array centered on some point with data in all second arrays of the same size over a neighboring search area, the TREC method objectively finds the best-matched initial and second arrays.

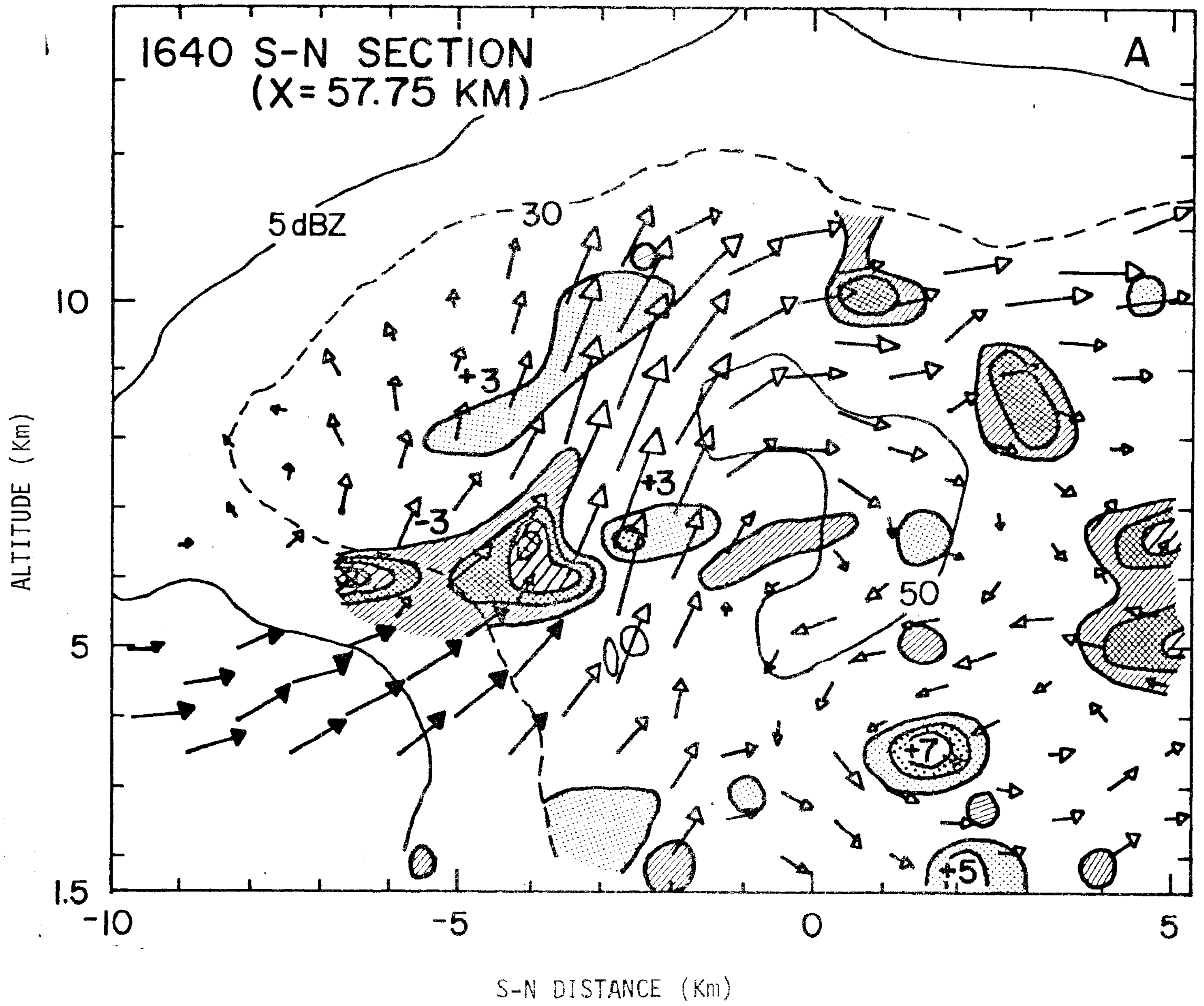

Figure 4. Vertical section of data oriented from south to north through the updraft region. Arrows show the storm relative winds, where a 1 km arrow length = 15 m s^{-1} wind velocity. Arrows which are filled in show winds estimated from the subcloud aircraft. Dual-wavelength signals are indicated as shaded and dotted regions. Regions of negative hail signal (graupel regions) are indicated from -3 dB, in increments of -2 dB. Regions of positive hail signal (hail) are indicated as dotted regions, from +3 dB, in increments of +2 dB. Radar reflectivity data are indicated as solid and dashed contours, at 5, 30, and 50 dBZ.

One of the advantages of TREC is the fact that it detects both tangential and radial components of velocity. Thus, in principle, TREC is capable of detecting three-dimensional motions with data from a single conventional radar, although to date only the horizontal velocities have been considered in detail. The ability to operate with data from only one radar simplifies both the data collection and cost constraints during field operations as well as the data processing and analysis. Further, TREC can be used with any existing data set already collected provided the spatial and temporal resolutions are adequate.

To better understand the potential as well as the limitations of TREC, artificial reflectivity fields were generated and moved about by specified flow fields generated using potential flow theory. In this way errors produced by TREC were readily detected and the conditions causing the errors identified. This study showed that the ability to track reflectivity patterns depended upon several things. These include the existence and persistence of reflectivity patterns, the size of these patterns relative to the array size used by TREC, the nature and relative strengths of the various components of the flow field, the location of flow field centers relative to the reflectivity field center, the array spacing and overlap, and the resolution of the available data set. An additional parameter that relates to trackability is the time lag between data sets; the best results come with the shortest lag times, down to times of the order of 10 s.

When TREC data were examined for self-consistency (i.e., comparing TREC vectors with their neighbors) on the 22 July 1976 case described in the previous section it was found that using 5 km arrays produced an inconsistency rate of about 4%, whereas that with 10 km arrays was only 2%. The above comparison was made with data from a single volume scan. The inconsistency rates for the time data were about a factor of two or so lower (i.e., better) than those of the volume scan data. Overall, TREC produced results which were quite consistent over both space and time.

At least two possible objective means of eliminating some fraction of the erroneous or inconsistent vectors were identified. One is to recognize that reflectivity itself is quasi-conservative and use this fact in a rejection criterion. The second method is to eliminate vectors whose correlation coefficients between best-matched initial and second arrays fall below some arbitrarily selected threshold. In either case, a number of correct or consistent vectors would also be eliminated. The value of such rejection criteria has not yet been fully explored.

Another approach to establish the accuracy of TREC is to compare it with the results of a triple-Doppler analysis on an actual storm. Using triple-Doppler data from the 22 July 1976 case study being analyzed by Frank (CSD), TREC was tested against a real storm situation. Because of the fundamental differences in the way TREC and Doppler radars operate, the resolution available from a triple-Doppler analysis is perhaps a factor of two to three better than that available from TREC, with both varying with range to the storm. Thus, to make the comparison more valid, the Doppler data were averaged over areas comparable to the TREC array sizes used.

Qualitatively the agreement between the two data sets is quite reasonable except at the lowest level; TREC showed motions from the west to northwest everywhere, whereas the triple-Doppler data showed motions from the northeast to southeast everywhere. Some of this difference is attributable to TREC (to be discussed shortly), although some is likely caused by systematic errors in the Doppler data because of beam blocking at the lowest elevation scans for one or more of the three radars used. Above cloud base the agreement is much better, with both schemes showing similar features in the three storm cells present at the time of the comparison.

A quantitative comparison of the motion speeds and directions was made at the 4 and 8 km levels of the storm. The overall result of this comparison was that the differences in speeds averaged about 0.5 m/s between TREC and Doppler data and the differences in directions averaged 18°. Though there were regions where the disagreement was much larger, the overall comparison shows that the TREC vectors were in reasonable quantitative agreement with the results of the triple-Doppler analysis.

Perhaps the most significant conclusion to be drawn from comparison of TREC and triple-Doppler data, one that has important implications for the utility of the scheme in general, is that the patterns followed by TREC can originate well above or well below the level being examined. The height difference between where the Doppler data were in best agreement with TREC vectors averaged 550 m but had a standard deviation of 1.8 km. This large standard deviation resulted because, in some cases, the height of best agreement of Doppler data was as much as 6 or 7 km from the height of the TREC vectors being determined. Fortunately the regions of largest difference were in relatively weak echo such as beneath the storm's anvil. Near the echo cores the height difference was usually much closer to zero. Thus, there are situations in which the motions found by TREC are not the same as the air motions in the storm. Nevertheless, TREC is still quite capable of resolving significant internal flow features and provides much useful information on the kinematic structure of storms.

Recently TREC was also applied to the mesocyclone case of 25 July 1978 using data from the Northern Illinois Meteorlogical Research on Downbursts (NIMROD) project collected and supplied by James Wilson of the NCAR Field Observing Facility. The fields of velocity from TREC were in good agreement with an analysis of dual-Doppler results conducted by Theodore Fujita of the University of Chicago.

It thus appears that TREC is a simple yet powerful technique for determining the motion of reflectivity patterns within storms. While it has limitations related to the data resolution, the parameters used in the processing, the scales of motion present in the storm, and the location where the reflectivity pattern is generated within the storm, it nevertheless yields considerable information about the storm's kinematics. The relative simplicity of the data processing and the need for only a single radar make the approach attractive in many situations in which multiple-Doppler systems are unavailable.

Convective Storm Modeling

As part of our modeling effort in the Convective Storms Division progress has been made toward producing a realistic parameterization of microphysics for the dynamical models. Over the past year we developed a two-dimensional slab symmetric cloud model which incorporates detailed treatments of the water and ice phase. The liquid phase processes considered include condensation, stochastic coalescence, sedimentation, and breakup. The ice processes include nucleation, diffusional growth, and accretional growth. Cloud simulation studies are currently being investigated. Preliminary results indicate that model supersaturations often reach values larger than 5% with respect to water when raindrops appear within updraft regions. These results corroborate earlier findings by modelers. Other results illustrate the importance of recyclying in transporting ice particles from their preferential nucleation area in the upper portion of the cloud to lower-level, preferential accretional growth regions of larger liquid water content.

The results of this two-dimensional microphysical model are currently being compared with presently available microphysical parameterizations that can be incorporated directly into the three-dimensional cloud model. Modifications of these schemes are being considered that will put us on firmer physical ground, including adding some extra field variables in order to eliminate some of the more arbitrary and nonphysical aspects. One rather obvious example is the incorporation of raindrop numbers into the Kessler scheme. Melting of graupel into raindrops results in not only a well-defined water content (the only field variable of the Kessler scheme for rainwater) but also in a number concentration. Thus with such additions, a more meaningful terminal velocity and evaporative cooling response can be obtained.

Studies relating to the influence of cloud microphysical detail on the dynamics and thermodynamics of severe convection have also progressed over the last year. One aspect of three-dimensional cloud simulations which had been hampering these types of studies was the sensitivity of the solutions to small changes in the lateral boundary conditions. The commonly used extrapolation schemes which consider no strong level of specification at inflow boundaries lead to runaway values of horizontally-averaged vertical velocities as well as high levels of sensitivity on the local structures of the basic fluid dynamical fields. Briefly stated, these types of lateral boundary conditions are ill posed. This problem has been overcome by using a time relaxation to specification for the inflow normal velocities and total specification for all other field variables at inflow. Calculations with different domain sizes and in one case higher resolution all produced similar results after 96 min of cloud simulation. The statistical variable of horizontally averaged vertical velocity remained relatively unchanged over an assumed test area for all domain sizes treated, and the values are not considered unrealistic. The local structure of the thermodynamic fields was also relatively unchanged over an assumed test area for all domain sizes treated.

Now that the lateral boundary conditions are not leading to an ill-posed problem we are in a position to isolate sensitivities due to the physical processes in the three-dimensional severe storm simulations. Effects of microphysics and initialization procedures are currently under investigation.

Final Report on the National Hail Research Experiment

As mentioned in the Introduction, the final report of the National Hail Research Experiment (NHRE) is an effort to summarize the knowledge gained from the physical research, as distinct from the statistical experiment. In addition to summarizing case study results and other research already published, a lot of new analysis has been done to attempt to generalize conclusions and to obtain general descriptions using the whole data set. We mention here two items from that report: the climatology of the northeastern Colorado region with respect to weather during the NHRE period, discussed in brief, and mechanisms of precipitation formation, presented in somewhat more detail.

Climatology of the NHRE area

The work in this area has been completed by James Fankhauser and Charles Wade and emphasizes the structure of the environment during periods of convective activity, along with more general climatological characteristics. Their work represents a synthesis of a number of previous studies, mostly unpublished, but includes several new results as well. Specific topics covered include: (a) Characteristics of precipitation in the NHRE region, (b) large-scale environmental features, including mean surface and upper level flow patterns and departures from these patterns observed during the NHRE experiment, (c) representative soundings and vertical wind profiles on experimental storm days, and (d) association between synoptic flow patterns and storm types.

Perhaps the most interesting results were obtained in the area of precipitation climatology. Analysis of cooperative precipitation reports for the four-month "convective" season (May through August) dating back to the 1880s shows that the decade of the 1970s in northeastern Colorado was one of the driest on record, ranking second only to the 1930s. Further, four of the five years during which major field experiments were conducted (1971, 1973, 1974, and 1976) rank in the driest 15% of the 92 summer seasons dating back to 1888. Ironically, the decade when the NHRE experiment was conceived (1960s) was the wettest on record. These results explain the low number of storm cases observed in NHRE compared with what was expected. There is no reason to believe that seeding effects would have been different in wet years, though one's ability to detect such effects would certainly have been greater because of the larger number of cases.

Further analysis of the cooperative precipitation data collected in the northeastern Colorado region over the past 20 years supports a previously suspected trend, namely, that precipitation occurrence in the NHRE region has a strong intraseasonal variation, with a maximum occurring in late May and a minimum in late June.

Representative sounding data for the three seasons of randomized seeding were used to obtain curves demonstrating intraseasonal variability in convective cloud thermodynamic characteristics. These will prove useful for making comparisons with convective environments in other geographic regions.

Precipitation Formation in the Convective Storms of NHRE

The microphysics chapter of the NHRE report was written by Charles Knight, with sections by William Cooper and Gabor Vali of the University of Wyoming and Daniel Breed and Ilga Paluch of CSD. Andrew Heymsfield, James Dye, Peter Johnson, Nancy Knight, and Joanne Parrish helped to assemble data. The microphysical results from aircraft are primarily based upon 1976 data from the University of Wyoming Queen Air, the South Dakota School of Mines and Technology armored T-28, and the NCAR/NOAA sailplane. Earlier data are largely ignored because of the great improvements in aircraft cloud physics instrumentation between 1974 and 1976. Some of the more important general conclusions are summarized here under three headings: hail size relative to updraft speed, precipitation particle growth trajectories, and depletion of cloud water.

Hail Size Relative to Updraft Speed

The principle that has been used for many years in attempting to predict maximum hailstone size is to predict the updraft velocity of a storm and suppose that the maximum hail size produced is that which can be just balanced in the updraft. The assumption in this supposition --usually unstated--is that the microphysical growth processes within the cloud are adequate to produce such sizes and even larger; except for the fact that larger particles would fall out.

One general conclusion from the NHRE results is that this assumption is incorrect, and importantly so. In every case studied the maximum updrafts are stronger than that required to balance the largest observed hail. The updrafts are sometimes adequate to suspend hail more than twice the size of that observed. The clear conclusion is that the residence time in cloud of a growing hailstone and of smaller precipitation particles as well is influenced in important ways by the three-dimensional wind field, by the wind field's steadiness in time or, most probably, by both. Thus a large hailstone is unlikely to remain within its bounds long enough, and it is unlikely to form in a strong updraft of short duration.

The same conclusion applies even more to smaller precipitation, snow, and graupel, in the NHRE area of interest. In both sailplane and T-28 flights, updrafts of 15 m s^{-1} or more were not uncommon in the absence of a radar echo or any detectable precipitation.

These observations underscore the fact that the important interactions that do determine the production of precipitation within a convective cloud are those between the airflow field and the microphysical growth processes, that is, the coupling between the particle growth rates and residence times within cloud provided by the many potential particle trajectories.

Precipitation Particle Growth Trajectories were a major focus of the 1976 NHRE field season, from which airflow fields have been deduced by analysis of multiple-Doppler radar data. Precipitation data from penetrating aircraft, radar reflectivity factor measurements, and ground sensors have been combined with the air motion data to deduce growth trajectories in a number of cases.

Before summarizing the results, we need to present a brief perspective of the nature of present models of precipitation growth in storms. In these concepts, storms are considered to be either steady-state or systematically evolving, without important, irregular airflow variations in space or time. In other words, turbulence in the storm is considered not to be important as far as the trajectories of precipitation particles are concerned, and particle growth trajectories can be traced in a deterministic fashion to obtain growth times and estimates of final size. However, many measurements within NHRE and elsewhere, using penetrating aircraft and Doppler radar, have shown that the interiors of storms are nearly always turbulent. The question has been whether viewing particle growth trajectories with the simplifying assumptions of these concepts is adequate: whether, in other words, the more disorganized, turbulent motions within the storms are so important that they have to be taken into account to obtain a usefully quantitative understanding of precipitation. The conceptual model of a storm as composed of many successive thermals, put forth by Ludlam more than 20 years ago, though not often appealed to recently, is an alternative that does allow for much more complexity.

Numerical models are just now approaching the degree of realism that allows this question to be approached theoretically, but the NHRE field results and other investigations are showing conclusively that the smaller scale and/or less "organized" features of storms are indeed important to precipitation growth and cannot be ignored. All of the 1976 case studies are giving this result in principle, though they differ in detail.* In the 22 July case, analyzed by Foote, Heymsfield, Jameson, Frank, and Wade, transfer of particles between cells has been shown, with "embryos" forming in one cell and growing into hail in another. In the 25 June case analyzed by Dye, L. Jay Miller (NOAA/WPL), and Brooks Martner (University of Wyoming), a fairly systematic recycling of precipitation within a single cell of a weak multicell complex has been shown to be important to the attainment of the maximum precipitation particle size. In the severe 22 June case, analyzed by Knight, Fankhauser, and Ian Harris, the vertical components of the hail growth trajectories appear to be essentially chaotic, with residence times determined by the horizontal component of airflow through the storm and size determined by whatever growth environments were encountered along the way. (It is interesting that the best growth environments in this storm were probably in the moderate rather than the very strong updrafts, because the stronger updrafts would elevate all ice particles above the -40°C level, where they cannot grow.)

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*Three of the case studies are summarized in this and the last two <u>NCAR Annual Scientific Reports</u> to <u>NSF</u>.

General evidence for complex and variable growth trajectories in severe storms comes from the long-recognized layering of hailstones. It has been observed in CSD (by N. and C. Knight) and elsewhere that hailstones not only possess a complex layering but that the layering is usually extremely variable among hailstones from a single storm, and even in brief collections at single spots under a storm. The message of extreme trajectory variability is nearly inescapable.

The strikingly uniform ice particle size distributions observed from the T-28 and analzed by Paul Smith, Dennis Musil, (South Dakota School of Mines and Technology) and Heymsfield are another piece of evidence for the importance of mixing. While size distributions in rain can change by breakup and coalescence processes, ice particles rarely either breakup or stick together. (Aggregation of snow is a sometimes major exception.) Thus a distribution of ice particles ranging in size from a few hundred microns to a few centimeters must have come together from a range of points of origin (nucleation) spanning a few kilometers in distance and a few tens of minutes in time. That the size distributions tend to be highly regular and uniform would seem to imply a high degree of random mixing, or turbulence.

Similar kinds of complexities are also abundantly evident in the early stages of cell formation. While the first radar echoes are usually found within updrafts, it is often observed that the ice particles that produce these echoes are too big to have formed within that updraft. Aircraft evidence of especially great concentrations of precipitation at updraft-downdraft interfaces supports the general importance of recycling of particles in downdrafts and back into updrafts at lower levels. The existence of concentrations of ice particles far too large to be explained by primary ice nucleation likewise suggests transport from higher, colder regions, and such transport is supported by the finding of penetrative downdrafts within the clouds.

In all, the evidence is becoming strong that the overall picture of growth trajectories within storms will not in general fit the kind of simple systematic model that has been proposed in the past, perhaps with the exception of Ludlam's concept of a storm as an aggregation of thermals. Either smaller or briefer scales of motion must be taken into account, or a random element must somehow be introduced.

<u>Depletion of Cloud Water</u> by the growing ice particles is obviously fundamental to precipitation efficiency, and it is fundamental also to weather modification. The primary hypothesis of hail suppression is that adding more embryos can increase the depletion of cloud water, reducing ultimate hail size by "competition" between the embryos, and

the primary hypothesis of artificial precipitation augmentation is that the natural depletion can be increased by forming more depletors--either ice particles or water drops larger than the cloud droplets.

In the simple case of a single size of accretor particle, and a collection efficiency for all of the cloud water droplets of unity, the depletion rate is simply WV_TAN, where W is the liquid water content, V_T is the terminal velocity, A is the cross-sectional area (πr^2) and N is the concentration of the accretor particles.

$$\frac{1}{W}\frac{dW}{dt} = -V_TAN$$

Integrating this produces

$$V_TAN\Delta t = -\Delta \ln W,$$

and a depletion time, τ, can be defined as

$$\tau = (V_TAN)^{-1} ,$$

the time required to reduce the initial W to a value of W/e, assuming that the accretor particles do not grow or change in any way. Thus, τ is a kind of instantaneous depletion time and is independent of W under the assumptions; τ is therefore an overestimate of the real depletion time, since the depletors do grow, and larger particles deplete W more rapidly. However, τ is probably even more of an <u>underestimate</u> for the NHRE situation because the collection efficiency, E, is nearer 0.5 than 1 for most of the circumstances encountered. Foote estimated that as long as W divided by the precipitation water content was less than 2, τ is less than about 30% too high because of the no-growth simplication.

With τ as an estimate of depletion time, one also needs an estimate of the time available for depletion, so that a comparison between the two can be used to estimate roughly a "depletion efficiency." Limiting our attention to the stronger updrafts that are necessary to produce hail and assuming an average updraft throughout this growth layer of 20 m s^{-1}, we obtain a residence time for a water droplet, traveling with the air, of about 250 s, or about 4 min. It can be concluded that depletion times of a few minutes imply "reasonably effective" depletion, whereas times of about 15 min or more (about 10^3 s or more) imply "reasonably ineffective" depletion, within the limitations of the approximations involved in these estimates.

Heymsfield has calculated depletion times for the T-28 penetrations, and it is interesting that the results are so variable as to defy generalization. While the 22 July 1976 case produce rather large values of τ in the updrafts — 10^3 s or more nearly always — some of the other cases exhibited shorter times. On 25 July 1976 for instance, times of 400-500 s were found within updrafts, and on other days the values of τ range as low as about 200 to far over 10^4. If there is a generalization from the data, it is that the strongest updrafts (such as those on 22 July) tend to have longer depletion times than weaker updrafts; however, inspection of the data reveals a great deal of scatter. The conclusion to be made at this point is that the results are variable within the important ranges, from effective to ineffective depletion; and from effective to ineffective competition. More case studies will be needed to proceed farther with understanding this important variability.

It is interesting to note a few general properties of τ, the depletion time:

For an exponential size distribution of particles, $N = N_0 e^{-\Lambda D}$, if one assumes that density and drag coefficients are independent of D, the minimum of τ as a function of particle size is easily shown to be at $D = 2.5/\Lambda$, which is substantially smaller than the median volume diameter $D_0 = 3.67/\Lambda$.

If the size distribution obeys a power law rather than an exponential, the contribution to depletion increases steadily with decreasing size.

If all the accretors are the same size, then for a given mass of accretors — a given ice water content — τ decreases strongly with decreasing particle size.

Obviously, the radar echo has little relation to τ.

Depletion times and particle size spectrum parameters were calculated as a function of particle size, using the T-28 data from ten flights. Using the fact that in an exponential size distribution the size interval centered at $2.5/\Lambda$ is the most effective for depletion, the size spectrum data give a most effective size of about 2 mm for the larger particles (>1 mm diameter) and about 0.5 mm for the smaller. (The two size ranges were fitted to separate exponential distributions.) In fact, when depletion times per millimeter size interval are calculated directly for many size ranges, a more or less distinct minimum is usually found in the vicinity of 1 mm in diameter.

This leads to the interesting and important conclusion that the prospect for hail suppression by adding to the concentration of actual hail embryos is fundamentally quite uncertain. In a recent discussion Foote pointed out that since the natural depletion is dominated by smaller particles, the safest way to increase depletion is to increase the concentration of the smaller particles. The size distribution itself would have to be altered very appreciably before the largest sizes influence competition very much. The smaller particles will themselves not grow into hail but will melt into rain before reaching the ground, thus avoiding the risk of increasing hail by seeding. Also it appears that it may be easier to introduce such "rain embryos" into the updraft, as the dynamical selection process seems to be less constraining than for hail embryos.

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Ronald Biondini, University of Virginia;
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Steven Hunter, University of Wisconsin;
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Arthur Jameson, Illinois State Water Survey;
Microphysics Group, 12 February - 11 March 1979.

Thomas Kerrigan, Drexel University;
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ADVANCED STUDY PROGRAM

INTRODUCTION

In order to fulfill the two main missions of NCAR, it is clear that a high level of intimate and long-term interactions between NCAR and university scientists is essential and that the best scientific talent is needed. The Advanced Study Program (ASP) provides a number of visitor and educational programs designed to promote these interactions and to develop this talent, including postdoctoral fellowships, graduate assistantships, summer fellowships for women and minority students, and summer colloquia workshops.

Research on problems "of central importance to society" is not complete without an examination of the impacts of the results of this research on society--how these results can best be used, how to avoid misuse, and what future research might yield the most beneficial future results. ASP is examining some of these impacts through its Environmental and Societal Impacts Group (ESIG).

ASP regular full-time Ph.D. staff members (outside of ESIG) are responsible for running the ASP visitor and educational programs. These staff members also conduct individual research on scientific problems.

POSTDOCTORAL FELLOWSHIP PROGRAM

The ASP postdoctoral fellowship program is designed to provide a substantial, flexible opportunity for the best new Ph.D. scientists to be exposed to major atmospheric research programs at NCAR, to interact with these programs and the individual scientists working in them, and to learn about and use major atmospheric science research facilities, such as the Control Data 7600/CRAY-1 computer system, research aircraft, and radar. Most of these are scientists already working on atmospheric problems; some are scientists interested in applying their background in physics, mathematics, chemistry, engineering, and, in a few cases, social sciences.

A principal goal is to encourage ASP Fellows to form or enhance long-term association with NCAR beyond their fellowship, through:

(1) assuming regular appointments to various projects in the NCAR program;

(2) assuming or returning to faculty and reseach positions in UCAR and other universities doing atmospheric research;

(3) collaborative research with its staff, either individually or as part of large programs; and

(4) continued use of its facilities.

In achieving this goal, the fellowship program exploits the unique educational opportunities provided by the expertise of NCAR's individual staff members, its large coordinated research projects not usually found at universities, and its large research facilities. These opportunities are complementary to the educational activities in the atmospheric sciences at the universities.

The NCAR experience should therefore help enrich the research and teaching talent in atmospheric sciences. Conversely, the fellows influence NCAR scientists, programs, and activities in substantial ways, through infusion of fresh points of view and new expertise.

It is our conviction, supported by experience, that the identification by the fellows of their scientific interests, rather than the ab initio assignment of fellows to projects, promotes strong and healthy interactions between them and the NCAR staff and programs. Many fellows are uncertain as to where their interests center before they arrive, and others change their minds for good reason after they are here. Some also have specific educational goals as part of their plans, and others intend to interact in substantial ways with more than one project. Experience has shown many times that the direction of research taken by some of our most successful fellows would have been hard to anticipate.

Included at the end of this section are lists and present or previous affiliations of the ASP fellows for the academic years 1978-79 and 1979-80. Each group contains scientists from a wide range of disciplines, and the disciplines represented vary widely from one year to the next depending on the nature of the applicant pool.

Space does not allow a comprehensive discussion of the achievements of each fellow. We will mention, therefore, the noteworthy research of only a few.

Peter Bannon (1979-80) has investigated the flow of a rotating barotropic fluid over a finite isolated Gaussian obstacle. Emphasis was placed on determining the blocking efficiency of the obstacle in various flow situations. Quasi-geostrophic theory indicates no blocking efficiency of the obstacle in various flow situations. Quasi-geostrophic theory indicates no blocking of the flow by the obstacle (i.e., just as much goes over a mountain as is incident upon it). This deficiency arises because quasi-geostrophic theory restricts attention to nondivergent flow.

The limitations of quasi-geostrophic theory were removed using the shallow-water equations. Finite Rossby number solutions were obtained analytically and numerically for steady-state situations. The effects of friction, a free surface, horizontal shear in the upstream inflow, and variations in the Coriolis parameter (beta-effect) were addressed.

Joseph Tribbia investigated the nature of a nonlinear normal mode initialization scheme in the equatorial region he developed along with Ferdinand Baer (University of Maryland). Primitive-equation (P.E.) numerical prediction models incorporate more complete dynamics than their filtered counterparts (e.g., quasi-geostrophic models); unfortunately, P.E. models also sustain transient high-frequency gravitational oscillations that are not believed to be of importance on the large scale. These modes of oscillation are often excited through the use of inconsistent or incorrect initial data fields. The scheme used by Tribbia, and other similar methods, allow one to "correct" the initial state so that these high frequency modes are not excited initially, nor do they re-establish themselves during model integrations. The above-mentioned initialization methods, however, require that the frequencies of the modes to be initialized are very much greater than the characteristic frequency of meteorologically significant motions. This condition is violated to some extent in the tropics. However Tribbia showed that by using a higher order version of the initialization scheme, one could obtain low-frequency model evolution.

UCAR FELLOWSHIP PROGRAM

UCAR has provided a limited number of graduate fellowships for study in the atmospheric sciences leading to the Ph.D. During the academic year, these fellows attended the graduate school of their choice, and spent their summer in ASP. As fellows they received a stipend, and their tuition was paid by UCAR. We attempted to support the best students, whether or not they had had previous training in the atmospheric sciences. Our primary concern was that the student was interested in pursuing a graduate career in the atmospheric sciences (broadly defined) and that he or she had the ability and motivation to attain the Ph.D. The principal ASP and NCAR objective in conducting the UCAR Fellowship Program was to expose scientists at an early stage in their professional careers to the facilities and programs of NCAR. Like the postdoctoral fellows, many of these students have formed longer term association with NCAR by using its facilities for their dissertation research and beyond, by participating in NCAR projects when appropriate, and even by subsequently being hired by NCAR.

Included at the end of this section are lists of the UCAR fellows for the year 1978-79. We regret that because of a budget stringency, the UCAR Fellowship Program was terminated in September 1979.

NCAR GRADUATE ASSISTANTSHIPS

The NCAR Graduate Assistant Program is designed to foster cooperation between NCAR and academic institutions by providing some financial support for graduate students of atmospheric science to pursue master's or doctoral work while in residence at NCAR. Awards are made on the basis of proposals jointly conceived and written by the graduate student, the student's academic supervisor, and an NCAR scientist who agrees to act as scientific cosupervisor of the dissertation, and who also agrees to be a member of the dissertation committee. The dissertation work must normally contribute to the goals of the NCAR project under which it falls and must also be satisfactory to the home institution. So that residence at NCAR will not interfere with the academic program, the appointments are for one-half time, 12 months of the year, and normally begin after the student has completed formal course work and passed the comprehensive exams. Once granted, the appointment normally continues until completion of the degree program, provided that satisfactory progress is being made, as judged by both NCAR and the student's academic department.

This program was made part of ASP in 1978. At any one time, approximately seven graduate assistants are in residence at NCAR. The research being conducted by the assistants is quite diverse, ranging from atmospheric chemistry to climate to upper atmospheric dynamics. The work of two graduate assistants is highlight below:

In the stratosphere, the products of solar photolysis reactions both produce and destroy ozone, while in the troposphere, photolysis products both produce and remove air pollutants such as ozone (O_3), oxides of nitrogen (NO_x), carbon monoxide (CO), and sulfur dioxide (SO_2).

Models of atmospheric chemistry must calculate photolysis rates with the time-consuming, and often inaccurate, methods of integration.

Russell Dickerson has been involved in developing and improving techniques to measure photolysis rates directly and absolutely. New instruments, called actinometers, measure the rates of photolysis of O_3 and NO_2

$$O_3 + h\nu \xrightarrow[\lambda<320\text{nm}]{} O_2(^1\Delta_g) + O(^1D)$$

$$NO_2 + h\nu \xrightarrow[\lambda<420\text{nm}]{} NO + O$$

which are prominent in both tropospheric and stratospheric chemistry. These actinometers first measured photolysis rates on the ground, as a function of overhead ozone column, solar zenith angle, and cloud cover. They have been redesigned and mounted on NCAR's Electra to study the effects of altitude, latitude, aerosols, and albedo on the photolysis rates. Finally, the effects of temperature and pressure were measured.

Different models sometimes calculate absolute photolysis rates which differ by more than an order of magnitude. The results of direct measurements not only give accurate absolute rates but also show that clouds reduce ultraviolet photolyzing radiation much less than they reduce total solar radiation. In addition, altitude and pressure were found to have little effect on photolysis rates. Albedo strongly affects both O_3 and NO_2 photolysis rates, but temperature affects only O_3 rates.

William Kohri has been involved in the development of a technique which produces reliable daily synoptic estimates of the global temperature, ozone, and geopotential height distributions in the stratosphere and lower mesosphere. The data used in these analyses were obtained from the Limb Radiance Inversion Radiometer (LRIR) that was flown on board the Nimbus 6 spacecraft. Since conventional types of stratospheric observations (i.e., balloons and rockets) do not extend much above 30 km, the ability to produce global daily synoptic analyses in the middle and upper stratosphere by using the statistical filter method developed in this project should prove to be beneficial for further dynamical studies of the stratosphere which utilize satellite data.

The daily Northern Hemisphere temperature and geopotential analyses, which were deduced from LRIR data obtained during November and December 1975, were used to determine the structure of the stationary planetary waves present in the stratosphere during that time. The geopotential analyses were used to obtain the Northern Hemisphere geostrophic wind structures. A review of theoretical works that dealt with stationary planetary wave structure and propagation was undertaken in order to determine the extent of agreement of discrepancy between observations and theoretical model predictions. Results showed that although conclusions obtained from one-dimensional β-plane type models of vertical propagation were in general verified, a proper explanation of wave structure and propagation can be obtained only through consideration of the two-dimensional structure (i.e., vertical and meridional) of the mean zonal wind. The meridional variation of the zonal wind was shown to be particularly important in the determination of stationary wave propagation.

Calculations of the heat and momentum transport accomplished by stationary planetary waves one and two were also performed. Results show that these two wave components are responsible for a large portion of the total transport that takes place. Results such as these, especially for the region above 30 km, should extend our knowledge of energetics present in the upper stratosphere and mesosphere.

SUMMER FELLOWSHIPS FOR WOMEN AND MINORITY STUDENTS

NCAR recognizes that far too few women and ethnic minority members are presently found in professional positions in the atmospheric sciences, both at NCAR and elsewhere. A large part of the problem is that not enough women and minority students have started through the atmospheric sciences academic "pipeline." ASP is helping to correct this situation by running a summer fellowship program specifically for women and minority students. Such a program is supportive of NCAR's main objective in at least two ways. First, important new sources of talent for solving atmospheric problems will now be tapped. Second, as a practical matter, federal funding for atmospheric sciences research both at NCAR and universities may be threatened if sufficient attention is not given to an affirmative action program.

Each summer, we bring to NCAR women and minority students with undergraduate training in physics, mathematics, chemistry, and computer science. The students are given a brief, intensive course in FORTRAN, so that they can use the NCAR computing system during their visit. They are also given an introductory course in atmospheric sciences. Finally, and probably most important, they are assigned to work with an interested NCAR staff member on a carefully selected research project. We try to choose projects that will leave the students with a feeling of accomplishment by the end of the summer, rather than long-term, large-scale research efforts. We hope that the summer experience will be so positive that students will subsequently apply to graduate school in atmospheric sciences.

Listed at the end of this section are the participants in our program for the summer of 1979.

SUMMER COLLOQUIUM

Nearly every year since 1966 NCAR has sponsored or cosponsored summer colloquia, typically for a two-month period, on a variety of important atmospheric science topics of interest to NCAR and universities; topics have included thermal convection; the solar corona; acoustic and gravity waves; solar magnetohydrodynamics; dynamics and microphysics of convective clouds; planetary magnetospheres and aurorae; dynamics of the tropical atmosphere; subsynoptic extratropical weather systems; the dynamics, physics, and chemistry of the stratosphere and mesosphere; weather forecasting; and the general circulation. These colloquia have been primarily for university graduate and postdoctoral students and have included many principal lecturers and seminar speakers from universities. The colloquium notes produced from these sessions have been widely used as reference materials at NCAR and in university courses.

The colloquium clearly represents an important mode of interaction with universities that can be used in the future in partial support of NCAR's major mission of large coordinated attacks on major atmospheric research problems. Specifically, we have had a policy of choosing many colloquium topics to complement NCAR research projects. Bringing together students, faculty, and NCAR project staff to review in depth the "state of the art" in a particular research area of growing importance on the NCAR or national scene should serve to stimulate more Ph.D. work and closer collaboration between NCAR and the universities in the particular subject area.

No colloquium was held in 1979.

STAFF RESEARCH - MAURICE BLACKMON

Blackmon, in collaboration with Ngar-Cheung Lau of the Geophysical Fluid Dynamics Laboratory (GFDL), completed a study of the seasonally averaged statistics of a general circulation model developed at GFDL.

Using previous observational work for comparison, model statistics were calculated for means and variances of 1,000 mb height, 500 mb height, and 850 mb temperature. Dynamically important covariances, such as 850 mb sensible heat flux and 300 mb momentum flux were also calculated. Some quantities were temporally filtered to partition the variance, or covariance, into low and high frequency parts. One field, the 500 mb height, was also expanded into spherical harmonics in order to partition the corresponding variance into spatial scales.

The results of the comparison show that the model does not simulate the low frequency fluctuations (periods of 10-90 days) well. In particular, the synoptic scale, low frequency fluctuations were not generated by the model to any appreciable degree, although these fluctuations make important contributions to the variance of the 500 mb height. The authors found that the eddy statistics of the model were most realistic in the lower troposphere. Although the vertical structure of the fluctuations generated by the model was in agreement with observations, the amplitude of the fluctuations in the upper troposphere was too small. The value of maximum zonal wind velocity was also too small by about 50%.

Blackmon is also completing a study of the regional characteristics of the autocorrelation functions for 1,000 mb height, 500 mb height, and 850 mb temperature. Autocorrelations were calculated for daily data for lags of 1 through 30 days. The time between independent samples, as defined by Cecil Leith (AAP) and previously calculated by Roland Madden (AAP) for 1,000 mb height, was calculated. Interestingly, this result agrees with Madden's calculation, which uses an independent data set and a different method of calculation. Furthermore, the time between independent samples is shown to be quite different for different fields. Finally, five-day averages and ten-day averages are used to calculate the autocorrelation functions for multiples of five-day and ten-day lags, respectively. Interesting connections are found between the autocorrelation functions and the teleconnection patterns recently discussed by John Wallace (University of Washington).

ENVIRONMENTAL AND SOCIETAL IMPACTS GROUP

In 1979 the Denver Regional Air Mangement Study Group (DRAMSG) completed many important activities. This group, which is a subgroup of ESIG, has as its main research goals the development of a set of models which project, for the next twenty years, the quality of the air of the metropolitan Denver area and which show the effects on air quality of the possible management policies. These quantitative models are then linked to a model developed by behavioral scientists, which optimizes the trade-offs necessary between effectiveness and acceptability of the management options.

The first major accomplishment was the development of a simple, regional model for carbon monoxide (CO) concentrations as a function of meteorological conditions (for example, wind speed and lapse rate) and emissions. The emissions are of two types--stationary and mobile sources. Stratification into stationary and mobile sources is important because it reveals the relative impacts of regulations on, for example, auto emissions or power plant emissions. Using models of economic activity, population growth, traffic flow, and projected auto emissions, typical wintertime estimates of CO concentrations can be produced for the next 20 years. Various management options, say, inspection and maintenance on automobiles, staggered work hours, four-day work weeks, or increased public transit, can be assessed. First results indicate that presently mandated improvements in auto emissions plus an effective inspection and maintenance program will decrease CO concentrations over the next several years. However, CO concentrations are forecast to increase significantly by the year 2000 unless additional management options are used.

DRAMSG has also begun work on the visibility problem. A comprehensive visibility study needs a model with realistic photochemistry included. Paulette Middleton is developing this model. Another important and interesting piece of the visibility problem is whether peoples' perceptions of pollution are correlated to what is presently being measured, for example, the coefficient of haze (COH). DRAMSG has conducted two field studies, one in August 1979 and another from December 1979 through January 1980, to compare the perceptions of meteorologically untrained observers with instrumental readings. For the summer study, we find that unsophisticated observers do not distinguish well between pollution and naturally occurring haze (associated with thunderstorms, for example). Nonetheless, there is a correlation between COH measurements and perceptions of pollution. Winter results are not available yet. However, the period chosen for the field study had many days when the "Brown Cloud" was well developed as well as days which were clear, so interesting results are anticipated shortly. Finally, the observers in our study also made a detailed photographic record of the two periods. We will continue our study using series of photographs to test whether the perceptions of pollution obtained from photographs are as accurate as direct observations. If so, we will be able to increase our group of observers easily, and thus determine more precisely the correlations between measurements and perceptions.

Finally, DRAMSG conducted a two-day workshop in September 1979 in Boulder. The purpose of the workshop was to bring together representatives from various government agencies and interested citizen's groups in order to inform them what our research program is and to encourage them to use our methods for developing public policies. While each group seemed interested in particular results of our study, usually the results that directly affected each particular group or agency, few of the workshop participants seemed to grasp the comprehensive structure being presented. We plan to have other workshops to continue our efforts in information transfer.

A major research effort started by Michael Glantz in 1979 was the analysis of the impact of the Yakima streamflow forecast. This study concerns the impact of an actual forecast of Total Water Supply Available (TWSA) for irrigators in the Yakima River Valley. The allocations are made by the Water and Power Resources Service (WPRS) (formerly the U.S. Bureau of Reclamation).

The Yakima Basin is in the rain shadow of the Cascades and is arid, with precipitation in the area varying from 17 to 25 cm (7 to 10 in.) per year. The major part of the water supply derives from snow melt and runoff in the mountains. In February of each year, monthly projections of the amount of water available for the irrigation season are made. The actual TWSA has generally been favorable in the basin since the mid-1940s. In 1977, however, several conditions, some actual and some perceived, brought drought "hysteria" throughout the western part of the United States and especially in California.

Estimates of TWSA (traditionally calculated by combining natural flow estimates, water storage, and return flow) that were issued in February 1977 by the Bureau of Reclamation for the coming crop year suggested that less than half of the long-term average water supply would be available. The WPRS allocated the estimated TWSA accordingly. Water rights issues arose when those having "senior" (nonproratable) water rights were informed that they would be served first and "junior" (nonproratable) water rights would get a share of what would be left. As of the February projections by the WPRS, those with nonproratable water rights were to get 98% of their normal water allocation, while those with proratable water rights were to receive about 7%.

Those with perennial crops had to protect their crops (for example, fruit trees, mint plants, hops) at any price, or face the possibility of personal financial disaster, A variety of measures prompted by the forecast and the allocations based on the forecast were undertaken by various individuals, companies, and governments, at great expense to all. It was clear that many of those decisions were influenced by the forecast; that is, the forecast prompted farmers, companies, and governments to do what they might not have otherwise done. Responses to the forecast included well drilling, pumping dead storage from reservoirs, physically moving crops out of the basin, consideration of trans-basin diversion, and so on.

In each successive month the TWSA projections and therefore water allocations increased. By April the farmers questioned the validity of the WPRS's earlier projections. In May, the WPRS admitted that some errors had been made. They rechecked their calculations of TWSA, uncovering some assumptions that had distorted their projections. The WPRS apologized; the farmers, however, chose to take legal action against the WPRS to recover expenses incurred in response to the WPRS's erroneous projections and allocations.

This study raises questions about the validity of streamflow projections and societal responses to them and about the benefits to society of good forecasts and the cost to society of erroneous ones. (One of the impacts of this bad forecast is a $25 million lawsuit.) This study also raises questions about responsibilities associated with certain types of forecasts. In other words, should forecasters be responsible for their forecasts?

Work on this project is continuing.

ADVANCED STUDY PROGRAM

Division Staff:

Maurice Blackmon, Chairman
Bernhard Haurwitz, NCAR Senior Research Associate
Verlene Leeburg
Karen Lynch
Ursula Rosner
Betty Wilson

Environmental and Societal Impacts Group (ESIG):

Robin Dennis
Michael Glantz
Richard Katz (to 30 September 1979)
Maria Krenz
William Lord (long-term visitor, University of Colorado, 1 October 1979-present)
Paulette Middleton
Jeryl Mumpower (long-term visitor, University of Colorado, 1 June 1978-present)
Allan Murphy (to 31 August 1979)
Suzanne Parker
Jan Stewart

Graduate Assistantships:

Russell Dickerson, University of Michigan
Dale Durran, Massachusetts Institute of Technology
Ronald Ferek, Florida State University
Laurence Goldberg, University of Colorado
William Kohri, Drexel University
Paul McKenna, University of Colorado
Robert Rasmussen, Drexel University
Susan Solomon, University of California, Berkeley
Bruce Wielicki, University of California, San Diego

VISITORS

Postdoctoral and Senior Postdoctoral Fellows:

Peter Bannon, previous affiliation: University of Colorado, November 1978-present.

Richard Bogart, present affiliation: NASA Ames Research Center, February 1978-February 1979.

Byron Boville, previous affiliation: University of Washington, September 1979-present.

Robert Cahalan, present affiliation: NASA Goddard Space Flight Center, September 1978-September 1979.

George Carnevale, previous affiliation: Harvard University, September 1979-present.

John Corbett, present affiliation: Florida International University, August 1978-August 1979.

Paul Dusenbery, previous affiliation: University of New Hampshire, September 1978-present.

Ronald Errico, previous affiliation: Massachusetts Institute of Technology, October 1979-present.

Ronald Gilliland, previous affiliation: University of California, Santa Cruz, September 1979-present.

John Grant, present affiliation: Science Applications, Inc., La Jolla, CA, November 1978-November 1979.

Gary Greenhut, present affiliation: NOAA Environmental Research Laboratories, July 1978-July 1979.

Richard Grotjahn, previous affiliation: Florida State University, June 1979-present.

David Hathaway, previous affiliation: University of Colorado, June 1979-present.

Peter Hildebrand, present affiliation: RAF, NCAR, August 1978-August 1979.

James Kasting, previous affiliation: University of Michigan, September 1979-present.

Barbara Mihalas, previous affiliation: University of Colorado, September 1979-present.

Edward Niple, previous affiliation: Ohio State University, June 1979-present.

Richard Peltier, present affiliation: University of Toronto, October 1978-April 1979.

John Pflaum, previous affiliation: University of California, Los Angeles, September 1978-present.

Thomas Phillips, previous affiliation: University of Wisconsin, September 1979-present.

Murry Salby, previous affiliation: Georgia Institute of Technology, June 1978-present.

Richard Siquig, present affiliation: Ocean Data Systems, San Diego, CA, June 1978-June 1979.

Joseph Tribbia, present affiliation: AAP, NCAR, August 1978-August 1979.

Stephen Warren, present affiliation: CIRES, University of Colorado, January 1978-January 1979.

Philip Wilksch, present affiliation: Mauson Institute, University of Adelaide, Australia, July 1978-July 1979.

UCAR Graduate Fellowships in the Atmospheric Sciences, 1978/79:

Mary Anne Carroll, Massachusetts Institute of Technology
Richard Deininger, Massachusetts Institute of Technology
Leo Donner, University of Chicago
Dale Durran, Massachusetts Institute of Technology
Matthew Hitchman, University of Washington

Summer Fellowship Program for Women and Minority Students, 1979:

Ernest Agee, permanent affiliation: Purdue University, Lafayette, IN (lecturer)
Jane Becker, Hunter College, New York City, NY
Patricia Brown, Jackson State University, Jackson, MS
Debra Cassels, Del Mar College, Corpus Christi, TX
Lori Holdridge, University of New Mexico, Albuquerque, NM
Susan Higginbotham, Louisiana State University and A&M College, Baton Rouge, LA
Kathryn Kost, Elmira College, Elmira, NY
Tracy Nishikawa, Humboldt State University, Arcata, CA

Ad-Hoc Faculty:

Stella Coakley, University of Denver, February 1977-present

Philip Graves, University of Colorado, June-July 1979 (ESIG)

Edward Lorenz, Massachusetts Institute of Technology, June 1979

Thomas Lundgren, University of Minnesota, June-August 1979

Robert Malone, Los Alamos Scientific Laboratory, June-August 1979

Robert Taylor, University of Colorado, June-July 1979 (ESIG)

Val Veirs, Colorado College, January and June-August 1979 (ESIG)

Ad-Hoc Students:

Haydee Ernst, University of Missouri, St. Louis, June-July 1979

Laurie Isenberg, University of Colorado, June 1979-present (ESIG)

Jeffry Rothermel, Purdue University, June-August 1979

Benjamin Schoepfle, University of Indiana, May-September 1979 (ESIG)

James Ward, University of Colorado, October 1979-present (ESIG)

Glenn White, University of Washington, November 1978-June 1979

James Yarbrough, University of Georgia, September 1979-present (ESIG)

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ATMOSPHERIC TECHNOLOGY DIVISION

INTRODUCTION

The mission of the Atmospheric Technology Division (ATD) is to identify, develop, and make accessible to the atmospheric science community selected research capabilities of outstanding quality. Funding realities require wise priority-setting to insure a balance between support of research projects and development of new capabilities, and to insure that the available funding is committed to the most essential of the proposed developments.

ATD is made up of four facilities whose primary responsibility is providing support to atmospheric research projects but who also contribute in a substantial way to the development of the sensing and data management systems which they use. These are the Research Aviation Facility (RAF), the Computing Facility (CF), the Field Observing Facility (FOF), and the National Scientific Balloon Facility (NSBF). Additionally there are two ATD groups dedicated almost wholly to the development of research instrumentation and of atmospheric measurement techniques: the Research Systems Facility (RSF) and the Global Atmospheric Measurement Program (GAMP).

The past year has seen a sustained high demand for the services of ATD facilities. Examples of participation in important research programs are: RAF, GAMP, CF, and RSF which all contributed to portions of the Global Weather Experiment (GWE) and the Monsoon Experiment (MONEX) conducted worldwide in 1979; FOF and RAF were involved in the Severe Environmental Storms and Mesoscale Experiment (SESAME), a multi-agency program, studying severe storms in Oklahoma; NSBF received a special NASA award for providing "ground truth" support for the Limb Infrared Monitor of the Stratosphere instrument on board the Nimbus 7 satellite.

In the area of improving research capabilities much effort has been spent over the past year in planning for the replacement of the Queen Air aircraft with modern turboprop planes with higher performance capabilities. Of considerable importance is the current development effort by RSF and GAMP of an upper-air sounding system with accuracies greatly improved over presently available sounding equipment. During the year the FOF assumed responsibility for the CP-2, S-band radar, previously managed by the NCAR Convective Storms Division. FOF is presently installing a new data processing and recording system and is adding an X-band capability to make the unit dual-wavelength. Lastly FOF will make the radar highway transportable -- no small feat when considering the fact that this radar has an 8.5 m diameter dish antenna.

During the past year much of the attention of the ATD Director has been centered on the selection of new managers for the Research Aviation Facility and the Computing Facility. In September 1979 Byron Phillips was appointed manager of the RAF and in February 1980 Walter Macintyre accepted the position of Computing Facility manager.

RESEARCH AVIATION FACILITY

Mission and Role of the RAF

The Research Aviation Facility (RAF) supports programs in atmospheric dynamics, cloud physics, air chemistry, and pollution with the Electra, Sabreliner, and two Queen Air aircraft. In 1979, a total of 993 hours were flown.

Highlights of 1979

Highlights of the programs supported include the Summer Monsoon Experiment (MONEX), for which the Electra was deployed to Bombay and Calcutta, India, for research flights over the Arabian Sea and Bay of Bengal. The Electra was equipped with a variety of instrumentation, ranging from the turbulence gust probe package to an Omega dropwindsonde system and specialized instruments from the university scientific community. The 1979 SESAME program in Oklahoma was supported with the Sabreliner and one Queen Air (McCarthy, University of Oklahoma). In another program, the measurement of spatial separation properties in the boundary layer was accomplished using both of RAF's inertial navigation-equipped Queen Airs (Lenschow, NCAR). A Queen Air was also used in the multi-investigator Acid Precipitation Experiment (APEX) (Lazrus, et al.). Cloud physics work was supported by a Queen Air in the Colorado Orographic Seeding Experiment (COSE) (Grant, Colorado State University). The total list of all programs and principal investigators supported is presented in Table 1.

Accomplishments

In 1979, the RAF completed the installation and improvements of the Airborne Recording and Instrumentation System (ARIS IV) on the Sabreliner and Queen Airs. ARIS IV is an all-digital microprocessor-based data system which provides some display of in-flight calculations of meteorological variables in addition to recording the data on computer-compatible digital tape. The systems, designed and constructed at the Research Systems Facility (RSF) of NCAR, have been modified and ruggedized for reliable operation in the aircraft environment. A high-altitude radar altimeter was installed on the Sabreliner which provided the measurement of pressure gradients in the jet stream. By this technique, the geostrophic wind can be reliably calculated. Following the successful performance of the unit on the Sabreliner, the system was installed on the Electra for the MONEX project. For better measurements of humidity, the development of an improved fast-response Lyman-alpha hygrometer was undertaken with the RSF. A low-temperature cooled-mirror hygrometer was also tested in order to improve RAF capability to measure frost points below -30°C. New de-iced gust probe vanes were installed on the Electra and Queen Airs for turbulence measurements. One Queen Air now has a vibration-isolated nose boom directly attached to the inertial navigation unit (similar to the Electra) for high-quality turbulent air motion measurements. RAF initiated a replacement program for many of the standard sensors--pressure, temperature, and sensor transducers--to improve the reliability and performance of these; many of the existing sensors are out of production and are no longer serviceable. In data processing, an efficient and general-purpose digital filter program was developed.

Scientific expertise and participation in programs increased in 1979 through the addition of professional staff. RAF staff additions during 1979 include Dr. Peter Hildebrand, Dennis Knowlton, Jacques Brun, and Byron Phillips. Knowlton serves as Chief, Instrumentation, and Phillips as RAF Manager.

Support Operations

As shown in Table 1, during calendar year 1979, a total of 20 field experiments were supported by the RAF, ten with the Queen Airs, eight with the Sabreliner, and two with the Electra. In terms of flight hours, 426 hours were flown on the Queen Airs, 198 hours on the Sabreliner, and 369 hours on the Electra. Two major programs, MONEX and the Brush Fire project, were outside of the U.S.. The (summer) MONEX project was supported in India for three months with the addition of a well-qualified temporary flight crew to enable the Electra to meet the rigorous flying schedule. Also, the RAF Manager or Deputy Manager were in India to lead the Electra operation and its interaction with the MONEX scientists. The participation of the Electra in MONEX appears to have been successful; all flights but one were flown on schedule; a total of 245 Omega dropwindsondes were used, with a success rate of 88%; aircraft and instrumentation problems were in general minimal and did not impact on the research plan. (Some problems were found with the Electra data system but these did not interfere with the flight requests except on one occasion. The Electra suffered a cracked windshield late in the experiment which caused it to miss the last two planned research flights.)

The Brush Fire project in Brazil, while a smaller field program than MONEX, went well with no major aircraft or instrumentation problems.

In the U.S., the major field effort was the SESAME project in Oklahoma which the RAF supported with a Queen Air and the Sabreliner. Some data system problems were encountered which were repaired in the field and which initiated a program for improving these systems for the aircraft environment. With this exception, the RAF support and data quality appeared to be good. The Acid Precipitation Experiement (APEX) utilized a Queen Air on three separate occasions. RAF supplied technical assistance in designing an efficient rain scoop collector. A mini-data system was designed for this project as the size, weight, and power requirements of the rain equipment carried by the investigators does not permit the standard RAF data system to be carried on board.

Support for the other projects are not given here in detail. In general, aircraft and systems performance were improved over last year. In 1979, the RAF used the BAO 305 m tower for aircraft fly-bys to verify and calibrate pressure, temperature, and dew point measurements. The results of the tower and multi-aircraft intercomparisons were very good, which adds confidence to the data supplied by RAF to the scientific users.

Summary

The programs supported in 1979 were of high scientific quality and required a maximum commitment of the resources of the RAF.

RAF personnel responded well to the challenges of each program. Data quality continued to improve, due to the efforts and high standards of the RAF technical and scientific personnel. Scientific involvement in programs is increasing, and should provide better scientific results for the community in the future.

Limitations in the performance of the Queen Airs became more evident in 1979 in the cloud physics and air chemistry programs. The payload, power, and size restraints of the Queen Airs have limited these programs to some extent. The RAF has initiated a plan to replace one of the Queen Airs with a modern, twin-turboprop aircraft.

Limitations of the Electra Data System were also evident in 1979. Many of the hardware components are no longer serviceable, nor is the basic operating software system. Therefore, plans were made in 1979 to replace the data system with a type which will be compatible with that for the proposed new twin-turboprop aircraft.

Table 1

RAF PROGRAMS
1 January - 31 December 1979

Investigator	Institution	Type of Program	Aircraft	Location	Hours Flown
Connell	Battelle	Boundary-Layer	Queen Air	Idaho	41
RAF	NCAR	Nose-Boom	" "	Boulder	1
Lenschow & Mahrt	NCAR Oregon State	Boundary-Layer (SESAME)	" "	Oklahoma	21
McCarthy	Oklahoma	Meso-Scale (SESAME)	" "	"	80
Lenschow	NCAR	Boundary-Layer	" " (2)	Boulder	35
Podzimek	Missouri	Sea Salt Nuclei	" "	Texas	38
Lazrus	NCAR	Acid Rain (APEX)	" "	Central & East Coast U.S.	71
Lazrus	NCAR	APEX II APEX III	" "	"	74
Grant	Colorado State	Cloud Physics (COSE)	" "	Colorado	49
Weickman & Riehl	NOAA	Cloud Physics	" "	Colorado	16
Mankin	NCAR	Chemistry	Sabreliner	Boulder	5
Mankin	NCAR	"	"	Washington	16
Shapiro	NCAR	Jet Stream	"	Central, Southern, Western U.S.	35
Gage	NOAA	Meso-Scale	"	Boulder	2
McCarthy	Oklahoma	Cloud Physics (SESAME)	"	Oklahoma	46
Crutzen	NCAR	Brush Fires	"	Brazil	57
Grams	Georgia Tech	Chemistry	"	Alaska	32
RAF	NCAR	Low Temperature Dew Point	"	Boulder	5
Hobbs	Washington	Cloud Physics	Electra	Washington	66
Kuettner et al.	NCAR, Universities	Meso-Scale Boundary-Layer Cloud Physics (MONEX)	"	India	303
					993

COMPUTING FACILITY

Mission and Goals

The NCAR Computing Facility (CF) is commissioned to provide computing service to the national atmospheric research community. This includes computing support of independent research by NCAR or university scientists, joint projects between NCAR and university scientists, and large national or international programs that involve university and NCAR scientists. The Computing Facility emphasizes large-scale computing for running large simulation models and processing very large data sets from data collection systems or numerical models. In support of this computing capability, it provides extensive archive storage for these data sets and a powerful graphics system to aid the scientists in the comprehension and presentation of their research.

To meet the requirements of this user community, the Computing Facility must provide high-speed computers, efficient software systems for running large models, high-speed transmission of data, and large storage capacities for these data sets. It must also provide access to the computers from remote sites, libraries of software tools and methods, sophisticated consulting support, and a variety of services to support user requirements.

The CF is organized into four sections and several staff functions reporting to the manager. The User Services Seciton provides consulting services to users, communication and documentation of services, policies and procedures, software libraries of numerical and utility tools, and special software products.

The Systems Section provides maintenance of all operating systems and sub-systems in the major facilities. It develops network and communication software to link the various elements of the NCAR system. It develops and enhances system software to provide better service on the systems.

The Operation Section provides efficient and effective operation and maintenance of the central CF. It is also responsible for the digital data library, microfilm/microfiche and movie services, user information data base, and digitizer services.

The Data Support Section is responsible for the collection, maintenance, and distribution of high-quality meteorological and climatological data sets to the atmospheric science community. It also participates in national and international planning of climate data archives.

In addition to these four sections, the CF has an Advanced Methods Group, responsible for informing the community of advanced techniques in numerical methods, data management, and other computing topics. Because of the need to use the high-speed computers efficiently, this group guides the users to state-of-the-art methods and software for the solution of problems. Particular development effort has been spent on Poisson solvers, spectral methods, and elliptic partial differential equation solvers.

The administrator is responsible for managing the CF budget and the management reporting system. The Clerical Support Group provides clerical services to approximately 95 members of the CF.

The atmospheric research community has extended its efforts along two major lines of activity. Large cooperative field experiments, conducted by several agencies, are providing huge amounts of data, measuring all scales of phenomena from global to convective cloud systems. Coupled to this are extensive modeling efforts to simulate atmospheric and oceanographic processes. The models range in size and complexity from simplified studies of a single process to extensive simulations of the dynamics and physics of major systems. The diversity and complexity of the modeling effort and the analysis of field experiment data is demanding high-speed computers. The large amounts of data produced by both field programs and models require large archives and data handling systems.

The NCAR CF has acquired and developed computer hardware and software systems to meet the demands of the atmospheric research community for large computing capacity. The mission of the CF emphasizes the need to provide computing power and tools to support development of large numerical models as well as the processing of very large data sets. The complexity of this research has demanded sophisticated support in software tools, consulting, and system designs. The CF provides these facilities through its system of large computers and archives, with user access provided by a remote job entry (RJE) system.

Major components of the CF system are the CRAY-1 computer, a Control Data 7600 computer, an Ampex Terabit Memory System (TMS-4) with 66,000 megabytes of on-line storage, a Modcomp computer used for RJE, a Network Systems Corporation network configuration to link the various systems, and a DICOMED graphics system.

The CRAY-1 computer, accepted in December 1977, is providing extremely reliable service to the numerical models for which it is well suited. The research supported by these large models covers a broad range of studies. Oceanographic and atmospheric general circulations, cumulonimbus and severe storms, climate, atmospheric chemistry, and solar dynamics are some of the studies currently being modeled on the CRAY-1.

These large models are producing large history files of data that must be archived and analyzed. A billion-byte data set is not rare these days from large models. With field programs like the Solar Maximum Mission (SMM) producing five magnetic tapes every day for at least one year, the CF must provide extensive archiving and processing capability. This it does with the Control Data 7600 and the TMS-4.

Accomplishments of the Past Year

During FY 1979 the CF served 550 users; half of these were university users working on individual projects or engaged in joint projects with NCAR scientists. Some 485,000 jobs were run on the Control Data 7600 computer and nearly 125,000 jobs were run on the CRAY-1. Scientists at 68 universities used the NCAR computers from remote locations, an increase of six remote computing sites over the past year. The growth in RJE continues to be substantial as more users acquire terminals and small systems for RJE communication.

The network development project has successfully completed the first phase of the development. The protocol has been designed and implemented on three machines. The next phase is a testing of concepts and a refinement of strategies to mamage the network. When delivered, the network will enable the CF to integrate a diverse set of systems and upgrade the facility in a graceful way. This year we have also specified a new system to enhance our RJE capability and provide additional access to the faciltity. The request for proposal will be issued in the spring for this system.

VISITORS AND USERS OF THE COMPUTING FACILITY IN 1979

USER NAME	AFFILIATION	START DATE	END DATE	PROJECT	DAYS
ACKERMAN, BERNICE	ILLINOIS WATER SURVEY			35481005	
AGEE, ERNEST	PURDUE UNIVERSITY			35291005	
AHLQUIST, JON	UNIVERSITY OF WISCONSIN			35381011	
AHMED, HABIB	ARGONNE NATIONAL LAB	790701	790703	43513023	3
AHMED, HABIB	ARGONNE NATIONAL LAB	790610	790611	43513023	2
ALPERT, JORDAN	UNIVERSITY OF MICHIGAN			5013600	
ALPERT, JORDAN	UNIVERSITY OF MIAMI-MIAMI	790521	790615	35191007	26
ANTHES, RICHARD A.	PENNSYLVANIA STATE UNIVERSITY			35281008	
ANTHES, RICHARD A.	PENNSYLVANIA STATE UNIVERSITY			35281011	
AOKI, TADAO	FRENCH MET. OFFICE			13013041	
ARAKAWA, AKIO	UCLA			35681004	
ATWATER, MARSHALL	CTR FOR ENVIRONMENT AND MAN			36121004	
ATWATER, MARSHALL	CTR FOR ENVIRONMENT AND MAN			36121011	
AYAD, SAMIR S.	COLORADO STATE UNIVERSITY	790531	0	35081050	0
AYRES, THOMAS	UNIVERSITY OF COLORADO			35071058	
BABOOLAL, LAL	UCLA	790811	790818	35681003	8
BAER, F.	UNIVERSITY OF MICHIGAN			35201006	
BAKER, GARY	FLORIDA UNIVERSITY	790122	790131	35931001	10
BAKER, GREGORY	MASSACHUSETTS INST. OF TECH.			35171021	
BANNON, PETER	UNIVERSITY OF COLORADO			35071052	
BARNES, IAN W.	FLINDERS UNIVERSITY	790601	790930	35771000	122
BARTLEIN, DICK	UNIVERSITY OF VIRGINIA	790226	790301	35691005	4
BASRI, GIBOR S.	UNIVERSITY OF COLORADO			35071044	
BAXTER, TOM	UNIVERSITY OF OKLAHOMA	791203	791207	35261002	5
BEARDSLEY, ROBERT C.	MASSACHUSETTS INST. OF TECH.			35171011	
BELL, DENNIS	UNIVERSITY OF WASHINGTON			35371013	
BENTON, NED	UNIVERSITY OF COLORADO			35071054	
BERNHARDT, PAUL A.	STANFORD			35661008	
BERNHARDT, PAUL A.	STANFORD			35661009	
BERNHARDT, PAUL A.	STANFORD			35661014	
BESSEY, ROBERT J.	UNIVERSITY OF WYOMING			35711010	
BLACKMON, MAURICE L.	UNIVERSITY OF WASHINGTON			31103014	
BLAKE, DONNA	FLORIDA STATE UNIVERSITY			35111025	
BLECK, R.	UNIVERSITY OF MIAMI-MIAMI			35191003	
BLECK, RAINER	UNIVERSITY OF MIAMI-MIAMI	791026	791028	35191008	3
BOUDRA, DOUGLAS	UNIVERSITY OF MIAMI-MIAMI			35191005	
BOUDRA, DOUGLAS B.	UNIVERSITY OF MIAMI-MIAMI	790627	790807	35191010	42
BOVILLE, BYRON	UNIVERSITY OF WASHINGTON			35371007	
BOWSER, RON	HARVARD UNIVERSITY			35121013	
BRANTSTATOR, GRANT	PURDUE UNIVERSITY			5013532	
BRIGGS, PAUL	COLORADO STATE UNIVERSITY	781204	791231	35081048	393
BROWN, PHILIP	CTR FOR ENVIRONMENT AND MAN	790709	790710	36121000	2

BROWN, PHILIP	CTR FOR ENVIRONMENT AND MAN	790521	790524	36121005	4
BROWN, PHILIP	CTR FOR ENVIRONMENT AND MAN			36121009	
BUCY, RICHARD	UNIV OF SOUTHERN CALIF.			36381000	
BURGGRAF, ODUS	UNIVERSITY OF CHICAGO			35061025	
BURGGRAF, ODUS	COLORADO STATE UNIVERSITY			35081041	
BUSALACCHI, ANTONIO	FLORIDA STATE UNIVERSITY	791208	791217	35111043	10
BUSALACHI, TONY	FLORIDA STATE UNIVERSITY	790610	790618	35111029	9
BUZYNA, GEORGE	FLORIDA STATE UNIVERSITY			35111036	
BYRON-SCOTT, ROLAND	FLINDERS UNIVERSITY	790525	790831	35771000	99
CANFIELD, R.	UNIV. OF CALIFORNIA-SAN DIEGO			36011003	
CARR, FREDERICK	STATE UNIVERSITY OF NEW YORK	791117	791125	35251003	9
CASTLEMAN, A.W.	UNIVERSITY OF COLORADO			35071064	
CHALLA, MALAKONDAYYA	FLORIDA STATE UNIVERSITY			35111030	
CHANG, L. P.	UNIVERSITY OF COLORADO	791231	800108	35071084	9
CHANG, L.P.	IOWA STATE UNIVERSITY	791018	791031	35461004	14
CHEN, TSING-CHANG	IOWA STATE UNIVERSITY	791018	791031	35461004	14
CHIPMAN, ERIC	UNIVERSITY OF COLORADO			35071000	
CHIPMAN, ERIC	UNIVERSITY OF COLORADO			35071061	
CHU, JAN-HWA	UNIVERSITY OF WISCONSIN			35381006	
CHYLEK, PETR	STATE UNIVERSITY OF NEW YORK			35251007	
CICERONI, RALPH J.	SCRIPPS INST. OF OCEANOGRAPHY			35631010	
CICERONI, RALPH J.	UNIVERSITY OF MICHIGAN			35201010	
COAKLEY, STELLA	DENVER UNIVERSITY			35101015	
CONTI, PETER S.	UNIVERSITY OF COLORADO			35071025	
COSTENOBLE, STEVE	CTR FOR ENVIRONMENT AND MAN	790709	790710	36121000	2
COTTON, WILLIAM R.	COLORADO STATE UNIVERSITY			35081013	
COTTON, WILLIAM R.	COLORADO STATE UNIVERSITY			35081045	
COX, STEPHEN	COLORADO STATE UNIVERSITY			35081030	
CRAVENS, THOMAS E.	UNIVERSITY OF MICHIGAN			35201021	
CURRY, JAMES	MASSACHUSETTS INST. OF TECH.			35171018	
DALY, STEVE	UNIVERSITY OF CHICAGO	790510	790522	35061026	13
DANIELSEN, EDWIN	OREGON STATE UNIVERSITY			35271005	
DANIELSEN, EDWIN	OREGON STATE UNIVERSITY			35271006	
DAS, PHANINDRAMOHAN	TEXAS A+M UNIVERSITY	790815	790831	35311024	17
DAVEY, MICHAEL	UNIVERSITY OF WASHINGTON	791010	791017	35371014	8
DAVIS, JOHN	COLORADO STATE UNIVERSITY			35081039	
DENAVIT, J.	NORTHWESTERN UNIVERSITY			36101001	
DERICKSON, RUSS	COLORADO STATE UNIVERSITY			35081005	
DOLE, RANDALL	MASSACHUSETTS INST. OF TECH.			35171020	
DOMM, JEFF	MASSACHUSETTS INST. OF TECH.			35171019	
DONNER, LEO	UNIVERSITY OF CHICAGO			35061030	
DWIVIDI, PARMESH	DENVER UNIVERSITY			35101016	
EBERLY, J.H.	UNIVERSITY OF ROCHESTER			36521000	
ECCLES, MARGARET	UNIVERSITY OF COLORADO			35071050	
EDMON, HAROLD, JR.	UNIVERSITY OF WASHINGTON			35371012	
ELLIS, JAMES S.	COLORADO STATE UNIVERSITY			35081027	
EMSLIE, GORDON	HARVARD UNIVERSITY			82233023	

ESBENSEN, STEVEN	OREGON STATE UNIVERSITY	790324	790327	35271009	4
ESPOSITO, LARRY	UNIVERSITY OF COLORADO			35071059	
ESTOQUE, M.	UNIVERSITY OF MIAMI-C. GABLES			35501012	
ESTOQUE, MARIANO	UNIVERSITY OF MIAMI-C. GABLES	791102	791103	35501008	2
ESTOQUE, MARIANO A.	UNIVERSITY OF MIAMI-C. GABLES	790715	790815	35501011	32
EVERHART, EDGAR	DENVER UNIVERSITY			35101010	
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	790906	790911	35641009	6
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	790201	790208	35641009	8
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	790705	790710	35641011	6
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	790307	790315	35641011	9
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	791102	791108	35641015	7
FERNALD, FRED	DENVER UNIVERSITY			35101019	
FINDIKAKIS, ANGELOS	STANFORD	790626	790706	35661012	11
FINGERHUT, WILLIAM	COLORADO STATE UNIVERSITY			35081057	
FRAZIER, ED	HARVARD UNIVERSITY	790924	790924	35121010	1
FRISCH, URIEL	HARVARD UNIVERSITY			35121018	
FRITTS,DAVE	UNIVERSITY OF COLORADO			35071079	
FUA, DANIELE	UNIVERSITY OF COLORADO			35071092	
FUJITA, THEODORE	UNIVERSITY OF CHICAGO			35061029	
FYFE, DAVID	UNIVERSITY OF IOWA			35471001	
GAL-CHEN, TZVI	UNIVERSITY OF TORONTO			35341001	
GAL-CHEN, TZVI	UNIVERSITY OF TORONTO			35341002	
GARY, JOHN	UNIVERSITY OF COLORADO			35071042	
GARY, JOHN	UNIVERSITY OF COLORADO			35071087	
GATES, LAWRENCE	OREGON STATE UNIVERSITY			35271008	
GEISLER, JOHN	UNIVERSITY OF MIAMI-C. GABLES			35501013	
GELLER, MARVIN A.	UNIVERSITY OF MIAMI-MIAMI			35191002	
GIAMPAPA, MARK	UNIVERSITY OF COLORADO			35071094	
GOERSS, JIM	UNIVERSITY OF OKLAHOMA	791203	791207	35261002	5
GOLDMAN, AHARON	DENVER UNIVERSITY			35101018	
GOLDMAN, AHARON	DENVER UNIVERSITY			35101025	
GORDON, ROBERT	UNIVERSITY OF MICHIGAN			35201020	
GRAMS, GERALD	GEORGIA TECH			36511000	
GRANT, L. O.	COLORADO STATE UNIVERSITY			35081042	
GRAY, WILLIAM M.	COLORADO STATE UNIVERSITY			35081014	
GRAY, WILLIAM M.	COLORADO STATE UNIVERSITY			35081051	
GRAY, WILLIAM M.	COLORADO STATE UNIVERSITY			35081052	
GRAY, WILLIAM M.	COLORADO STATE UNIVERSITY			35081058	
GURMAN, JOSEPH	UNIVERSITY OF COLORADO			27103013	
GUSTAFSON, CARL	UNIVERSITY OF COLORADO			35071080	
HAAR, PATRICK	COLORADO STATE UNIVERSITY			35081038	
HACHKE, PETER	CTR FOR ENVIRONMENT AND MAN	791016	791021	36121008	6
HAFITIZI, BAHMAN	UNIVERSITY OF COLORADO			35071045	
HAGAN, DENISE	TEXAS A+M UNIVERSITY	790625	790901	35311006	69
HAGAN, DENISE	TEXAS A+M UNIVERSITY	790102	790110	35311006	9
HAIDVOGEL, DALE	WOODS HOLE OCEANOGRAPHIC INST.	791030	791105	35781010	7
HAIDVOGEL, DALE	WOODS HOLE OCEANOGRAPHIC INST.	790804	790902	35781010	30

HAIDVOGEL, DALE	HARVARD UNIVERSITY	790616	790625	35121011	10
HAIDVOGEL, DALE	HARVARD UNIVERSITY	790301	790320	35121011	20
HAN, YOUNG-JUNE	OREGON STATE UNIVERSITY			35271010	
HANEY, JAMES	ST. LOUIS UNIVERSITY	790203	790208	35301003	6
HARRIS, RONNEY D.	UTAH STATE UNIVERSITY			35361003	
HART, JOHN	MASSACHUSETTS INST. OF TECH.			35171012	
HARTMANN, DENNIS	UNIVERSITY OF WASHINGTON			35371010	
HASCHKE, DIETER	CTR FOR ENVIRONMENT AND MAN	791201	791205	36121002	5
HASCHKE, DIETER	CTR FOR ENVIRONMENT AND MAN	790521	790524	36121005	4
HEBURN, GEORGE	FLORIDA STATE UNIVERSITY	790507	790515	35111029	9
HELSDON, JOHN	SOUTH DAKOTA SCHOOL OF MINES	790312	790315	35641011	4
HENDERSHOTT, M. C.	SCRIPPS INST. OF OCEANOGRAPHY			35631003	
HERBERT, FLOYD	UNIVERSITY OF ARIZONA			35021007	
HERZEGH, PAUL	CTR FOR ENVIRONMENT AND MAN	791112	791118	36121006	7
HESTBECK, J.	UNIV OF CALIFORNIA AT DAVIS	790615	790930	36131001	108
HEYMSFIELD, GERALD	UNIVERSITY OF CHICAGO			35061022	
HILDEBRAND, PETER	ILLINOIS WATER SURVEY			35481007	
HILL, JIM	IOWA STATE UNIVERSITY			35461000	
HOBBS, PETER V.	UNIVERSITY OF WASHINGTON			35371002	
HOBBS, PETER V.	UNIVERSITY OF WASHINGTON			35371015	
HOLLOWAY, GREG	WOODS HOLE OCEANOGRAPHIC INST.			35781005	
HOLLOWAY, GREG	SCRIPPS INST. OF OCEANOGRAPHY			35631006	
HOU, ARTHUR	HARVARD UNIVERSITY			35121017	
HOUGHTON, DAVID	UNIVERSITY OF WISCONSIN			35381007	
HSU, CHIH-PING FLOSS	UNIVERSITY OF WASHINGTON			35371004	
HSUEH, YA	FLORIDA STATE UNIVERSITY			35111031	
HUBBARD, LYNN	UNIVERSITY OF CALIFORNIA AT RI	790312	790401	36571000	21
HUMMER, D. G.	UNIVERSITY OF COLORADO			35071006	
HUMMER, D. G.	UNIVERSITY OF COLORADO			35071077	
INAN, UMRAN	STANFORD	791023	791111	35661015	20
INAN, UMRAN	STANFORD	790925	791001	35661015	7
INAN, UMRAN	STANFORD	790611	790616	35661015	6
INAN, UMRAN	STANFORD	790323	790405	35661015	14
INAN, UMRAN S.	STANFORD			35661007	
INAN, UMRAN S.	STANFORD			35661013	
JACOBS, CLIFFORD	CTR FOR ENVIRONMENT AND MAN	790521	790524	36121005	4
JACOBS, CLIFFORD	CTR FOR ENVIRONMENT AND MAN	791016	791021	36121008	6
JAMES, IAN N.	FLORIDA STATE UNIVERSITY	791130	791206	35111041	7
JAMESON, ARTHUR	ILLINOIS WATER SURVEY			35481008	
JOHNSON, DAVID B.	UNIVERSITY OF CHICAGO			35061023	
JOHNSTON, ANDY	NOAA			71413008	
JONES, HERBERT	FLORIDA A+M UNIVERSITY	790723	790806	36061000	15
JOYCE, GLENN R.	UNIVERSITY OF IOWA			35471000	
JULIAN, LESLEY T.	UNIVERSITY OF COLORADO			35071060	
KAHN, PHILIP	UNIVERSITY OF WASHINGTON	790105	790125	44093025	21
KALOS, GEORGE	WAYNE STATE UNIVERSITY	790820	790826	36311000	7
KAO, S.K.	UNIVERSITY OF UTAH			35351009	

KASTING, JAMES	UNIVERSITY OF MICHIGAN			35201019	
KEEN, CECIL S.	UNIVERSITY OF CAPE TOWN			36611000	
KELCH,WALTER	UNIVERSITY OF COLORADO			35071048	
KELLEY,MICHAEL	CORNELL UNIVERSITY			35091004	
KELLY, GRAEME	UNIVERSITY OF WISCONSIN	790212	790216	35381008	5
KIERNAN, JAMES	UNIVERSITY OF WYOMING	790518	790831	35711014	106
KIKUCHI, MASAO	UNIVERSITY OF OKLAHOMA	791203	791207	35261002	5
KILADIS, GEORGE	UNIVERSITY OF COLORADO			35071074	
KITTEL, TIM	UNIV OF CALIFORNIA AT DAVIS	790615	790930	36131001	108
KLASSEN, GARY P.	UNIVERSITY OF TORONTO			35341006	
KLEIN, RICHARD I.	BRANDEIS UNIVERSITY			35761002	
KLEIN, RICHARD I.	UNIVERSITY OF COLORADO			35071039	
KLINCK, JOHN	FLORIDA STATE UNIVERSITY	791208	791217	35111043	10
KNUTI, JOHN	USSR ACAD OF SCIENCES			36581001	
KOPP, FRED	SOUTH DAKOTA SCHOOL OF MINES	790528	790602	35641008	6
KOPP, FRED	SOUTH DAKOTA SCHOOL OF MINES	790201	790208	35641009	8
KOPP, FRED	SOUTH DAKOTA SCHOOL OF MINES	790912	790922	35641011	11
KRAICHMAN, ROBERT	NO AFFILIATION			35791001	
KREISS, OTTO	NEW YORK UNIVERSITY			9013001	
KRISHNAMURTI, T. N.	FLORIDA STATE UNIVERSITY			35111034	
KRISHNAMURTI, T. N.	FLORIDA STATE UNIVERSITY			35111040	
KRISHNAMURTI, T. N.	FLORIDA STATE UNIVERSITY			35111045	
KRISHNAMURTI, T.N.	FLORIDA STATE UNIVERSITY	791018	791025	35111038	8
KUNASZ, PAUL	UNIVERSITY OF COLORADO			35071075	
KURUCZ, ROBERT	SMITHSONIAN	791127	791215	35651000	19
LABITZKE, KARIN	FREE UNIV. OF BERLIN			36491000	
LANGER, STEVEN	STANFORD			35661005	
LEE, DONG KYOU	UNIVERSITY OF WISCONSIN			35381010	
LEFEUVRE, FRANCOIS	STANFORD			35661016	
LEITH, C.	MASSACHUSETTS INST. OF TECH.			9013002	
LEVINE, RANDOLPH	HARVARD UNIVERSITY	790725	790825	35121010	32
LEVINE, RANDOLPH	HARVARD UNIVERSITY	790725	790825	35121015	32
LEVINE, RANDOLPH	HARVARD UNIVERSITY	790220	790222	35121015	3
LEVINE, RANDY	HARVARD UNIVERSITY	790924	790927	35121010	4
LEWIS, FRED	UNIVERSITY OF UTAH			35351010	
LIN, YUH-LANG	SOUTH DAKOTA SCHOOL OF MINES	790307	790309	35641011	3
LIOU, KUO-NAN	UNIVERSITY OF UTAH			35351004	
LIOU, KUO-NAN	UNIVERSITY OF UTAH			35351008	
LIST, ROLAND	UNIVERSITY OF TORONTO			35341003	
LIU, SHAW C.	UNIVERSITY OF MICHIGAN			35201014	
LONDON, J.	UNIVERSITY OF COLORADO			35071062	
LONDON, RICHARD	UNIVERSITY OF MIAMI-MIAMI			35191009	
LOVELL, CLIFTON	SCIENCE APPLICATIONS, INC.			36481000	
LUTHER, MARK	UNIVERSITY OF NORTH CAROLINA	790618	790625	36461000	8
MACPHERSON, A. K.	LEHIGH UNIVERSITY			35941000	
MACPHERSON, A. K.	LEHIGH UNIVERSITY			35941001	
MARCUS, PHILIP	CORNELL UNIVERSITY			35091008	

MARKER, WALTER	UNIVERSITY OF CHICAGO			35061027	
MARMORINO, GEORGE	FLORIDA STATE UNIVERSITY	790219	790226	35111039	8
MASSIE, STEVEN T.	UNIVERSITY OF COLORADO			35071078	
MCCLYMONT, ALEXANDER	UNIV OF CALIFORNIA AT DAVIS			36131002	
MCCOMAS, CHARLES HEN	WOODS HOLE OCEANOGRAPHIC INST.	790216	790415	35781008	59
MCCORMICK, STEPHEN	COLORADO STATE UNIVERSITY			35081053	
MCCRAY, RICHARD	UNIVERSITY OF COLORADO			35071034	
MCCRAY, RICHARD	UNIVERSITY OF COLORADO			35071081	
MCELROY, MICHAEL	HARVARD UNIVERSITY			35121016	
MCKART, TOM	OREGON STATE UNIVERSITY	790324	790327	35271009	4
MCKEE, THOMAS B.	COLORADO STATE UNIVERSITY			35081029	
MCKEEN, STAN	STATE UNIVERSITY OF NEW YORK			35251005	
MCNIDER, RICHARD	UNIVERSITY OF VIRGINIA	790706	790725	35691004	20
MCWILLIAMS, JIM	UNIVERSITY OF WASHINGTON			7013014	
MEGILL,LAWRENCE	UTAH STATE UNIVERSITY			35361004	
MERRILL, J. T.	UNIVERSITY OF MIAMI-MIAMI			35191004	
MIGLIULO, STEFANO	DENVER UNIVERSITY			35101024	
MIHALAS, BARBARA	COLORADO STATE UNIVERSITY			35081037	
MILES, JOHN	UNIV. OF CALIFORNIA-SAN DIEGO			36011004	
MILLER, JAY	NOAA			71413007	
MILLER, TIM	UNIVERSITY OF ARIZONA	790604	790731	35021008	58
MOBLEY, ROBERT	OREGON STATE UNIVERSITY			35271007	
MOE, KENNETH	NORTHROP UNIVERSITY			36441000	
MOHNEN, VOLKER A.	STATE UNIVERSITY OF NEW YORK			35251006	
MOORE, DENNIS	NOVA UNIVERSITY	790402	790407	35571001	6
MUELLER, EUGENE	UNIVERSITY OF ILLINOIS			35141015	
MURAKAMI, MASATO	CORNELL UNIVERSITY			35091005	
MURCRAY, D.	DENVER UNIVERSITY			35101020	
MURCRAY, D.	DENVER UNIVERSITY			35101022	
NAGY, ANDREW	UNIVERSITY OF MICHIGAN			35201028	
NAKANO, KUNI	UNIVERSITY OF OKLAHOMA	791203	791207	35261002	5
NELSON, LOREN	UNIVERSITY OF CHICAGO			35061019	
NELSON, LOREN	COLUMBIA UNIVERSITY			36041000	
NGHIEM-PHU, LAN	UNIVERSITY OF MIAMI-MIAMI	790716	790731	35191006	16
NORCROSS, DAVID	TEXAS A+M UNIVERSITY			35311013	
NORCROSS, DAVID	UNIVERSITY OF COLORADO			35071022	
NORCROSS, DAVID	UNIVERSITY OF COLORADO			35071071	
OGURA, Y.	UNIVERSITY OF ILLINOIS			35141006	
ORR, KEN	UCLA	790820	790905	35681001	17
ORSZAG, S. A.	MASSACHUSETTS INST. OF TECH.			35171013	
ORSZAG, S. A.	MASSACHUSETTS INST. OF TECH.			35171017	
ORVILLE, HAROLD	SOUTH DAKOTA SCHOOL OF MINES			35641012	
OTT, EDWARD	CORNELL UNIVERSITY			35091006	
OTTO-BLEISNER, BETTE	UNIVERSITY OF WISCONSIN	790203	790302	35381005	28
OTTO-BLIESNER, BETTE	UNIVERSITY OF WISCONSIN	790716	790722	35381005	7
OWENS, W. BRECHNER	WOODS HOLE OCEANOGRAPHIC INST.			35781007	
PAEGLE, JAN	UNIVERSITY OF UTAH			35351006	

PAEGLE, JAN	UNIVERSITY OF UTAH			35351007	
PAEGLE, JULIA	UNIVERSITY OF UTAH			35351011	
PAN, HUA-LU	FLORIDA STATE UNIVERSITY			35111035	
PAN, HUA-LU	FLORIDA STATE UNIVERSITY	791018	791025	35111038	8
PANDOLFO, JOSEPH	CTR FOR ENVIRONMENT AND MAN	791201	791205	36121002	5
PARK, C.	STANFORD			35661011	
PARRISH, JOANNE	UTAH STATE UNIVERSITY			35361002	
PASSARELLI, RICHARD	UNIVERSITY OF CHICAGO			35061024	
PAZAN, STEPHEN	SCRIPPS INST. OF OCEANOGRAPHY			35631008	
PEARSON, CARL	UNIVERSITY OF WASHINGTON			35371006	
PEFFLEY, MONTY	FLORIDA STATE UNIVERSITY	790219	790226	35111029	8
PELTIER, W. R.	UNIVERSITY OF TORONTO			35341000	
PERKEY, NADINE	DREXEL UNIVERSITY			35431003	
PESKIN, RICHARD	RUTGERS UNIVERSITY			36151000	
PESKIN, RICHARD	RUTGERS UNIVERSITY			36151001	
PETERS, L. K.	UNIVERSITY OF KENTUCKY			35971001	
PEYREFITTE, ASHTON	UNIVERSITY OF UTAH			35351005	
PFEFFER, RICHARD	FLORIDA STATE UNIVERSITY			35111037	
PLATZMAN, GEORGE	UNIVERSITY OF CHICAGO			35061021	
PLOOSTER	DENVER UNIVERSITY			35101012	
PLOOSTER	DENVER UNIVERSITY			35101023	
PRELLER, RUTH	FLORIDA STATE UNIVERSITY	790610	790614	35111029	5
PRELLER, RUTH	FLORIDA STATE UNIVERSITY	790219	790226	35111029	8
RANDALL, JOAN MARY	UNIVERSITY OF TORONTO			35341004	
RANDALL, JOAN MARY	UNIVERSITY OF TORONTO			35341005	
RAO, G.V.	ST. LOUIS UNIVERSITY	790203	790208	35301003	6
REES, DAVID	UNIVERSITY OF SYDNEY			28403048	
REES, M. H.	UNIVERSITY OF ALASKA			35011000	
REITER, ELMAR R.	COLORADO STATE UNIVERSITY			35081047	
REITER, ELMAR R.	COLORADO STATE UNIVERSITY			35081056	
RHINES, PETER	WOODS HOLE OCEANOGRAPHIC INST.			35781006	
RICHARDS, PHILIP	UNIVERSITY OF MICHIGAN			35201030	
RICHTER, FRANK	UNIVERSITY OF CHICAGO	790510	790522	35061018	13
RINEHART, RON	METEOROLOGY TECHNOLOGY ENTER.			33223000	
RISER, STEPHEN C.				36621000	
ROBLE, R.	UNIVERSITY OF COLORADO			14013002	
ROBLE, R.	UNIVERSITY OF ALASKA			14013004	
ROGERS, JEFFREY	UNIVERSITY OF COLORADO			35071076	
ROSINSKI, JAN	UNIVERSITY OF MISSOURI-ROLLA			33173000	
ROSS, RANDY R.	UNIVERSITY OF COLORADO	791001	791020	35071085	20
ROTUNNO, RICHARD	UNIVERSITY OF COLORADO			35071051	
ROTUNNO, RICHARD	UNIVERSITY OF COLORADO			35071089	
ROUSSEL-DUPRE, DIANE	UNIVERSITY OF COLORADO			35071069	
RUBENSTEIN, DAVID	UNIVERSITY OF COLORADO			35071065	
RUDD, ROBERT	DENVER UNIVERSITY			35101021	
RUMBLE, JOHN	UNIVERSITY OF COLORADO			35071063	
RUSCH, DAVE	UNIVERSITY OF MICHIGAN			35201022	

RUSCH, DAVE	UNIVERSITY OF COLORADO			35071082	
RUSTAN, PEDRO	FLORIDA UNIVERSITY	790122	790131	35931001	10
SAENZ, RICHARD	COLORADO COLLEGE			36351000	
SALPETER, E.E.	CORNELL UNIVERSITY			35091007	
SAMIR, URI	UNIVERSITY OF MICHIGAN			35201017	
SAMUEL, MICHAEL	UNIV OF CALIFORNIA AT DAVIS	790615	790930	36131001	108
SAND, WAYNE R.	UNIVERSITY OF WYOMING			35711015	
SANI, ROBERT	UNIVERSITY OF COLORADO			35071057	
SANI, ROBERT	UNIVERSITY OF COLORADO			35071068	
SARKISYAN, A.S.	USSR ACAD OF SCIENCES			36581000	
SARKISYAN, A.S.	USSR ACAD OF SCIENCES			9013013	
SCHERRER,PHILIP	STANFORD			35661010	
SCHLESINGER, ROBERT	UNIVERSITY OF WISCONSIN			35381004	
SCHLESINGER, ROBERT	UNIVERSITY OF WISCONSIN	790212	790216	35381008	5
SCHMID, GARY	UNIVERSITY OF MINNESOTA			35211000	
SCHMITZ, JOYCE	TEXAS A+M UNIVERSITY	790625	790901	35311006	69
SCHUBERT, WAYNE H.	COLORADO STATE UNIVERSITY			35081026	
SCHUNK, ROBERT	UTAH STATE UNIVERSITY			35361005	
SCHWARTZ, ARTHUR	UNIVERSITY OF PITTSBURGH	791111	791118	35601000	8
SCHWARTZ, KENNETH	UNIVERSITY OF ARIZONA			35021006	
SEATON, M.J.	UNIVERSITY COLLEGE, LONDON			36221000	
SEKORSKI, JOSEPH	CTR FOR ENVIRONMENT AND MAN	791201	791205	36121002	5
SEKORSKI, JOSEPH	CTR FOR ENVIRONMENT AND MAN	791016	791021	36121008	6
SHEN, HSIEH WEN	COLORADO STATE UNIVERSITY			35081043	
SHOUB, EDWARD C.	UNIVERSITY OF COLORADO			35071055	
SIEVERING, HERMAN	GOVERNORS STATE COLLEGE			36401000	
SIGGIA,ERIC	CORNELL UNIVERSITY			35091009	
SILVA DIAS, MARIA F.	COLORADO STATE UNIVERSITY			35081054	
SMITH, DAVID	TEXAS A+M UNIVERSITY	790513	790613	35311028	32
SMITH, ERIC	COLORADO STATE UNIVERSITY			35081061	
SMITH, JR., PAUL L.	SOUTH DAKOTA SCHOOL OF MINES			35641013	
SMITH, LINDA	NOVA UNIVERSITY	790402	790407	35571001	6
SNOW, TIMOTHY	UNIVERSITY OF VIRGINIA			35691003	
SNYDER, RUSSELL L.	NOVA UNIVERSITY			35571000	
SOLL, DAVID	UNIV OF SOUTHERN CALIF.			36381001	
SOONG, SU-TZAI	UNIVERSITY OF ILLINOIS			35141012	
SOONG, SU-TZAI	UNIVERSITY OF ILLINOIS			35141013	
SRIVASTAVA, R. C.	UNIVERSITY OF CHICAGO			35061012	
SRIVASTAVA, R. C.	UNIVERSITY OF CHICAGO			35061013	
SRIVASTAVA, R. C.	UNIVERSITY OF CHICAGO			35061028	
STEDMAN, DONALD H.	UNIVERSITY OF MICHIGAN			35201025	
STEINOLFSON, RICH	UNIVERSITY OF ALABAMA	791215	791231	36471001	17
STEINOLFSON, RICH	UNIVERSITY OF ALABAMA	790711	790901	36471001	53
STEINOLFSON, RICH	UNIVERSITY OF ALABAMA	790701	790815	36471001	46
STEINOLFSON, RICH	UNIVERSITY OF ALABAMA	790128	790228	36471001	32
STEINOLFSON, RICH	TEL AVIV UNIVERSITY	781218	790110	35881000	24
STENCEL, ROBERT	UNIVERSITY OF MICHIGAN	790516	790523	35201016	8

STEPHENS, JESSE	FLORIDA STATE UNIVERSITY			35111042	
STEWART, A. I.	UNIVERSITY OF COLORADO			35071046	
STRUB, PAUL	UNIV OF CALIFORNIA AT DAVIS	790615	790930	36131001	108
STRUB, PAUL TED	UNIV OF CALIFORNIA AT DAVIS			36131003	
SUTERA, ALFONSO	CTR FOR ENVIRONMENT AND MAN			36121007	
SWARZTRAUBER, PAUL	UNIVERSITY OF COLORADO			43513022	
SWEETON, EDWARD	CTR FOR ENVIRONMENT AND MAN			36121003	
TAKAHASHI, TSUTOMU	UNIVERSITY OF HAWAII-HILO			35451005	
TAKAHASHI, TSUTOMU	UNIVERSITY OF HAWAII-HILO			35451006	
TAKAHASHI, TSUTOMU	UNIVERSITY OF HAWAII-HONOLULU			35131001	
TAKAHASHI, TSUTOMU	UNIVERSITY OF HAWAII-HONOLULU	790702	790724	35131003	23
TENCH, ALAN H.	COLORADO SCHOOL OF MINES			35801001	
TENCH, ALAN H.	INDEPENDENT - BOULDER			36341002	
THOMAS, GARY	UNIVERSITY OF COLORADO			35071066	
THOMAS, GARY	UNIVERSITY OF COLORADO			35071073	
TOOMRE, JURI	UNIVERSITY OF COLORADO			35071088	
TORR, MARSHA R.	UNIVERSITY OF MICHIGAN			35201029	
TRENBERTH, KEVIN	UNIVERSITY OF ILLINOIS	790621	790802	35141014	43
TRIPP, DAVID	WEBER STATE COLLEGE	791216	791222	36451000	7
TRIPP, DAVID	WEBER STATE COLLEGE	790514	790519	36451000	6
TRISCHKA, JOHN	SYRACUSE UNIVERSITY			36541000	
UNKNOWN	HARVARD UNIVERSITY			35121001	
UNKNOWN	UNIVERSITY OF COLORADO			35071053	
VAN HELVOIRT	UNIVERSITY OF VIRGINIA			35691006	
VASTANO, ANDREW	TEXAS A+M UNIVERSITY	790625	790901	35311006	69
VASTANO, ANDREW	TEXAS A+M UNIVERSITY	790102	790110	35311006	9
VASTANO, ANDREW	TEXAS A+M UNIVERSITY	790202	790216	35311025	15
VASTANO, ANDREW C.	TEXAS A+M UNIVERSITY			35311018	
VAZIRI, ARSALAN	UNIVERSITY OF DELAWARE			35751001	
VAZIRI, ARSALAN	UNIVERSITY OF NEVADA			35231000	
VIGDORCHIK, MICHAEL	UNIVERSITY OF COLORADO			35071067	
VILLUMSEN, JENS VERN	YALE			36211000	
VOLMER, JOHN	FRENCH MET. OFFICE			5013716	
VONDER HAAR, ET AL	COLORADO STATE UNIVERSITY			35081046	
VONDER HAAR, ET AL	COLORADO STATE UNIVERSITY			35081049	
WAGNER, JOHN	UNIVERSITY OF ALASKA	790725	790810	35011002	17
WAITE, J. HUNTER	UNIVERSITY OF MICHIGAN			35201024	
WAITE, J. HUNTER	UNIVERSITY OF MICHIGAN			35201027	
WALKER, JAMES C.G.	NATIONAL ASTRONOMY & IONOSPHER			36551000	
WALLACE, JOHN	UNIVERSITY OF WASHINGTON			35371008	
WALSH, JOHN E.	UNIVERSITY OF ILLINOIS			35141011	
WEARE, BRYAN	UNIV OF CALIFORNIA AT DAVIS	790615	790930	36131001	108
WEATHERFORD, CHARLES	FLORIDA A+M UNIVERSITY	790723	790806	36061000	15
WELCH, RONALD	COLORADO STATE UNIVERSITY			35081040	
WELCH, RONALD	COLORADO STATE UNIVERSITY			35081044	
WESEMAEL, FRANCOIS	UNIVERSITY OF ROCHESTER	790523	790610	36521001	19
WESSEL, WILLIAM R.	FLORIDA STATE UNIVERSITY			35111013	

WESTHOFF, DANIEL	COLORADO STATE UNIVERSITY			35081034	
WHITBY, KENNETH	UNIVERSITY OF MINNESOTA			35211001	
WHITE, DICK	UNIVERSITY OF COLORADO			28403017	
WHITE, DICK	UNIVERSITY OF COLORADO			28403047	
WHITEHEAD, JOHN	WOODS HOLE OCEANOGRAPHIC INST.			35781009	
WILLIAMSON, ROGER	STANFORD			14013005	
WONG, VANCE	FLORIDA STATE UNIVERSITY	791130	791202	35111038	3
WROBLEWSKI, JOSEPH	FLORIDA STATE UNIVERSITY	791203	791215	35111024	13
WU, SHI T.	UNIVERSITY OF ALABAMA			36471000	
YEH, T.	METRO STATE COLLEGE			36601000	
YOUNG, KENNETH	UNIVERSITY OF ARIZONA			35021005	
YOUNG, KENNETH	UNIVERSITY OF ARIZONA	790610	790815	35021008	67
YOUNG, KENNETH	UNIVERSITY OF ARIZONA			35021010	
ZABUSKY, NORMAN	UNIVERSITY OF PITTSBURGH	791111	791118	35601000	8
ZDUNKOWSKI, WILFORD	UNIVERSITY OF UTAH			35351003	

FIELD OBSERVING FACILITY (FOF)

Mission and Goals of FOF

The mission of the Field Observing Facility is to provide surface-based measurements for the atmospheric sciences in support of experimental meteorological programs throughout the United States and occasionally around the world. In meeting its mission requirements, FOF engages in the following major activities.

1. Operation of advanced remote- and immersion-sensing systems to support the research of atmospheric scientists in universities and NCAR.

2. Development of new measurement systems, in cooperation with the Research Systems Facility, to meet the needs of atmospheric science.

3. Development of operational and analytical techniques for optimum use of its facilities, and transfer of these techniques to the atmospheric sciences community. These techniques include instrument deployment, data collection, software development, data processing, data display, and scientist-machine interaction.

Although FOF's charter is broad, its emphasis in recent years has been directed at support to mesoscale and boundary-layer meteorology in accordance with the growing national scientific interests in convective storms, winter cyclonic storms, boundary layer processes, and air pollution as it is coupled to boundary layer turbulence, transport, and diffusion.

Strategies Adopted for Current Operations

After several years of intensive field program support, FY 1980 appears to offer an opportunity to take stock and to prepare for the 1980s. As we examine the future, we see a trend toward more organized planning, on the national level, in the area of mesoscale research. Such planning has already influenced the 1979 SESAME program and the CSD-HIPLEX collaborative effort in FY 1981. This national planning, taking place as a consequence of NSF's leadership and initiative, seems to be leading to the following conclusions:

- Large cooperative programs in the future will be carefully planned at the national level.
- Large programs such as SESAME will not take place year after year but are likely to be spaced at three-year or four-year intervals, thus permitting ample time for analysis.
- There is a trend toward larger field programs but some smaller programs led by individual investigators will be conducted.

- Large programs will require virtually all of the nation's field observing resources, and therefore will preempt the use of resources in smaller programs.

- Mesoscale meteorology in the 1980s will require more advanced field observing facilities than now exist.

It appears that mesoscale meteorological interests in the 1980s will continue to be focused on convective storms, atmospheric electricity, winter storms, the boundary layer, and cloud physics. Motivation for pursuing basic work in these areas stems from the nation's underlying needs for improvements in short-term weather prediction, air pollution monitoring and control, weather modification, and public and air traffic safety. We can expect a CSD effort in FY 1981, a new winter storm initiative in FY 1982, and a multi-scale SESAME in FY 1983. It is clear that, if all of these programs are supported, the number of smaller programs which can be supported will be severely limited. Programs such as NIMROD, TRIP, the University of Washington's next generation of winter storm studies, and various experiments at the BAO would all experience greater difficulty in obtaining the facilities they need from FOF. Given that current budgets are not likely to increase sufficiently to accommodate all of these needs, we are forced to conclude that the FOF's support capabilities will fall short of demand. Recognizing this fact, FOF will stress improved quality rather than quantity in its plan for the future. We plan to do this by advancing our existing capabilities and developing a few new tools which will, in the main, replace existing systems in the mid-80s. These will take the form of new Doppler radars and techniques, an improved PAM, and new sounding measurement systems. We will also continue a modest but well-focused effort on data processing and interactive analysis techniques.

Accomplishments of the Past Year (1979)

Field Program Support. During February and March the CP-3 Doppler radar was located at Ocean Shores, south of the Olympic Peninsula of Washington, in support of the Studies of Extratropical Cyclonic Storms (CYCLES) headed by Professor Peter Hobbs. The University of Washington CYCLES program emphasizes the study of kinematic fields and precipitation structure. The coastal location for the radar was selected in order to observe storms as they made the transition from sea to land.

The CP-4 radar and the portable Automated Mesonetwork (PAM) were moved to Central Oklahoma in April to support SESAME. Shortly thereafter, the CP-3 radar was transported directly to Oklahoma from the CYCLES program in Washington. The Field Observing Facility also provided two GMD-1A rawinsonde sets which were used within SESAME's regional and storm-scale upper air sounding network.

A cooperative program of the University of Virginia, the Illinois State Water Survey, and scientists within NOAA's NHEML (VIN) was conducted in East-Central Illinois from 1 June until 30 August 1979. VIN scientists studied relationships between boundary-layer mesometeorological processes and convective precipitation. A second objective was aimed at defining the potential of dynamic seeding for precipitation enhancement in the Corn Belt. The PAM system was transported directly from SESAME to Illinois where it was based in Champaign for the duration of VIN.

The Thunderstorm Research International Project conducted at Socorro, New Mexico, in 1979 received the services of the CP-4 Doppler radar from mid-July through August. CP-4 formed part of a triple-Doppler network for observations of thunderstorms occurring over the Langmuir mountaintop laboratory. The objective of this experiment was to relate high-resolution Doppler observations to a variety of electrical measurements made at and around the laboratory.

In September the facility lent support to the Boulder Low-level Intercomparison Experiment which was co-hosted by NOAA and NCAR at the Boulder Atmospheric Observatory near Erie, Colorado. This experiment, sponsored by the WMO's Commission on Instruments and Meteorological Observations (CIMO), involved some 40 scientists from eight countries who assembled to compare different methods of measuring temperature, humidity, and wind in the lower levels of the atmosphere. The sounding systems included four kinds of free-rising sondes, four tethered sondes, one remotely piloted aircraft, one kite system, several acoustic sounders, radar, and lidar. The tower served as the standard for comparison.

Other Accomplishments. In addition to its program of field support the FOF engaged in a number of other activities to improve the quality of service provided.

1. Radar Video Recorder. For example, with the cooperation of the Research Systems Facility a video recorder for coherent Doppler radar has been developed. This technique preserves significantly more of the information in the radar signal than has heretofore been practical. The recorder was used with the CP-2 radar during the 1978 summer CSD field program and was assigned to the CP-4 radar during the 1979 SESAME in Oklahoma.

2. PAM Calibration. During this reporting period the PAM system was augmented with a portable mini-base station. This is a suitcase-size, self-powered station which can interrogate a remote station and display the received data message on an interval printer. Its purpose is to provide a method for checking remote station operation during set up. The mini-base station, with a special set of sensors, also constitutes a portable reference remote station which is used for sensor intercomparison and calibration.

3. Radar Automation. The radar data acquisition systems were fully automated in the past year. A minicomputer is now used to control antenna scans to select processing parameters. Pre-programmed antenna scans, stored on magnetic discs, are easily selected through a terminal keyboard. This technique, which removes much of the tedious and repetitous work required during operations, offers great flexibility and allows added time to be devoted to real-time interpretation of the radar displays.

4. Airborne Doppler Radar. FOF worked with NOAA/ERL in conducting preliminary tests of an airborne Doppler radar aboard the NOAA P-3 aircraft. NOAA engineers in Boulder developed the radar assisted by FOF engineers Charles Frush and Grant Gray. Frush and Gray also interfaced an FOF data processing and acquisition system to the radar and supervised the data collections. Results have been quite encouraging to date.

5. Software Development and Data Processing. FOF has continued to provide large quantities of archived radar data and further development of the Doppler radar software library has taken place. Much of this work has been accomplished by Computing Facility applications programmers with the help of FOF student assistants. All data which have been requested for analysis during the past year have been archived on a timely (one-month) basis. This effort represents about 300 tapes and 200 radar hours of data. The software library (for higher levels of processing) has experienced substantial growth during the past year. New capabilities such as single-radar filtering to Cartesian space, dual-Doppler filtering to cylindrical space, power spectral analysis of radial velocity and reflectivity fields, and major streamlining of the data archive and access software have been realized during this period.

6. Technique Development. FOF staff scientists have been involved in several cooperative efforts. Collaboration with the University of Chicago in connection with Project NIMROD has revealed exciting applications of the RDSS for data analysis. Fujita and Wilson have demonstrated the value of color time-lapse motion pictures of Doppler radar data for studying severe storm development, downburst propagation, and tornado genesis. One joint publication is in progress and more are likely to follow. Richard Carbone's collaboration with the University of Wyoming, Bureau of Reclamation and NOAA/WPL, in connection with the Sierra Cooperative Pilot Project, has resulted in unique triple-Doppler radar data of a severe winter storm. His findings relate to the fundamental dynamical structure of cold frontal passages on the west slope of the Sierras and also have relevance to techniques for deploying and using multiple-Doppler radars for studies of convective storms. Finally, John McCarthy, a visiting scientist in FOF, has worked closely with Wilson, Carbone, and Serafin in determining the severity of wind shears and propagating gust fronts as they affect aviation safety.

Field Observing Facility Users

Bernice Ackerman	Illinois State Water Survey
Ronald Alberty	National Severe Storms Laboratory
Stanley Barnes	NOAA
Dale Durran	NCAR
Gordon Ellis	Boulder Valley Schools (RE-2)
M. E. Harward	Oregon State University
Peter Hobbs	University of Washington
Raymond Jordan	Colorado School of Mines
Chandran Kaimal	NOAA
J. E. Kuettner	MONEX
Roger Lhermitte	University of Miami
E. Markworth	Steven F. Austin University
Charles McGinn	University of California (Davis)
Maynard Miller	Foundation for Glacier and Envir. Res.
Robert Rader	Solar Energy Research Institute
Peter Ray	National Severe Storms Laboratory
Colin Ramage	University of Hawaii
Jesse Stephens	Florida State University
Aylmer H. Thompson	Texas A&M University
Norman K. Wagner	University of Texas
Elizabeth Wright-Ingraham	Wright-Ingraham Institute

RESEARCH SYSTEMS FACILITY (RSF)

Missions and Goals of RSF

The Research Systems Facility is a team of scientists, engineers, and technicians dedicated to advancement in the technology of atmospheric instrumentation and measurement. Developing instrumentation and seeking more accurate measurement methods are, of course, complementary efforts--each gaining from the other. The development of new instrumentation is aimed at supporting requirements of other ATD facilities. In addition, these efforts often play a major role in national and international programs such as the Global Weather Experiment (GWE). RSF also works to improve atmospheric technology through engineering services, thereby supporting the larger scientific mission of the entire center. This support includes the Machine Shop, the Mechanical Design Group, and the Instrument Shop.

A strong development program is evident through all phases of RSF work. The objective is to provide research systems which will enable university and NCAR scientists to make the greatest possible progress in atmospheric research. Through the transfer of knowledge and technology to other organizations, RSF contributes a piece to the scientific world.

In planning future projects, RSF is in tune with the needs of the ATD facilities. Together with the facilities, RSF reviews the need for new instrumentation or for more accurate measurements. Projects are selected which will aid important specific atmospheric research. The method of selection includes reviewing proposed developments and evaluating these based on inputs from scientific user requests, advisory panel reviews, etc. Highest priority is given to projects which will serve a large number of university and NCAR scientists through established NCAR Facilities rather than developments which will serve only individual needs.

Accomplishments of the Past Year

Machine Shop and Mechanical Design Group. A relocation this year involved the incorporation of the HAO Machine Shop, and a unified location for all staff in the Machine Shop and the Mechanical Design Group.

Several significant developments saw completion in the Mechanical Design Group: the design of a modified NIKE Hercules pedestal, a new cryogenic air sampler, and the successful operation of the U2 sampler.

The NIKE Hercules pedestal modification was the result of the combined efforts of Michl Howard, Edward Lambdin, and Paul Johnson and will replace the pedestal currently being used on FOF's C-band radar systems. The pedestal design is a unique one in that it involves a four-bar nonlinear linkage system to drive the reflector, wherein the drive ratio changes with the position of the antenna dish. Basically the new design involved relocating the elevation axis and changing the drive method of the dish. The result is that the dish is now mounted to minimize the inertia, which in turn reduces the power required to produce a given dish acceleration.

The design will be used in the field this spring by FOF. The mobile radar system with the new pedestal design can operate in high winds without a radome. This facilitates simple assembly and disassembly of the system and increases the quality of the radar signal.

The cyrogenic whole-air sampler involved a design effort by Edward Lambdin, Jim Guenther, and Paul Johnson in collaboration with Richard Lueb of the Atmospheric Quality Division. The sampler will be used to gather information on atmospheric gases. It includes a compact heat exchanger and a newly designed opening and closing valve for the air sample. A significant factor in the design is the fact that it can now be used with inexpensive, solid-fuel rockets. The result is a greatly reduced cost in data gathering.

The U2 sampler was successfully flown in the spring and summer of this year. It is basically a filter device designed to be carried on a U2 aircraft to measure gases and particulates in the stratosphere. The instrument was delivered to Bruce Gandrud and Allan Lazrus of the Atmospheric Quality Division and was flown in support of the NASA ACE (Aerosol Climate Effects) program in February and March and again during the summer months. The design is particularly significant due to the extreme temperatures that are encountered during a typical flight.

Neither the Machine Shop nor the Mechanical Design Group confines its efforts only to ATD programs. Each supplies important support to all of NCAR. The shop personnel are skilled instrument makers who work very closely with NCAR experimenters translating their concepts into reality. Some major projects were:

William Mankin, AQD; absorption cell
Walter Berg, AQD; total chlorine sampler
NSBF; balloon launch spool
Bruce Gandrud, AQD; carousel filter
Allan Lazrus, AQD; tri-pack filter
FOF; new radar pedestal
Arden Buck, RSF; hygrometers and humidity console.

Instrument Shop. The Research Systems Facility maintains an Instrument Shop which provides calibration and repair services for all of the RSF research instrumentation as well as for the other ATD facilities. The time and money saved by such an in-house effort are significant. It has been repeatedly shown that this shop indirectly earns back its cost by comparison with known costs at vendor repair facilities. The added advantages are quick emergency repairs, expertise in the use of sophisticated instruments, and confidence that all instruments are working and accurate.

Technical Documentation. While the development of instruments for the atmospheric research community is the main emphasis within RSF, significance is also placed on the documentation for these instruments. The documentation process is the result of the combined efforts of the engineers and technicians from a project working closely with a technical writer. The resulting manuals provide detailed information on maintenance and operation for the users of RSF developments. They also include complete drawing sets and parts lists.

Universities or other agencies sometimes use RSF documentation to build their own systems. This has been true of the RSF dropwindsonde which was built by NOAA and the Lyman-alpha hygrometer which has been built by the University of Wyoming and the University of Nebraska, among others. In addition, every effort is made to publish journal articles which are an important vehicle in the transfer of information concerning developments to a wide audience of the scientific community.

The Research Data Support System (RDSS) is an interactive color graphic display system which aids in the analysis of large data sets, for example, the data from FOF's Doppler radars. The system is the result of hardware and software development by Victor Borgogno, Robert Brown, Kenneth Norris, and David Bargen. The RDSS is designed to fit between and complement the existing computer facilities at NCAR, which include field data acquisition systems with real-time display capabilities and the batch-oriented CDC 7600 computer with microfilm graphic capabilities. The general purpose of the RDSS is to allow the user to interact with the data to produce high-resolution color images.

There are three main groups of RDSS hardware: the PDP 11/60 minicomputer system, the Comtal video display subsystem, and the built-in-house coordinate converter. The outstanding hardware features include: (1) two large-capacity disk drives that make it practical to store images and whole tapes; (2) the multi-user, multi-terminal configuration that permits software development to proceed simultaneously with scientific investigation; and (3) the new Trilog color line printer that provides immediate (4 min per page) color hardcopy on standard 11" x 14" computer paper. A commercially purchased multi-user operating system, RSX-11M, supports all application and software development tasks.

The basic software program reads the NCAR standard format digital radar data and creates calibrated, scaled and annotated color displays. Input data contains both raw Doppler velocity processor counts and raw power counts (proportional to reflectivity) in ray format, along with housekeeping parameters for each ray. Display output formats include PPI, RHI, and THI; all scan types may also be output in B-scan format. The user may display any portion of a scan at any desirable magnification up to X30. The time required to create the Doppler velocity and the reflectivity image pair is about the same as the data collection time in the field. In the primary mode of operation the user interactively builds the display by selecting parameters from menus presented to him at an alphanumeric terminal. Both radar images are created by the hardware coordinate converter and are viewed on the same high-resolution color monitor. A secondary mode of operation runs unattended; the user selects parameters for a group of scans, and the program builds each image and prints it on the color line printer for later review.

The newest interactive program displays radar volume slices produced by NCAR's CDC 7600. The selected data volume is calibrated and interpolated to Cartesian slices by the batch machine and the output tape is transferred to the RDSS for display. There the user has local control over color enhancement and hardcopy is available either on film or from a color printer.

Many special software features were developed this year and are now available to the user via the display program. Data may be displaced with a bias added to either the range or the angle or both. A trackball and a displayable cursor are used to locate the exact range, angle, and gate number of any point on the screen. The same scan may be repeatedly read and displayed at various magnifications in order to locate and focus specific areas of interest. Because two colocated images are always available, intercomparisons of successive scans or of two variables from the same scan are possible. The touch of a button displays an image in color, in black and white, or switches between the two images. By rapidly transferring images from the disk to alternate display memories, time-lapse sequences can be generated with a new image presented every second. An algorithm has also been implemented in FORTRAN which offers rapid, accurate unfolding of Doppler velocity data. Speed of throughput is achieved by providing a combination of automatic unfolding with user input of boundary conditions as required. The automatic part of the process is fast enough and effective enough to be useful in real-time field velocity displays.

Based on expanded user requirements and the enthusiastic user response to date, RSF expects to continue development of the system. Future additions to RDSS will include a satellite data system and a fixed-head disk emulator. The satellite data system will provide low-resolution IR and visible images of the earth. These images can be enhanced, colored, and sent to the color printer for hardcopy. For production runs, only the Lazerfax black and white printer will be available. The fixed-head disk emulator will enhance software operations by providing faster turnaround of compile and task build operations. The increased use of the RDSS makes this an attractive addition.

Future applications include the superposition of two data sets. For example, a background gray scale or color image from the radar data set might be used along with color overlays of meteorological variables from NCAR's Portable Automated Mesonet, a sophisticated weather station network. Presently there is much software being developed for the interactive editing of standard radar data which up to now are only viewed without editing. In addition to the software development within RSF, at least four other groups within NCAR are writing significant programs to be used on the RDSS.

Dropwindsonde. The dropwindsonde was developed as a team effort in RSF and was used in GATE in 1974. Last year (in 1978) RSF transferred the technology, and an improved design, to the National Oceanic and Atmospheric Administration, and also provided that agency with technical support during the manufacture of 8500 sondes. This year the dropwindsonde played a major role in obtaining wind measurements in two international scientific programs: GWE and MONEX. In addition, RSF's Justin Smalley served as director of dropwindsonde operations at Ascension Island during two GWE special observing periods from 5 January to 4 March and from 1 May to 30 June of 1979.

The dropwindsonde is an instrument crucial to the observation of winds in the tropics and was used for such observations in GWE over the Atlantic, Indian and Pacific Oceans. It is designed to be dropped from an aircraft and can therefore be used in regions where large expanses of ocean prevent the use of radiosondes. The dropsonde instrument package contains an Omega signal receiver in addition to pressure, temperature, and humidity sensors. The worldwide Omega navigation signals are used to measure the winds. In GWE the sondes were parachuted every 350 km along the flight track at altitudes of 9-11 km. The nominal descent rate is 25 mb/min (300 m/min); as the sonde descends the data are transmitted to the launching aircraft where they are recorded as well as processed into real-time scientific data. Roughly every other sounding was transmitted to the Global Telecommunications System and provided real-time data worldwide.

The GWE also used two Omega Signal Monitors which were designed and built in RSF by Julian Pike and Dale McKay. These monitors provided valuable information during the program concerning diurnal variations in the Omega signals. This information is now being used by Dr. Paul Julian and Brewster Rickle during the post processing of the dropwindsonde records to remove those diurnal effects from the wind data.

All of the dropwindsonde data is currently in post-processing and will be archived in Stockholm as part of the entire GWE data set.

Lyman-Alpha Hygrometer. Two of the latest model Lyman-alpha hygrometers are presently being used on aircraft at NCAR's Research Aviation Facility to obtain humidity variation data. These instruments (improved versions of the earlier RSF design) are lighter weight and provide better performance and reliability than previous models. The Lyman-alpha development, involving Arden Buck, Bryan Lee, and Michl Howard, has been underway for a number of years and has resulted in innovative solutions to a long-standing problem in the meteorological community. As a result of this long-term effort, it is now the preferred way to measure fast-fluctating humidity.

The technique uses a source of UV radiation at the Lyman-alpha line (hydrogen lamp), and a detector (ion chamber) which is separated by a small gap. As the radiation crosses the gap, it is partially absorbed by water molecules in the air. The attenuation of the received signal thus provides a measure of humidity. The technique is quite simple, but had been rejected by most meteorologists due to severe drift and linearity problems. Arden Buck, RSF engineer, found solutions to those problems. Buck solved the drift problem by measuring absorption at two different path lengths. This makes the instrument self-calibrating and drift-free. The linearity problem was solved by adding hydrated uranium to the source. Spectral purity was improved almost two orders of magnitude and the lamp life was greatly extended. Information on the design of the source was turned over to a glass blower who has made that technology commercially available.

In addition to its use on the RAF aircraft, two hygrometers will be used by NOAA on the BAO tower where they will be used for a variety of research applications. The University of Wyoming has also used the hygrometer design and the University of Nebraska is currently using it for agricultural crop studies. In addition, the spectrally pure source has attracted the attention of spectroscopists and others outside the meteorological community.

Differential Temperature Sensor. A development team of Harold Cole, Phyllis Carlson, Dean Lauritsen, and Bryan Lee designed, built, and calibrated an improved differential temperature sensor. The system, which is now undergoing intercomparison tests, will be delivered to the Field Observing Facility. There it will be used in conjunction with the Portable Automated Mesonet in micrometeorological studies. The differential temperature system will be used to sense the temperature at two levels, 1 m and 4 m. The difference between these two levels can be measured by approximately $\pm 0.05^{\circ}C$. This will provide an estimate of temperature stability and vertical heat flux. The PAM system, developed by RSF in 1976, has been used by FOF to support many major scientific programs as enumerated in the FOF portion of this report.

Air Motion Sensing Vanes. RSF developed a de-iced air motion sensing vane for RAF. The de-icing feature has been incorporated for safety reasons since an increasing number of flights involve potential icing conditions. Two vanes were placed on RAF aircraft this year and performed successfully for a substantial number of flight hours. The instrument is becoming standard flight equipment. The accepted design is now in the final stages of refinement. Further research will involve an attempt to waterproof the instrument, a continuing long-term fatigue test, and an experimental design with conservative beams to study failure rate.

Radar Video Recorder. The radar video recorder, which was designed and developed in RSF by George Saum and Mark Wharton, was delivered to FOF in 1978. During the past year the recorder was installed at FOF's radar site (the Marshall site) where it proved to be a valuable tool. The recorder first records and then plays back radar data for quality evaluation and analysis of mean velocity and spectral radar data. It remained at Marshall until early spring, 1979, when it was moved to Oklahoma during the SESAME project in support of studies by Florida State University in conjunction with the C-band radar. Following the SESAME project the recorder is again being used at Marshall for radar data reduction.

Calibration Laboratories: Pressure, Temperature and Relative Humidity.

An intense effort has been underway to complete a pressure, temperature, and relative humidity calibration laboratory within RSF. The significance of the effort will be to provide computerized calibration procedures which can be used both by RSF teams in sensor development work and by other NCAR groups to calibrate working standards. Julian Pike and Bryan Lee have completed the hardware design and implementation for the temperature facility which includes a temperature bath and a standard platinum resistance thermometer with a computer readout offering a resolution of $\pm 0.003^{\circ}C$. Software support of the system is under development. At its completion the system will provide fully automated calibration of temperature sensors and automatic recording of the data.

The pressure laboratory uses a primary dead-weight pressure standard as a reference. A programmable pressure generator with internal transfer standard is computer-controlled, thus providing an accurate, time-efficient system for calibration. Automation also means a reduction of the possibility of human error due to lack of operator skill. RSF will use both the pressure and temperature standards in developing sensors for the atmospheric community and will also make this laboratory available to the ATD facilities for use in calibrating their equipment.

The RSF humidity console is currently the most accurate calibration facility in this area. In 1979 several RSF scientists and designers, including Arden Buck, Julian Pike, Bryan Lee, and Michl Howard teamed up to design and build a two-temperature humidity generator. The console works on the principle of saturating air at a known temperature and raising it to a second known temperature. Dewpoint can be measured to within ±0.1 °C at a variety of temperatures. At the present time the console is completed, has been tested, and is operating in a manual mode. It has been used in support of other ATD facilities for the calibration of sensors, for calibrating the Lyman-alpha hygrometer for use in the RAF field programs, and for calibrating the hygrometers used by NOAA at its BAO tower. Future applications include calibrating the humidity sensors for the latest Portable Automated Mesonet (PAM II) now under development in FOF. The RSF team is working to computerize the system. This will allow automatic logging of data and unattended operation of long-term experiments. At that time on-going research on the Lyman-alpha hygrometer requiring a stable humidity reference will be possible. This development has the potential of being within the financial reach of all universities as a near primary standard facility.

Safesonde. The safesonde is an upper-air sounding system, aimed at providing capabilities similar to the GMD, with considerably improved accuracy. As one of the major development efforts in RSF at the present time, it involves a team of engineers and technicians including Harold Cole (who is leading the effort), George Saum, John Green, Ken Norris, P.K. Govind, Dean Lauritsen, and David Bargen. This RSF team is collaborating with a team from NCAR's Global Atmospheric Measurements Program to come up with the very best design possible. Following completion of tests, RSF will develop a portable operation system which NCAR's Field Observing Facility can take into the field in support of university and other research programs.

The system is intended primarily for use in boundary-layer severe-storm and mesoscale research. A small sonde will be launched on a balloon, and tracked automatically by a ground receiving system. This year saw the completion of detailed analysis and testing of tracking systems which resulted in the selection of a range-angle tracking system. This system proved to be effective in meeting the major system objectives of a highly accurate system which is logistically easy to install and operate in the field. The design goals of the system are to measure wind speed to within ± 0.5 ms^{-1}, temperature within $\pm 0.25^{\circ}C$, and humidity within ±3%. These measurements will be made over an altitude range of 0-15 km with a height accuracy of 100 m. In addition, the system can be installed on a field project in less than a day and maintained and operated by a single person. Development of the prototype system for FOF is currently underway. If adequate funds are available, it is expected that three systems will be built for FOF's field operations; possible additional systems will be made available according to user demand, for use in forthcoming large research programs.

Users

Name	Affiliation	Project
E. C. Coulman	CSIRO, Australia	Air Motion Sensing Vane
Jim Morrissey	USAF, Bedford, MA	Dropwindsonde
Jim Purdom	NOAA/NESS	RDSS
Les Merrit	NWS	"
Jim Billingley	NASA	"
Several	People's Republic of China	"
Mike Byrne	NOAA/PMEL	"
David Lee	Naval Research, Monterey, CA	"
Helmut Rott	University of Innsbruck	"
Peter Ray	NSSL	"
Jim Tillman	University of Washington	"
Doug Lilly	MRS/NCAR	"
Dick Monroe	HAO/NCAR	"
Diane Friend	HAO/NCAR	"
--	Argentina	"
Bob Kelly	University of Chicago	"
Bruce Lites	HAO/NCAR	"
Roger Phillips	NOAA/NESS	"
Jim Wilson	FOF/NCAR	"
Bob Serafin	FOF/NCAR	"
Chuck Frush	FOF/NCAR	"
Aubrey Schumann	GAMP/NCAR	"
J. Heymsfeld	Goddard/NASA	"
D. Musil	South Dakota School of Mines	"
P. Hertzogh	Center for the Environment & Man	"
Carl Mohr	CSD/NCAR	"
Ed Zipser	AAP/NCAR	"
Dick Oye	ATD/NCAR	"
David Sime	HAO/NCAR	"
Jim Dye	CSD/NCAR	"
Harold Baynton	FOF/NCAR	"
Bill Moninger	NOAA	"
Everett Chang	Southern Colorado State College	"
Fred Gould	NOAA	"
Al Rodi	University of Wyoming	Lyman-alpha hygrometer
J. Y. Wang	San Jose State	"
C. M. Felton	San Jose State	"
Ron Bohlander	Georgia Tech	"
Shashi Verma	University of Nebraska	"
Doug Brown	Army Atmos. Sci. Lab, Los Alamos	"
Pierre Ravussin	EPFL, Lausanne, Switzerland	"
Shigern Marabayashi	Nagoya University, Japan	"
Several	RAF/NCAR	"
Chandran Kaimal	BAO Tower/NOAA	"
Gordon Lerfald	WPL/NOAA	"
	Indian Institute of Tropical Meteor. Poona, India	
	BTH Cemicals Ltd., Poole, England	"
	Bell Labs	"
	Max Planck Institute, Germany	"

GLOBAL ATMOSPHERIC MEASUREMENTS PROGRAM (GAMP)

Mission and Goals

The primary functions of the Global Atmospheric Measurements Program (GAMP) are the innovation, development, and feasibility demonstration of basic balloon technology, particularly of superpressure balloons, and of the associated meteorological sensing systems; and cooperation with the atmospheric scientific community in utilizing these techniques in research endeavors.

Strategies

Much of GAMP's efforts over the past several years has centered on the preparation of a constant-level balloon system to provide direct measurements of winds in the tropics as an essential component of the observing system for the GARP Global Weather Experiment (GWE).

GAMP has primarily contributed to the development and improvement of two of the three major superpressure balloon flight programs collecting global meteorological data. These programs were the Tropical Wind, Energy Conversion and Reference Level Experiment (TWERLE), 1970-1975, and the Tropical Constant Level Balloon System (TCLBS) during 1976-1979.

The major activity of the GAMP program this year has been the successful launch of 313 TCLBS platforms in the deep tropics (10^{o}N to 10^{o}S) during the 30-day intensive periods within the two Special Observing Periods (SOP) of the GWE. Costs for this program are shared by NSF and the National Oceanic and Atmospheric Administration (NOAA), with NOAA providing funds for special project staff, production of flight systems, and the logistics costs of operating launch sites on Canton, Ascension, and Guam Islands. The fixed dates for balloon launches (January and May 1979) dictated that this program receive the first priority.

After the TCLBS launches were completed, a considerable effort has been made to extract the maximum of significant results from the TCLBS program. We are now analyzing the data as Lagrangian trajectories rather than the synoptic format in the GWE data sets. An atlas of the integrated analysis of the long-term vertical currents, as measured by the two TCLBS balloons equipped with sensitive "Gill" anemometers, is in preparation. Professor Gerry Gill, University of Michigan, will co-author this planned paper.

The GAMP staff has begun a major effort on the development of a capability to fly a long-lived balloon system in the lower stratosphere as a vehicle for measuring stratospheric gases and aerosols. This vehicle, which will have a latitude-seeking capability, will complement satellite and earth-based measurements of importance to climate and air-quality research.

The μ-GHOST concept has been developed to meet the needs of an operational system as an integral part of the future World Weather System. GAMP has designed a low-cost operational balloon system for the mid-latitudes of the southern hemisphere. Flights will be at 200 mb and the wind field, as well as air temperature, will be measured.

Accomplishments of the Past Year

Tropical Constant Level Balloon System. Three hundred thirteen balloons, transmitting through the ARGOS system aboard the TIROS-N and NOAA-6 satellites, provided wind data in the upper tropical tropopause, particularly in the deep tropics (10°N to 10°S).

The TCLB system is a joint contribution of France and the United States to the Global Weather Experiment. This was particularly appropriate because the TCLB technology has been developed over the past decade by both countries. The TCLBS project office at NCAR was headed by Paul Julian.

The TCLBS superpressure GHOST balloon, made of bilaminated polyester, was 4 m in diameter and spherical when fully inflated. It weighed 4.5 kg and carried a payload weight of 2.9 kg. The average lifetime of the TCLBS balloon was two months, since balloons were cut down if they strayed too far from the equatorial regions.

The ARGOS system performed extremely well. On the average, data and locations were obtained for each balloon four times per day. This resulted in approximately 50,000 wind and temperature measurements for the complete program. The balloon platforms transmitted 1 W to the satellite; tests, however, have shown that 0.1 W would have given location and data for 70 percent of the overpasses. Balloons were located that had gone to the surface and were hanging in trees.

There were no independent means of locating the balloons, but the consistency of locations and wind velocities was so good that the investigators are convinced that the data exceeded the system design specifications.

The TCLBS gave a useful data set for the study of the wind circulation in the tropics. In addition, the program demonstrated that a balloon system is a practical and economical means of collecting meteorological data. The 50,000 wind data points cost approximately $16 per measurement.

In recognition of the accomplishments of the GAMP staff who worked on the TCLBS program, a group citation was presented by Dr. Richard Frank, Administrator of NOAA. Individual citations were presented to the following: M. Verstraete, J. Tefft, V. Lally, S. Stenlund, N. Carlson, E. Lichfield, C. Roark, M. Olson, and C. Morel.

The Long-Lived Atmospheric Monitoring Airship (LLAMA) is designed to fly above the air lanes. After the successful 40-day test flight of LLAMB (Long-Lived Atmospheric Monitoring Balloon) in 1978, the concept of powered control is being considered. Since the average meridional velocity at 20 km is near zero, the LLAMA can be controlled within reasonable limits to stay south of the equator rather than being destroyed because of overflight restrictions. It has logistical advantages: for example, it can be flown to the latitude of interest, thus eliminating the costly transportation of helium to distant launch sites.

Two 3 m spheres have been designed and purchased for conceptual testing in early 1980. One will be made of a clear polyester material so that the operation of the ballonet can be observed during inflation tests. The other sphere will be made of the flight model film, a laminate of polyester, metallized polyester, and dacron fabric. The Kevlar material used in the LLAMB flight is now far too expensive for consideration as a balloon material. The flight test LLAMA balloon will be 14 m in diameter and fully inflated with helium and air prior to launch. This will avoid pinholes during ascent as happened with the stiffer LLAMB film. During ascent the expanding helium forces the air out through a vent valve and the balloon retains a smooth spherical shape during ascent to float altitude. The 3 m test spheres will be evaluated in the Boulder laboratories of GAMP, while the flight model of LLAMA will be flown from Christchurch, New Zealand, in January 1981.

μ-GHOST. We have seen in the last ten years a continuing improvement in the capabilities of polar-orbiting satellites to locate and retrieve data from moving platforms. Nimbus 4/IRLS, EOLE, Nimbus 6/RAMS, and ARGOS have moved from $25,000 platforms to $2,500 platforms. The ARGOS system is now operational and can provide a valuable service for buoys, research balloons, and limited programs involving large numbers of balloons. However, the requirement for oscillator stability precludes the economic use of the system for a continuing operational balloon flight program.

To meet the needs for an operational system as an integral part of the future World Weather System the μ-GHOST concept has been developed. The μ-GHOST platform is envisioned as a low-cost superpressure balloon and frangible, state-of-the-art microelectronics. These platforms will provide a reference level and data set of the global wind and temperature fields at the 200 mb level in the midlatitudes of the southern hemisphere.

Goddard Space Flight Center is now developing a satellite interferometer system which will permit balloon location with no stability requirement on the platform other than transmission within the pass-band of the satellite receiver. This breakthrough permits the design of balloon electronic systems no more complex than good-quality radiosondes. Nighttime operation is possible without thermal mass or oven temperature control.

The reduced electronics mass permits the use of "tetrasphere" balloons with minimum seams and minimum costs. The projected costs for a balloon payload flying at the 200 mb level for three to five months is now reduced from $2,500 to less than $500. An operational "$\mu$-GHOST" system which can maintain hemispheric coverage with over 100 balloons flying at all times is now realizable -- at an annual cost of less than $200,000.

The superpressure balloon under investigation for the μ-GHOST program is a stretched tetrahedron, called a "tetrasphere." The NCAR design is made of bilaminated polyester film with bi-tapes (a sealing tape on both sides of the gore). This construction allows a higher overpressure and sufficient stretch or creep of the film to approach the shape of a sphere. The balloon is stressed for several hours at elevated temperatures and at overpressures 50 percent higher than will be experienced in flight. The balloon is permanently deformed into a spherical shape with four points. It now will perform equivalently to a sphere but with a minimum of seams and with a minimum of manufacturing cost. Pinholes will be detected and repaired in the field prior to launch to eliminate costly factory testing.

The satellite interferometer system greatly reduces the frequency stability requirements of the balloon transmitter. This opens the door to a whole group of new designs and experiments. It is now possible to build truly nonhazardous balloon systems and very lightweight low-power systems that can be used in applications that were previously not practical.

RACOON. The RACOON is a low-cost, sealed polyethylene balloon flying at 35-40 km during the day and at 20-25 km at night for 30 days or longer without ballast. Soundings of wind and temperature will be made during the dawn ascent and the sunset descent. Data from these flights will be collected by the TIROS/ARGOS system.

A test flight program has been developed and arrangements made for proof flights of the RAdiation Controlled ballOON (RACOON) from Kourou, French Guiana, in late 1980. Three polyethylene, zero-pressure balloons with a volume of 700,000 cubic feet have been purchased.

Middle Atmosphere Program (MAP). Professor L.R. Megill of Utah State University has asked the NCAR Global Atmospheric Measurements Program to assist in conducting a measurement program in the lower stratosphere of the southern hemisphere. In 1977 GAMP assisted USU with three flights from Christchurch by providing balloons, launch technique balloon hardware, assembly space, and launch support. These balloons provided the major test of the concept of the use of superpressure balloons for stratospheric measurements. Professor Megill and GAMP have submitted a joint proposal through NSF to NASA for a series of 12 flights during 1981. Float altitude will be 30 mb. These flights will be made in four groups of three balloons each. One of the three balloons will be heavily instrumented by USU to measure ozone overburden by absorption on the sun and ozone density, water vapor density, carbon dioxide density, hydroxyl density, $O2(^1\Delta_g)$ density, particle precipitation, and temperature, using emissions in the visible or infrared. All balloons will measure temperature and pressure. The data will be collected by the TIROS/ARGOS system four times a day.

MAP is planned to continue for several years and interest has been indicated from several groups in the United States, Norway, Japan, and Denmark.

NATIONAL SCIENTIFIC BALLOON FACILITY

Mission and Goals

The mission of the National Scientific Balloon Facility (NSBF) is to provide operational balloon support to the scientific community. The goal of the NSBF is to provide the most efficient and reliable operations support possible and through a research and development program, to anticipate and meet the changing scientific requirements.

Accomplishments of 1979

NSBF flew a total of 78 flights in 1979. Of these, 67 were in support of scientific experiments, nine were heavy-load test flights and two were tests of the long duration system. Ten flights were flown from remote locations, three from Australia, two from Canada, three from Brazil and one each from Malden, Missouri, and Greenville, South Carolina.

The number of flights in support of atmospheric sciences continued to grow, reaching 43% of the total scientific flights. Other disciplines supported were cosmic ray physics, x-ray, gamma ray, and infrared astronomy. A total of 32 U. S. and foreign institutions were supported during the year.

The NSBF was asked by NASA in 1978 to support a series of balloon flights for correlation with the Nimbus 7-LIMS Satellite. The task involved having a number of balloons at float altitude when the satellite orbit coincided with the balloon locations. This was successfully accomplished with three flights on 29-30 October 1979, three on 8 November 1978, two on 17 November 1978, two on 5 April 1979, and two on 24 April 1979.

The NSBF was awarded the 1979 NASA Group Achievement Award for outstanding, dedicated support and contribution to the Nimbus 7 Correlative Measurement Program.

At the request of the Canadian Government, we conducted a training course for three Canadian technicians.

Two new pieces of equipment have enhanced our meteorological support. The first is a system that allows us to view, on a standard telephone line, the current radar scan of the nearest NWS weather radar. This has been most useful in forecasting thunderstorms and frontal activity. The second system, again using standard telephone lines, connects a terminal at the NSBF with a computer bank of current weather data in Oklahoma City. Through this system we can obtain data not available on the existing teletype circuits.

One of the down-range mobile telemetry stations has been completely renovated and placed in operation. The second trailer will be renovated during the coming year.

Additional components have been procured to establish a dual telemetry and command capability. These have been installed in the new telemetry room. When operational, we will have the capability of fully supporting two flights simultaneously or checking out a second experiment while a flight is in progress.

The down-range land line data link was used on a scientific flight for the first time. We have also established the capability of sending commands from Palestine through the down-range transmitter. This system has been tested but not yet used operationally.

We have completed the conversion of the Vargo Building into the Engineering Laboratory. Test equipment is being moved in and the laboratory will be in operation during the coming year.

During the past years, we experienced an increasing number of failures with heavy-load flights. These are defined as flights with a total suspended weight in excess of 1,590 kg. With NASA funding support, we devoted a considerable effort to this problem in 1978 and 1979.

We developed a new design for heavy-load balloons. This design incorporates longer caps and a more conservative weight criteria.

A restraint collar was designed and tested. This collar restrains the bubble at launch and is released by command. This tends to reduce the large "sail" that develops in large balloons during the initial phases of the launch.

As a result of these and other improvements, the success rate on heavy-load flights improved dramatically. We flew 11 heavy-load scientific flights during 1979 with only one failure.

The other major development effort was in the long-duration balloon system. This system, called Sky Anchor, consists of a zero-pressure balloon for weight carrying and a super-pressure sphere for ballast. The present goal of this development is duration of 30-60 days at 36.5 km with a payload of 227 kg.

Two successful flights were flown during the year. The first, Sky Anchor IX, was launched in the evening of 20 June 1979 from Palestine, Texas. The balloon system consisted of a 14,160 m^3 zero-pressure balloon, a 147 kg payload, and a 5,132 m^3 super-pressure balloon.

Ascent went normally, all ballast was dropped, and the balloon system reached a night float altitude of 27.7 km. The system rose to 28.5 km the next day and was terminated that afternoon after a very successful 16 h float. This marks the second successful flight of this system.

In August 1979, the test flight of Sky Anchor X was conducted from Greenville, South Carolina. The system, consisting of a 117,091 m^3 zero-pressure balloon, a 246 kg payload, and a 35,483 m^3 super-pressure balloon, was launched from the East Coast to facilitate a transcontinental flight. The system was launched on the afternoon of 17 August 1979.

The system floated at an altitude of 36 km descending to 34.7 km at night. It was terminated in California near Reno, Nevada, after a flight of 46 h.

The success of Sky Anchor X was a milestone in the long-duration development program. It was the largest system of its kind ever to have flown successfully. A 256 kg payload was floated through two sunrises with a day float altitude of 36 km.

A contract has been let for the development of a transmitter and associated logic for the Long Duration Balloon System. This transmitter will link the system with the TDRSS satellite being developed by NASA.

National Scientific Balloon Facility Users

J. Anderson	Harvard College
T. Dean	University of Southampton, England
P. Evenson	University of Chicago
C. Farmer	Jet Propulsion Laboratory
G. Fazio	Smithsonian Observatory
H. Fischer	University of Munich
G. Fishman	NASA-Marshall Space Flight Center
G. Frye	Case Western Reserve University
J. Harries	National Physical Laboratory, England
L. Haser	Max-Planck Institute
M. Hauser	NASA-Goddard Space Flight Center
L. Heidt	NCAR
W. Hoffmann	University of Arizona
M. Israel	Washington University
R. Jennings	University College, London
N. Johnson	Naval Research Laboratory
R. Joseph	Imperial College, England
N. Kjome	University of Wyoming
D. Kniffen	NASA-Goddard Space Flight Center
M. Leventhal	Sandia Laboratories
W. Lewin	Massachusetts Institute of Technology
J. Lord	University of Washington
N. Louisnard	ONERA, France
F. Low	University of Arizona
K. Mauersberger	University of Minnesota
S. McBride	University of California
M. McFarland	NOAA
R. Menzies	Jet Propulsion Laboratory
J. Ormes	Goddard Space Flight Center
T. Parnell	Marshall Space Flight Center
M. Pelling	University of California, San Diego
L. Peterson	University of California, San Diego
D. Rabus	University of Munich
E. Reed	Goddard Space Flight Center
P. Richards	University of California
C. Seaman	Jet Propulsion Laboratory
A. Scheepmaker	University of Lieden, The Netherlands
A. Schmeltekopf	NOAA
V. Schoenfelder	Max-Planck Institute
B. Teegarden	Goddard Space Flight Center
M. Thompson	University of Durham, England
W. Traub	Smithsonian Observatory
R. Van Duinen	University of Groningen, The Netherlands
G. Villa	University of Milan, Italy
F. Witten	Goddard Space Flight Center
S. White	University of California, Riverside
R. Zander	University of Liege, Belgium

ATD Director's Office

Diane Eulian
Clifford Murino (Director)
Harry Vaughan III

Research Aviation Facility

Lawrence Abbott
Harold Barber
Edward Brown
Jacques Brun
Robert Burris
Robert Carl
Celia Chen
Mary Dick
Margaret Earley
Carl Friehe
Keith Griffith
Peter Hildebrand
Melinda Johnson
Terry Kelly
Alex Kennel
Annabelle Kintz
Dennis Knowlton
Donald Lenschow
James Lundahl
David McFarland
Roger McIntosh
Thomas McQuade
Clay Orum
Byron Phillips (Manager)
Charles Purdy
Reiko Raese
Ronald Ruth
Paul Spyers-Duran
John Stone
Gilbert Summers
George Tate
Richard Taylor
William Whelpley
Lester Zinser
M. Norman Zrubek

Computing Facility (as of 31 December 1979)

Jeanne Adams
John Adams
Daniel Anderson
Mary Bartels
Julia Bartram
Linda Besen
Gerald Browning
Mary Buck
Steven Chapel
Beverley Chavez
Betsey Chen
Bang-Yaw Chin
Frederick Clare
Ann Cowley
Willard Crittenden
Sylvia Darmour
Glen Davenport
Astrik Deirmendjian
Cynthia Del Pizzo
Benedict Domenico
John Donnelly
Margaret Drake (Acting Manager)
Dora Fahey
Salvador Farfan
Dean Frey
Karen Friedman
William Frye
David Fulker
Sandra Fuller
Bonnie Gacnik
Nancy Goldstein
Gilbert Green
Kenneth Hansen
Sue Hartter
Lofton Henderson
Stuart Henderson
Michael Hendrickson
Darrell Holley
Barbara Horner
Suzanne Hunter
Basil Irwin
Jesse James III
Roy Jenne
Sue Jensen
Sara Jones
Dennis Joseph
Wanda Keeney
David Kennison
David Kitts
Robert Lackman
Sara Ladd
Richard Lindenmoyer
Stephen Long
Jack Martindale
Stan McLaughlin
John Merrill
Pamela Moore
Donald Morris
Paul Mulder
Cindy Myers
Marc Nelson
Robert Niffenegger
Bernard O'Lear
Barbara Ostermann
Richard Oye
Harsh Passi
Percy Peterson
Vickie Pinedo
Herbert Poppe
Russell Rew
Cicely Ridley
Andrew Robertson
Paul Rotar
Richard Sato
Susan Schemel
Eugene Schumacher
Gwelda Scohy
Larry Scott
Valerie Shanahan
Robert Smith
John Snyder
Wilbur Spangler
David Strayer
Wallace Swanson
Paul Swarztrauber
Linda Thiel
Mary Trembour
Alfonso Trujillo

Richard Valent
Colleen Velie
Fred Walden
Jo Walsh
Gregg Walters
Gloria Williamson
Marie Working

Field Observing Facility

Gerald Albright
Harold Baynton
Richard Bobka
Robert Bowie
William Bragg
Fred Brock
Richard Carbone
John Cupp
Dana Dixon
Edward Elsberry
Gerald English
Don Ferraro
Charles Frush
Grant Gray
Peter Hildebrand (to 1 July 1979)
Arthur Klittnick
Robert Lee
Brian Lewis
Robert McBeth
John McCarthy (long-term visitor)
John Militzer
Steven Semmer
Robert Serafin (Manager)
Joseph Vinson
Billie Wheat
James Wilson

Research Systems Facility

Development

Victor Borgogno
Robert Brown
Arden Buck
Phyllis Carlson
Harold Cole
P.K. Govind
Dean Lauritsen
Bryan Lee
Bernice McCain
Kenneth Norris
Julian Pike
George Saum
Justin Smalley

Engineering Services

Edgar Aden
Page Baptist
John Beeby
Dee Forest Fisher
Henry Geisert
Gilbert Granger
James Guenther
Alvin Helfrich
Marvin Hewett
Charles Hodge
Michl Howard
Paul Johnson
Edward Lambdin
Ivan Lee
Edwin Lozada
Hayden Mathews
Dale McKay
Earl Morrison
Michael Moxey
Lynn Post
Dale Smith
Russell White
William Zelt

Management/Administration

David Bargen (Manager)
Carol Nicolaidis
Mary Ann Pykkonen

Global Atmospheric Measurements Program

Neil Carlson
Vincent Lally (Project Leader)
Nancy Leach
Ernest Lichfield
Claude Morel
Michael Olson (to 12 January 1979)
Ranjit Passi
A. Brewster Rickel
Chris Roark
Aubrey Schumann
Sigvard Stenlund
Jack Tefft
Marcel Verstraete

Special Project Staff

Jean Ebel
Paul Howes
Bernice McCain
William Whelpley

Visitors

Neil Nevils
Alan Plunkett

National Scientific Balloon Facility

John Bennett
Charles Burris
James Carroll
Grady Cole
Robert Collett
Oscar Cooper
Ron Costlow
Alice Cradler
J.R. Crocker
Bruce Cunningham
Harold Dean
Danelle Dickens
Lawrence Farley
Atlee Fritz

Bettie Furman
Jim Gesin
Mack Gore
Rodger Graham
Dennis Gray
Arthur Gusa
Ralph Harju
Ricky Harper
Billy Harrison
Clarence Heide
Delbert Hoefling
Lawrence Huffman
Johnny Mack Ingram
Theo Johnson
David Kent
Robert Kubara
Lloyd Lasiter
Jarvis Lehmann
Danny Masur
Harry Morris
Charles Palmer
Robert Perrin
Michael Poarch
Javiel Quintanilla
Mary Beth Reno
Bert Ricard
Marvin Riley
James Rotter
William Schumacher
Alfred Shipley (Manager)
Titus Sigler
Delwyn Sims
Earl Smith
John Sparling
Virgil Vice
Emmer Woodard
Homer Woody
Nuel Woolverton
Boyce Worley

PUBLICATIONS

Publications of NCAR staff and visitors that either appeared or were accepted between 1 January and 31 December 1979 are listed below. Because of a change in the reporting period of the *Annual Scientific Report* (which previously extended to 31 March 1979), some of the publications may be repeated from last year's report. They are cited again to ensure completeness of the list for the new reporting period. Coauthored publications whose authors are affiliated with more than one NCAR division are listed only once, according to the division of the first author. An asterisk indicates a non-NCAR coauthor.

Atmospheric Analysis and Prediction Division

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