National Center for Atmospheric Research
Annual Scientific Report
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(continued)

INTRODUCTION

The purpose of NCAR's Annual Scientific Report is to provide our federal sponsor, the National Science Foundation, with an account of scientific and facilities programs at the center during the past year, in accord with requirements of the prime contract for the operation of NCAR. The report thus discharges part of our responsibility to NSF to account for the use of public funds. It is also intended to provide background material for NSF's assessment of the program plan we present them for the coming fiscal year.

This report presents, in scientist-to-scientist language, a concise account of nearly all the research activities by resident and visiting scientists and facility groups during the past year. We therefore hope it will serve our colleagues in the atmospheric sciences as an indicator of the work we do, so that if they want to delve more deeply, they will know whom to contact.

Because the document tracks the work of individuals and small groups within NCAR--in order to be as comprehensive as possible in a report of manageable size--the web of research interactions among NCAR scientists and between us and the scientific community may be somewhat underplayed.

NCAR's major mission is to serve as a point of attack on fundamental problems of the atmosphere. We pursue this mission through:

- High-quality research carried out by the NCAR staff
- Collaborative efforts among NCAR scientists and university colleagues
- Organization of and participation in major national and international programs, many of which require extensive field experiments and data reduction
- Facility support to the atmospheric science community in field work, data handling, and large-scale computational tasks
- Visitor programs, colloquia, and workshops designed to identify major problems requiring concerted, long-term research; to plan collaborative programs where they are appropriate; and to allow individuals to determine how best to link their own research interests with the major challenges facing the science.

The practical imperatives pushing atmospheric research will be well known to nearly all who see this report: energy development, water supply, protection of the environment, and world food strategies. We must be sure that policy makers are fully aware of the research still to be accomplished before we can realize the full potential of atmospheric science in dealing with such problems. The long-term prospects are good, but there is a tough, intellectually challenging road ahead that demands incisive, imaginative, persistent effort.

Because so much of the work reported here involves university colleagues and other collaborators, our special thanks is due them.

Much of the work reported here was guided by my colleagues and predecessors in management, Francis Bretherton and John Firor, for whose friendship and wise counsel I am greatful. They head a long list of people who deserve the credit for the work reported here, and with whom I am proud to be associated.

Wilmot N. Hess
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, we deal 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. 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 much fidelity as existing observations allow, and to specify the accuracy of prediction that is attainable under the 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 program objectives or to subject areas that define a homogeneous group of subproblems, rather than a particular kind of approach. Thus, the administrative components of AAP are:

- Mesoscale Research Section (Lilly; Wyngaard, acting)
- Climate Section (Dickinson)
  Cloud-Climate Interactions Group (Ramanathan)
  Empirical Studies Group (Newton)
  Global Climate Modeling Group (Washington)
- Large-Scale Dynamics Section (Kasahara)
- Oceanography Section (Holland)

The activities of the research staff of AAP are complemented by the work of university visitors at NCAR and by various joint undertakings; this 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 1980 to January 1981, which describe that work in some detail. It is appropriate, however, to preface this account with a brief discussion of highlights of the past year's research.

Research Highlights

Perhaps the most important development in large-scale atmospheric analysis and prediction during the year was the remarkable improvement in forecast skill exhibited by the European Centre for Medium Range Weather Forecasts (ECMWF) in Reading, England. Compared to many other research and operational models, the ECMWF grid-point and spectral models have added about two days to forecast range. Thus, for example, their forecasts at five days have skill comparable to that of other models at three days.

The improvement appears to have come mainly from the increased model resolution available with the CRAY-1 computer and from a better initial state. It is the latter, providing about one day of the improvement, to which we have made significant contributions through work on analysis and initialization.

Paul Julian of the Climate Section, on a visit to ECMWF, developed many aspects of the analysis procedures for the Global Weather Experiment and for the ECMWF operational analysis cycle. David Williamson of the Large-Scale Dynamics Section, on an earlier visit, had introduced into the ECMWF model the nonlinear normal mode initialization (NLNMI) methods the development of which continues to be a major emphasis of research in that section. The NLNMI procedure has greatly improved the initial state, both directly by ridding it of gravitational wave components and indirectly by providing far better forecasts during the first day into which to assimilate new observations in the analysis cycle.

Gratifying as this practical success has been, we are more excited about the new insights being provided by NLNMI and the related bounded derivative method in understanding the basic nonlinear dynamical balances found in the atmosphere. These insights have contributed much to the progress described in the report of the Large-Scale Dynamics Section.

There has been considerable progress in the Mesoscale Research Section during the year in understanding the vorticity dynamics of convective storms through use of a three-dimensional numerical cloud model, analyses of multi-Doppler radar data, and theoretical analysis. By successively focussing with greater resolution on extreme vorticity regions in the model, we have been able to study the mechanisms which produce tornadoes. This is providing us with important new insights into one of the most destructive of weather phenomena.

Although the detailed prediction of severe storms and the tornadoes they produce remains elusive, we made progress during the year in understanding the role of larger scale environmental conditions on the overall structure and lifetime of storm cells. There are obvious potential applications in improved probabilistic prediction of severe storms.

The transfers of heat, momentum, water vapor, and other substances between the atmosphere and the earth's surface are important on all space and time scales of atmospheric behavior. These transfers take place through the highly complex and variable planetary boundary layer, the study of which is an important component of the Mesoscale Research Section program. We have made much progress this year in analysis of the Air Mass Tranformation Experiment (AMTEX) and the Stratocumulus Experiment (STRATEX). Our particular concern has been the understanding of cloud-topped boundary layers. These have important climatic consequences through their influence on the earth's radiation budget.

The role of clouds in the climate remains one of the major sources of uncertainty in predicting the sensitivity of the climate to various changing influences such as CO_2 amount. Part of the difficulty is that we do not know accurately the fractional cloud cover on different levels of the real atmosphere. The newly named Cloud-Climate Interactions Group of the Climate Section is tackling these problems through the use of satellite data. We have made progress this year in identifying limitations of earlier infrared sounding techniques for low-level clouds and in developing a new technique for determining small-scale cloud cover fractions from analysis of radiance mean versus variance diagrams.

A principal concern of the Empirical Studies Group of the Climate Section is the identification in climate records of the important modes of climate behavior. One of the most important is the Southern Oscillation and we have made progress during the year in identifying its global influences. In particular, we have identified the small but significant contribution it can make to seasonal predictions in parts of the United States.

A principal activity during the year has been the initiation of the Community Climate Model (CCM) project. Our goal for this project is to provide the research community with a basic climate model with more emphasis on documentation and reliability then on physical embellishments. Work during the year led to the definition, in January 1981, of our starting point, Model Zero, as a global spectral transform atmospheric model with realistic topography and computed clouds interacting with radiative transfer. Model Zero simulates 30 days per hour of CRAY computing time, and we find from simulations of several hundred days' duration considerable realism in jet stream and storm track behavior.

At the CCM Organizational Meeting in December 1980, involving NCAR and university participants, three developments toward Model One were considered to be most important. These were the introduction of annual cycle capability, improved surface hydrology, and coupling to an ocean model. We are making progress on all three, and we shall probably include them in a Model One within a year. The role of the ocean in climate is so important that it must be included in any true climate model.

The ocean is responsible for a significant part of the heat transport between the equatorial regions and higher latitudes that maintains the global energy balance. The work of the Oceanography Section continues to focus on understanding the basic dynamical processes in the ocean that are responsible for this heat transport. We have made considerable progress during the year in understanding the way in which the oceanic surface mixed layer interacts with and influences the atmosphere. The coupling of the mixed layer and the intermediate water beneath it can induce time delays of several decades in the response of the climate to changing CO_2 concentrations.

As can be seen from this summary of AAP research highlights, we are studying the climate as a complete dynamical and physical system with many complex interactions to be elucidated.

AAP Division Office

During the year, Jackson Herring engaged in three principal research efforts in fundamental turbulence theory: (1) investigation of available numerical techniques for implementing spectral closures, (2) development and use of the numerical code for direct numerical simulation of thermal convection, and (3) further research on a passive scalar (contaminant) convected by turbulence. Herring attended the LaJolla Institute Workshop Conference on Research Requirements for Advanced Computer Design, 5-6 August 1980, presenting a paper entitled "Large-Scale Turbulence Calculations in Geophysical Flow."

The numerical implementation of spectral closures can proceed either as a Galerkin or collocation method. The former has the advantage of preserving exact conservation properties and has been employed by a number of authors (Kraichnan, Leith, Andre and Lesieur, Lesieur and Schertzer, etc.). It is easily implemented but only for rather simple histogrammic functions. On the other hand, collocation can be extended to more satisfactory basis functions and is more flexible. It does not retain conservation properties. In January 1980, Herring began a systematic study comparing the two methods, utilizing B-splines as basis functions. The work was stimulated by Daniel Schertzer's (Directions de la Meteorologie, Paris) visit to NCAR. The results of this investigation, now being prepared for publication, show rather conclusively that the collocation method has clear advantages, especially for the study of inhomogeneous flows.

Substantial research effort has gone into developing and implementing the thermal convection code. Herring undertook this project in collaboration with Steven Orszag (MIT) with the goals of understanding (1) the onset of turbulence in convection, (2) the turbulence parameterization (i.e., that of Launder, Lumley, Lilly and Deardorff, etc.) as applied to convection, and (3) the nature of convective transport at low (astrophysical) Prandtl numbers. In goal (1), we have been joined by James Curry (University of Colorado). Also, interactions with Eric Siggia (Cornell University) were most productive in code development. The work on phase (1) is now nearing completion. What seems to have emerged is that the onset to chaotic behavior takes place via a transition to three-dimensionality; two-dimensional chaotic behavior of low-order spectral systems seems to be an artifact of truncation.

The work on the passive scalar problem has been extended to include a comparison of test field model (TFM) and direct interaction approximation (DIA) closures to direct numerical simulations (DNS), the latter being implemented by Robert Kerr (graduate student from Cornell University). In addition, Herring has completed a study of the scalar time scale, comparing predictions of TFM to the heuristic theory of Corrsin and others. This will be presented at the meeting of the American Society of Mechanical Engineers, Fluid Mechanics Session, in

June 1981. The numerical comparison of TFM to DNS suggests more accuracy for the TFM than previous comparisons to wind tunnel data suggested. However, there seems to be a significant discrepancy between theory and numerical experiment in the far dissipation range. This may be a result of intermittency, and strong non-Gaussianity there. We are examining this point now.

Cecil Leith has continued his investigations into the properties of the slow manifold generated by the NLNMI procedure. He has extended Tribbia's analysis of a shallow water vortex which gives the simplest possible slow manifold to show that a patch on the manifold may be unstable and radiate gravitational waves. He has also analyzed theoretically the problem of combining optimal statistical analysis procedures with the nonlinear constraints of NLNMI. Here he showed how first to map observations linearly into a probability distribution in a model phase space and then to define an optimal state on the slow manifold.

MESOSCALE RESEARCH SECTION

Administration and Planning

The Mesoscale Research Section (MRS) included on 31 December 1980 six Ph.D. scientists and seven supporting staff. Most MRS research activities are oriented around the study of buoyancy-driven or buoyancy-controlled atmospheric motions, including thermal convection, waves, and turbulence in the troposphere. MRS has been under the direction of Douglas Lilly since its inception in 1978, with John Wyngaard serving as acting head during Lilly's absence for most of 1980. During 1980 MRS kept one long-term (12 month) visitor position filled and had 16 short-term visitors with stays ranging from one week to three months.

In the area of managing and supporting large field programs, Lilly served as chairman of the steering committee for Project SESAME (Severe Environmental Storms and Mesoscale Experiment), and he and Wyngaard continue as members of that committee. At present Joseph Klemp and Lilly are involved in planning for ALPEX (Alpine Experiment), a study of airflow over the southern European mountains.

Research efforts within MRS have been greatly aided by the acquisition and use of a VAX 11/780 minicomputer system. This computer has a computing speed which is about 1/7 that of the Control Data 7600 and currently contains three megabytes of memory and 300 megabytes of disk storage. Software development by the system manager, Raymond Bovet, has provided a powerful text editor, a flexible remote job entry link to the Mesa computers, and interactive graphics capabilities which allow use of all NCAR computer graphics.

Severe Storms Research

Convective Storm Research. The MRS convective storm research is directed principally toward understanding the important mechanisms governing storm processes, determining and improving the ability to simulate observed storm features numerically, and investigating the interactions of storms with the larger scale environment. These topics are being addressed through the use of three-dimensional numerical modeling, analyses of multi-Doppler radar data, and quasi-analytic modeling of storm processes. Because of the great complexity of convective storms our research requires coordinated efforts which combine a variety of talents. Within MRS the contributing personnel are Klemp, Richard Rotunno, Lilly, and Morris Weisman. Other collaborations are maintained primarily through a Cooperative Observational and Modeling Project for the Analysis of Severe Storms (COMPASS) which includes, besides MRS staff, Robert Wilhelmson (University of Illinois), Peter Ray and Carl Hane (National Severe Storms Laboratory), Tzvi Gal-Chen (NASA), and Jerry Stephens (Florida State University).

A major emphasis of recent storm modeling conducted by Klemp has been focused on the tornadic supercell storms which occurred in central

Oklahoma on 20 May 1977. Several storms were simultaneously observed by up to four Doppler radars and are being analyzed in collaboration with Ray and Wilhelmson. A detailed investigation of one of these storms through the interactive use of Doppler radar analyses and numerical simulation reveals certain important storm features which are essential to maintaining its longevity and which promote the storm's transition to its tornadic phase. These features are strongly influenced by the rotational character of the storm, which allows precipitation to be separated from the updraft and orients the resulting downdrafts in a manner which reinforces low level convergence along the gust front to sustain the storm. The similarities in structure between the observed and the simulated storm suggest that the larger scale environment plays a dominant role in structuring even many of the detailed features of the storm.

Trajectory studies for this storm reveal in detail how the air and precipitation move through the storm during its mature phase. A striking result from this study is that air rising through the updraft turns anti-cyclonically with height in spite of strong cyclonic vertical vorticity through most of the updraft. The explanation for the result is currently being investigated by Lilly, Klemp, and Rotunno based on comparisons of a simplified solution to the vorticity equation with the full model simulation. These analyses of simulated and observed storm structure are greatly facilitated by the interactive capabilities of the MRS satellite minicomputer which has played a vital role in our storm research.

A study was undertaken during 1980 by Weisman and Klemp to assess the relative importance of environmental wind shear and potential instability in determining the overall storm structure and the ability to produce long-lived storms. These efforts have documented that for a given stability profile there is an optimal wind shear capable of producing a more intense and long-lived storm. By varying both the wind shear and potential instability it appears that the overall storm intensity and structure can be characterized in terms of a bulk Richardson number quantity.

An important goal of the MRS research is to understand the storm-scale features which are required to generate tornadoes and the processes by which vorticity is amplified to tornadic proportions. As part of this effort Klemp and Rotunno have been conducting high resolution simulations within the central portion of a previously simulated mature thunderstorm. In this manner smaller scale structures are resolved, particularly in the vicinity of the gust front, which are qualitatively very similar to observed storms in their tornadic phase. Vorticity studies reveal how large vorticity (order 10^{-1} s^{-1}) can be generated through the interaction of tilting and stretching processes, although further studies are needed to identify the actual sources of tornadic vorticity. These simulations in the vicinity of a tornado are the first ever conducted in a realistic storm environment.

In seeking to understand further this nature of tornadoes, Rotunno has conducted numerical simulations of vortex flows produced in a laboratory experiment which are believed to be particularly relevant to actual tornadoes. Earlier studies with an axisymmetric model documented the character of the vortex as a function of the intensity of rotation and the factors leading to vortex breakdown. During the past year a three-dimensional model was used by Rotunno and Lilly to study the flow asymmetries which occur in the laboratory vortex flow which produce multiple vortices. The model is successful in producing smaller circulations within the parent circulation. The multiple vortex does appear to originate through the instability of a vortex sheet. Its structure is highly asymmetric, with the circulation centered on the strong gradient of vertical velocity of the parent circulation. Rotunno has also been supervising Timothy Wilson's (University of California, Davis) master's degree investigation of vortex boundary layers which strongly influence the maximum winds generated within the low level vortex.

Mountain Wave Research. During 1980, Klemp and Lilly have supervised the Ph.D. thesis research of Dale Durran from MIT, who is a graduate assistant in the Advanced Study Program at NCAR. In this study the effects of latent heat release on the dynamics of mountain lee waves have been examined by numerical simulation. Resonant lee waves are investigated in three cases in which the atmosphere has a two-layer vertical structure. Changes in the moisture can produce three significant effects. Resonant waves in an absolutely stable environment can be distorted and untrapped by an increase in moisture. Resonant waves in a convectively unstable layer can be destroyed by an increase in moisture. Resonant waves in a moist environment can be detuned by a decrease in moisture. In all cases it is inappropriate to approximate realistic moisture profiles by assuming that some "moist" layer always remains saturated.

Lilly, Klemp, and Durran have continued to assist in the planning of ALPEX and to prepare for participation in the field program next winter. This experiment offers a unique opportunity to observe the mountain wave characteristics produced by an important mountain range.

A primary goal of MRS participation in ALPEX will be to describe the momentum transports which are produced by mesoscale (and smaller) mountain waves, in order to determine the effects of orographic drag on synoptic-scale weather patterns. A second goal of our work will be to investigate the mountain wave dynamics which can produce violent winds (the foehn and bora). We propose to accomplish these tasks by comparing several theoretical models, in order to understand the atmospheric physics which produce mountain wave drags and downslope winds. We anticipate that Lilly, Klemp, and Durran will conduct this research, with the latter two participating in the field experiment.

Boundary-Layer Research

The MRS boundary-layer research program is a fairly fundamental one, emphasizing the understanding of the basic structure and dynamics of boundary layer flow and its parameterization for applications. The users of such parameterizations form a very broad community which includes air quality meteorologists, meteorological modelers, wind engineers, and agricultural meteorologists. A fundamental program is appropriate to serve such a broad constituency.

The MRS boundary layer structure and parameterization research relies heavily on the analysis of data from aircraft-based measurement programs. A good example is the February 1975 Air Mass Transformation Experiment (AMTEX). This international GARP experiment included nine NCAR Electra flights (directed by Donald Lenschow) over the East China Sea during cold air outbreaks from Asia. The boundary layer was fairly convective, quite baroclinic, and capped by a strong inversion having jumps in both potential temperature and humidity, and thus quite representative of common daytime cases. While the large-scale flow was inhomogeneous, the turbulence structure was effectively homogeneous and steady, making its analysis and parameterization a manageable and meaningful undertaking.

The series of publications based on AMTEX data has extended considerably our understanding of the convective PBL. Lenschow and Wyngaard have deduced and parameterized the behavior of several of the second-moment budgets important in second-order turbulence modeling, making it possible to examine critically some of the closures in such models and to test model predictions. Wyngaard and Margaret LeMone have used the AMTEX data, as well as data from the GARP Atlantic Tropical Experiment and other experiments, and a simple closure of the scalar mean-field equations to develop accurate parameterizations for the refractive index structure parameter, the flow property most directly related to the scattering and distortion of electromagnetic waves. These parameterizations are valid from the surface to the top of the inversion layer, and are useful in both wave propagation and remote sensing applications. The authors suggest, for example, how their results can be used to infer properties of the inversion lid from remote scattering measurements. Lenschow and Pamela Stephens (National Science Foundation) have used the AMTEX data to investigate the structure of convective plumes, which transport most of the heat, moisture, and momentum in the convective boundary layer.

Lenschow and Borislava Stankov, in cooperation with Leif Kristensen (Risø National Laboratory, Denmark), have continued to analyze data from a series of aircraft formation flights. The two NCAR Queen Air aircraft were flown at approximately constant separation distances (both vertical and lateral), which were measured by combining photography with inertial navigation information. Calculations of coherence, which is the extent to which measurements from one aircraft agree with those from the other at varying separation distances, have been made for the three air velocity components and temperature.

Lenschow and Stankov are also analyzing data from the SESAME Nocturnal Boundary Layer Experiment. Several cases were selected for detailed study by the participants in this experiment, which also includes Lawrence Mahrt (Oregon State University), David Emmitt (University of Virginia) and Jan Paegle (University of Utah).

Richard Brost, working with Lenschow, Lilly, and Wyngaard, has spent much of his time since joining MRS in late 1979 in processing and analyzing data from five 1976 STRATEX flights in the cloud-topped boundary layers off the west coast of California. Wayne Schubert (Colorado State University) was principal investigator during these flights, and the research team also included Steven Cox (CSU), Lilly and Lenschow, and Robert Knollenberg (Particle Measuring Systems, Boulder, Colorado). The results indicate that in several cases the mixed layer below the stratus was not maintained by cloud-top cooling, as is sometimes assumed, but instead by shear production of turbulent kinetic energy. In these cases the mixed-layer resembled more nearly an inversion capped, baroclinic, neutral PBL than a buoyancy-driven layer. These studies, and their implications for cloud-topped PBL models, are summarized in a pair of manuscripts now in preparation.

MRS researchers are pursuing methods of improving the accuracy of boundary-layer measurements and developing new sensors. In the first area, Wyngaard has developed a theory for the effects of probe-induced flow distortion on turbulence measurements and plans to apply the theory to aircraft measurements in order to assess the adequacy of current boom designs. Wyngaard and Gal-Chen are determining the accuracy of vertical velocities measured from radars through the continuity equation technique. In the sensor development area, Lenschow and Stankov, in collaboration with Richard Pearson and Donald Stedman (University of Michigan) and Anthony Delany (Atmospheric Chemistry and Aeronomy Division), have utilized a sensitive fast-response ozone sensor on an NCAR Queen Air aircraft to measure turbulent ozone flux in a variety of situations. In an experiment over eastern Colorado, the aircraft measurements demonstrated that the observed increase with height in mean ozone concentration was due almost entirely to photochemical production of ozone in the lower part of the boundary layer. During the Pawnee Grasslands Experiment, which was a study of chemically active trace atmospheric constituents in the boundary layer over northeastern Colorado, both aircraft and concurrent tower measurements were obtained over range land away from major anthropogenic sources. These observations are now being analyzed. The airplane was also flown from Colorado to the Gulf of Mexico to measure surface ozone destruction over a variety of land surfaces and the ocean. The ozone deposition velocity over the Gulf of Mexico was measured to be 0.07 to 0.08 cm s^{-1}.

The MRS boundary-layer group is currently investigating some fundamental aspects of eddy diffusivity (K) and second-order closure modeling. The K research, motivated by its inevitable use in large-scale models, is being done in an attempt to learn under what PBL conditions the K-parameterization for turbulent stress is valid. Results to data indicate it holds under very convective conditions. One aspect of this research is a study of wind shear in the baroclinic, convective PBL; Wyngaard has developed a simple K-parameterization for this case which depends only on global PBL parameters, and its predictions are now being tested against observations. The objective here is a simple parameterization for wind shear throughout the baroclinic, convective PBL, which is the usual daytime state.

Recent studies by Brost and Wyngaard on the applicability of second-order modeling to convectively driven turbulence have shown that contemporary parameterizations for pressure covariances and dissipation rate do not perform well in convection. These are fundamental obstacles to the improvement of second-order models for application to the convective PBL, and we have concluded that future research here should concentrate on three-dimensional, large-eddy-simulation modeling.

Although relatively less is known about the structure of the stably stratified PBL, the data that exist are consistent with predictions of second-order models, for example, with those of the Brost-Wyngaard model. John Garratt, an MRS long-term visitor, has been using that model to study the influence of radiative flux divergence on the structure and evolution of the nocturnal PBL. He has found that its principal effect is in the temperature structure above the nocturnal boundary layer; the Richardson number, for example, can be driven to large values. This can modify strongly the gravity wave behavior there, and affect the large-scale coupling between the boundary-layer and topography, aspects which remain to be investigated.

CLIMATE SECTION

Introduction

The activities of individual groups are reported in the following segments. Here we provide a brief overview of the activities of the individual groups, and comment on those activities within the Climate Section that do not fall within their scope.

Climate research at NCAR over the last six years has established a well deserved international reputation as result of the excellent innovative research and scientific leadership it has provided to the community. The general role of the Climate Section is to carry out research on selected topics that we believe are crucial to furthering our knowledge of the climate system and applying this understanding to national needs. Our current research necessarily covers a wide range of such topics. However, we currently have three principal areas of activity. These are (a) the interconnections of natural climate fluctuations on time scales of seasons to decades, (b) the formation of clouds on climatic scales and the consequent radiative feedbacks, and (c) the application of three-dimensional global climate models to examining the sensitivity of the climate system to its various components and to external forcing. The Climate Section is divided administratively into three groups which are each responsible for one of these areas. These are, respectively, the Empirical Studies Group (ESG), the Cloud-Climate Interactions Group (CCIG, formerly the Climate Sensitivity Group), and the Global Climate Modeling Group (GCMG).

Our present program is modest in size but lies at the core of the National Climate Research Program and must remain closely in touch with the variety of research activities on climate carried out elsewhere.

In considering the reports of individual groups, the following highlights should be especially noted. The work of ESG in relating the southern oscillation to mid- and high-latitude variations may provide a general framework for describing many of the most important atmospheric teleconnections, such as in particular the associations between North Pacific Ocean temperature anomalies and U.S. West Coast climatic anomalies. The southern oscillation appears to lead the other variations as indicated by significant lag correlations for as much as a year in advance. The question as to whether these insights can provide improved tools for climatic forecasting is being tested. In any case the current studies should help inspire further theoretical studies attempting to describe the spatial interconnections between different parts of the troposphere and stratosphere.

Second, there has been a flurry of activity directed at a better understanding of the transient climate response to changes in external forcing. Stephen Schneider and Starley Thompson (student, University of Washington) have shown in the framework of a two-dimensional energy balance model that the latitudinal variation of the transient signal differs significantly from the final steady state pattern. In particular, they find a smaller ratio of high-latitude to low-latitude temperature change during the transient evolution of their model than is obtained after the eventual steady state is reached. V. Ramanathan has studied the feedbacks between water vapor and radiation that are required to obtain a correct steady state response to a carbon dioxide anomaly. Roland Madden and Ramanathan have considered the question of resolving the current and near future carbon dioxide warming from the noise of natural climate variations. Robert Dickinson has developed analytic solutions for a one-dimensional climate model with two ocean layers to examine numerical errors associated with various possible schemes for coupling an atmospheric to an oceanic model. Schneider has been working with L. Danny Harvey (student, University of Toronto) to further examine coupling scheme errors in the context of simple numerical models.

Dickinson has continued his work introducing into the grid-point model surface hydrological processes and has made initial attempts to relate them to plant growth procedures. He has worked with Richard Wolski and Bruce Briegleb at obtaining within a general circulation model large-scale drainage basins and hence river runoff. The runoff is needed as input to ocean models.

John Geisler (University of Miami) has carried out studies with a linear model of the Walker circulation. For the purposes of this model study the Walker circulation was defined as the steady response of a stratified atmosphere to an isolated equatorial heat source. The results showed that the overturning cell in the equatorial plane east of the heating is weaker than the overturning cell in the equatorial plane west of the heat source but of much broader longitudinal scale. The results also showed that the meridional circulation at and to the east of the heating has a sign opposite to that of the Hadley cell (i.e., the low level meridional flow is directed poleward).

Empirical Studies Group

The ESG extended the calculation of climatic statistics and studies of interrelations among climatic features in various regions, eddy heat flux and large-scale wave characteristics, detection of induced climate change against natural variability, and the mechanics of current systems.

Eddy Heat Transfer in the Southern Hemisphere. Knowledge of the magnitude of meridional energy transfer by waves and eddies, and of the time variations of this transfer, is essential for understanding the atmospheric general circulation and for assessing the validity of climate model results. Variations of eddy heat transfer have also been related to zonally averaged and regional climate variations. Eddy transfers are poorly established for the Southern Hemisphere, and it is desirable to identify data sources suitable for their calculation.

Harry van Loon computed the eddy transfer of sensible heat in the Southern Hemisphere with data from the Australian and NMC daily analyses to assess their value for flux computations and for other uses requiring correct daily analysis at single points. The data were not suited for the purpose as they produced transient-eddy fluxes about 50% below the actual value, mainly because their accuracy declined with distance from the few observing points. In the Australian analyses, vertical consistency was not good and the differences between six-year averages at the two synoptic hours were not passable. In addition to the spatial bias, NMC analyses gave an eddy transfer which was only half the actual one and whose peak was located well on the equatorward side of the jet stream in the zonal average. The appraisal of the analyses included five months of the FGGE.

<u>Southern Oscillation and Global Teleconnections</u>. G.T. Walker's "southern oscillation" concept is based on the correlation between sea-level pressure at a given location and that of other places over the globe. It thus affords a framework for examining anomalies of circulation patterns and climatic anomalies associated with them, and the "teleconnections" among different regions. Both enhanced data availability and access to the computer make it possible to greatly extend the worldwide correlations.

Van Loon is working with Roland Madden and Jeffery Rogers (Ohio State University) on a worldwide description of the southern oscillation. So far, they have outlined the space and time scales in sea-level pressure and surface air temperature by means of spatial correlations and time spectra of seasonally averaged values of the elements. The study is being extended by Madden to estimate the possible value of the relationships for prediction. Rogers and van Loon are working on teleconnections within the Southern Hemisphere and have computed interesting connections with eigenvectors of sea-level pressure and 500 mb height. The differences in the stationary-eddy fluxes of sensible heat between the extremes of the southern oscillation have been outlined, as well as the further association between these differences and changes in wind, temperature, and transient-eddy fluxes in the troposphere. The data suggest that storm tracks in the Northern Hemisphere move poleward and equatorward with changes in the southern oscillation. The work on the southern oscillation is being extended to cover the winter stratosphere in the Northern Hemisphere.

<u>A Large-Scale Traveling Wave during FGGE</u>. Earlier ESG studies have established connections between the meridional transfer of properties, such as sensible heat, and the variations of large-scale waves. A continuing interest is determination of the observed physical properties of such waves, their dynamics, and the interactions among waves. Madden completed a paper which establishes the horizontal and vertical structure of a large-scale traveling wave which was present during January 1979 (SOP I of FGGE). This work was begun during a collaborative visit to the Freie Universität in Berlin in the fall of 1979.

Detecting Effects of Carbon Dioxide Increase. An important aspect of the connection between fossil fuel and possible climate change concerns our ability to detect a surface warming (due to carbon dioxide increase) if and when it occurs. During the year, Madden and Ramanathan completed the first quantitative study of this problem. They compared the warming that is predicted by current climate models as a result of increased levels of carbon dioxide to the observed interannual variability of temperature. They concluded that predicted changes will be easiest to detect in summer. In addition, they argued that the change should be detectable now if positive feedback models are correct or by the year 2000 if zero feedback models are correct. No warming is currently evident. The time for detection may be delayed by the thermal inertia of the oceans. Furthermore, it is possible that some other compensatory climate change is occurring.

Development of Climatic Statistics. An adequate description of the world climate should include not only means and standard deviations of monthly values, but also the skewness and kurtosis which describe how these monthly mean values are distributed. Dennis Shea has begun work on a surface climate atlas for temperature, pressure, and precipitation. Data from several new sources are being collected and subjected to various statistical checks to ensure their integrity. The new data will be merged with existing data (archived in the Data Support Section of the Scientific Computing Division) and various statistics will be computed and mapped. These include: the first four moments noted above, eigenvectors, spectral analysis of long station records, and statistically significant trends. Preliminary statistics have been provided to the GCMG to aid in verification of the NCAR climate model.

Variations of Atmospheric Angular Momentum. A matter of interest to "solid earth" geophysicists is the variation in length of a day associated with atmospheric changes. Shea collaborated with Raymond Hide (Great Britain Meteorological Office) and others in a study relating atmospheric angular momentum fluctuations to observed short-term variations of earth rotation.

Global Weather Experiment Analyses. Paul Julian's work this year was performed at the European Centre for Medium-Range Weather Forecasts (ECMWF), one of the two institutions committed to producing analyses of the Global Weather Experiment data. The various tasks were all concerned with the analysis-forecast scheme developed at ECMWF to produce synoptic analyses that serve as initial data for numerical forecasts or for diagnostic purposes. Julian's earlier responsibility for data production, for two of the special observing systems deployed in the tropics for the Global Weather Experiment, motivated his involvement in the use of these data. Specific principal concerns were with (i) developing observational error statistics for use by the analysis scheme, (ii) developing an algorithm for adjusting the altitude assignments for cloud motion vectors, (iii) monitoring the analyses to detect and correct problems and irregularities in the observations used, and

(iv) comparing the divergent portion of the analyzed wind field with convective cloud and satellite data. Reports on this work were given at the Committee for Space Research meeting in Budapest (June); the Symposium on Early FGGE Results, Bergen (June); and the Seminar on Data Assimilation Methods, ECMWF (September).

Since his return to NCAR in November, Julian has been examining constant-level balloon trajectories in equatorial latitudes which exhibit characteristics of inertial flow. Previous theoretical work concerning pure inertial trajectories in low latitudes, where constant coriolis acceleration cannot be assumed, has been used as a starting point for the investigation. However, owing to the desirability of including the possibility of constant-in-time superimposed geostrophic conditions, numerical integration techniques have been developed. While certain trajectory segments have all the attributes of inertial flow, it is not yet clear if these attributes are in fact unique and how often such inertial behavior occurs.

Julian and Shea completed (July 1980) processing the FGGE dropwindsonde data for SOP I and SOP II and the Winter/Summer MONEX dropwindsonde data.

Inertial and Gradient Wave Properties. Chester Newton has examined the general properties of waves characterized by gradient motion and those in which ageostrophic motions (quasi-inertial oscillations) are prominent. Owing to correlation between real and geostrophic wind in jet streaks (local speed maxima) in the high troposphere, velocity oscillations in the jet core commonly have periods about twice the inertial period. The mean winter subtropical jet stream was shown also to be a planetary (constant absolute vorticity) wave. Divergence on the flanks is related to jet streak dimensions and the size of ageostrophic motions. The summer low-level monsoon jet over the Arabian Sea was examined in terms of an inertial oscillation initiated by ageostrophic winds that result from channeling of the flow across contours by the African orography. An inertial trajectory, taking into account damping by friction and the mean eastward decrease of geostrophic wind across the sea, is compatible with the gross observed features of the monsoon jet. Inertial trajectory properties may be useful in understanding the linkage between wind variations over East Africa and short-term climate variations over India.

Analysis has been resumed on a channel-model numerical experiment on cyclogenesis and upper-tropospheric frontogenesis (with Anna Trevisan, University of Bologna). Extending the Bjerknes-Holmboe wave theory, this demonstrates the patterns of confluence and vertical motion, in a wave on an upper-tropospheric jet stream, which account for generally greater baroclinicity in wave troughs than in crests.

Books and Reviews. By spring 1981, van Loon should have finished editing volume 15 of World Survey of Climatology, Climates of the Oceans, apart from indexing and proofreading.

An overview on convective storm systems, invited by the Cooperative Institute for Mesoscale Meteorological Studies (University of Oklahoma), was completed by Newton. This summarizes climatological aspects of thunderstorms, various physiographic regions, relations to synoptic features and interactions with the environment, and the nature of organized convective systems. Newton also completed an invited article on squall lines for the Bergeron Memorial Volume.

Cloud-Climate Interactions Group

Introduction. In the past, CSG (now CCIG) has placed a strong emphasis on the study of physical processes that are relevant to climate sensitivity. The processes studied include ice-albedo, lapse-rate, and cloud and ocean-atmosphere feedbacks. Work in these areas has been described in earlier reports. Now, however, given the limited resources of the group, the approach is to concentrate efforts on selected processes which demand immediate attention. The work done during the past year in the area of cloud-climate interactions has helped to formulate future plans for more focussed efforts.

New efforts were initiated this year in the areas of: satellite retrieval of cloud cover and cloud optical properties, use of satellite data for climate model validation, and parameterization of boundary layer clouds in GCMs. We also continued our past work on energy balance models, aerosols, and radiative effects of snow and clouds.

Cloud Properties Retrieved from Satellite Infrared Sounder Data. James Coakley and Bruce Wielicki have completed a theoretical error analysis of retrieval methods that might be applied to infrared sounder data in order to recover the amount of cloud cover as a function of altitude. The analysis reveals that such retrievals may yield reliable estimates of upper level clouds ($P < 500$ mb) even when the clouds are nonblack at infrared wavelengths. On the other hand, the analysis shows that because of errors associated with instrument noise and with uncertainties in temperature and humidity profiles, the retrieved properties of low level clouds can be in serious error. Because of these results Wielicki and Coakley recommend that sounder data be used to retrieve only upper level cloud cover.

To obtain the properties of low level cover, Coakley and Francis Bretherton (Oceanography Section) have developed retrieval procedures that recover the cloud-top pressure and amount of singly layered systems from high resolution scanning radiometer data. Unlike commonly used threshold techniques, the new approach uses the spatial structure of the emitted infrared radiance field to detect and allow for partially cloud-filled fields of view. The scheme has been used to determine the height and amount of a low level stratus system off the California coast. This system was low enough that the retrieval schemes using sounder data failed in accordance with the theoretical studies of Wielicki and Coakley.

As part of his thesis research, Wielicki has also explored methods of estimating the 11 μm emissivity of clouds from sounder data and the influence of scattering in the infrared on the retrieved cloud properties.

Ramanathan and Coakley have become members of the ERBE (Earth Radiation Budget Experiment) Science Team, and additional personnel to support relevant efforts such as those of Coakley described above will be supported by NASA. Ramanathan's work in connection with ERBE is concerned with an examination in a detailed quantitative manner of the extent to which satellite measurements can be used for model validation and climate studies. This research has only just begun.

Climate Model Development. General circulation model radiation-cloud modeling has consumed roughly 50% of Ramanathan's time for the last three years, and some results obtained this year demonstrate the value of this effort. The model he developed in collaboration with Dickinson was incorporated by Eric Pitcher (University of Miami) in a spectral general circulation model. This led to a significant improvement in the spectral general circulation model simulation of zonal winds and a perceptible improvement in other dynamical quantities, such as sea level pressure, when compared with the model's simulation incorporating the Geophysical Fluid Dynamics Laboratory's radiation model. Ramanathan has carried out extensive further checking and cleanup of the radiation aspects of this model and has consequently eliminated several remaining errors. It is this model that has been selected as the Community Climate Model Zero.

A detailed parameterization scheme for cloud formation was incorporated into the NCAR grid-point general circulation model. The scheme distinguishes between precipitating and nonprecipitating clouds. A distinguishing feature of the parameterization scheme is the use of static stability, surface moisture evaporation, and lifting condensation level to predict boundary layer clouds. Based on a preliminary seasonal experiment with the general circulation model, the scheme simulates the qualitative features of observed marine stratocumulus and Arctic stratus. A simpler cloud parameterization scheme has been developed by Ramanathan for use in the spectral general circulation model, Model Zero.

Ramanathan has also developed a one-dimensional model which contains the surface physical processes included in general circulation models to examine the role of ocean-atmosphere interactions in determining the climate sensitivity. A completed study using this model helps explain why some recent studies found very little temperature change due to increasing carbon dioxide. This model also provides a good tool for experimenting with one-dimensional models.

Schneider and Harvey began an investigation of the problem of coupling climatic models with thermal relaxation times that differ by an order of magnitude.

Effects of Trace Gases and Stratospheric Aerosols on Climate. Ramanathan continued his past studies on the trace gas effects on climate but from a different angle this time. He examined the interactive nature of the problem, i.e., simultaneous effects of fossil fuel combustion, fertilizers, refrigerants, and propellants. Based on currently accepted growth rates for the various pollutants, his model calculations suggest that anthropogenic sources of trace gases other than carbon dioxide can contribute as much as 40% additional warming beyond that due to carbon dioxide.

To validate model calculations for the radiative impact of stratospheric aerosols, Coakley compared a record of diffuse and direct solar radiative flux measurements that included signals from the aerosol layer which formed after the 1963 eruption of Agung with theoretical calculations of the aerosol's impact. The comparison revealed that the post-Agung layer was capable of producing two to three times the tropospheric cooling suggested by the models. Owing to the large observational uncertainties, however, the possibility that the model results are realistic cannot be ruled out.

In collaboration with P. M. Kolesnikov (Luikov Heat and Mass Transfer Institute, Minsk) and Robert Cess (State University of New York at Stony Brook), Coakley developed a new two-stream approximation to evaluate the impact of stratospheric aerosols on the earth's energy budget. The study revealed that the wavelength and angular-dependent scattering by the earth's atmosphere greatly reduce the impact of the aerosol when compared with the single wavelength calculations, which employ a diffusely reflecting earth to model the aerosol's impact. The study also tested a simple yet accurate scheme for evaluating the radiative impact of stratospheric aerosols. Because of its simplicity, the scheme is suitable for incorporation into large climate models.

Research with Energy Balance Climate Models. Schneider and Thompson have completed their study of the variation with latitude of the transient response to increasing carbon dioxide in the atmosphere. In particular, they considered the effect of including a realistic lower layer. This refinement reinforced their conclusions, reported in the 1979 Annual Scientific Report, of the importance of the latitudinal distribution of thermal inertia as determined by oceanic mixing among large thermal reservoirs. This distribution of thermal inertia regulates the latitudinal transient response of surface temperature to external forcing such as the radiative effects of increasing carbon dioxide.

Schneider, Thompson, and Tamara Ledley (MIT) continued their development of an axisymmetric hydrodynamic glacier model for investigating simple thermodynamic parameterizations for snow and ice ablation and accretion, as well as for sea ice.

Theory of Scattering of Radiation. Warren Wiscombe's past year's work has focussed on three main subjects:

(1) The complex angular momentum method for approximating Mie scattering calculations, jointly with Moyses Nussenzveig (University of São Paulo), which will result in increases in the speed with which such calculations can be done. At the same time, the new formulations allow better physical insights into the scattering process.

(2) The effect of large drops in clouds on their optical properties, both for understanding the energy budget of clouds and for applications in remote sensing of precipitation, jointly with William Hall (Convective Storms Division) and Ronald Welch (University of Mainz). Using drop distributions generated by Hall's one-dimensional parcel model and two-dimensional dynamical model (which is more realistic), they have shown that the absorptivity of a cloud may increase by as much as a factor of three as the large-drop portion of the distribution evolves, and furthermore that the development of this large-drop mode results in a characteristic depression of certain albedo peaks in the near-infrared which may be detectable from satellites.

(3) The effect of a high snow-covered ice cap (Antarctica or Greenland) on the earth's radiation balance, jointly with Stephen Warren (Cooperative Institute for Research in the Environmental Sciences) using their previously developed snow albedo model.

Global Climate Modeling Group

A Coupled Atmosphere and Ocean General Circulation Model Experiment. A coupled three-dimensional general circulation model of the atmosphere and ocean has been constructed by Warren Washington, Albert Semtner (Oceanography Section), Gerald Meehl, David Knight, and Thomas Mayer (Large-Scale Dynamics Section). With a coupled model, it is possible to perform a wide variety of climate sensitivity experiments, including an assessment of the possible climatic consequences of increased atmospheric carbon dioxide. The present configuration of the model involves an eight-layer, five-degree horizontal resolution, third-generation atmospheric general circulation model; a four-layer, five-degree horizontal resolution, primitive equation ocean model; and a simplified sea ice model. An alternate version is being coupled with the Community Climate Model. Because the atmosphere and ocean have such different time scales, coupling strategies are being tested to allow best for the nonsynchronous coupling of the atmosphere and ocean. Presently the atmosphere is run for four different seasons and used to force the ocean over several years. In terms of data exchange between the models, the ocean requires wind stress, precipitation, and some components of surface energy balance from the model 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.

Observational Studies. Maurice Blackmon (joined GCMG from Advanced Study Program, 1 October 1980) has been working on several observational studies. With Glenn White (student, University of Washington) he has investigated the heat flux and momentum flux of eddies of different spatial scales for both winter and summer seasons. Results were compared with a previous modeling study. For eddies with zonal wavenumber 6 and larger, observations agree with the modeling results; namely, the momentum flux is predominantly poleward and the heat flux has maxima near the surface and near the tropopause. For eddies of wavenumber 9 and higher, however, the observations show weak, poleward momentum flux, in contrast to the modeling results.

In collaboration with Thomas Phillips (Advanced Study Program post-doctoral fellow), Blackmon has been studying the general circulation of the Southern Hemisphere winter season. Variance and covariance quantities are partitioned into low-frequency (periods of 10-100 days) and high-frequency (periods of 1.5-6 days) components and mapped. Regions of strong baroclinic eddy activity (storm tracks) were identified and related to the mean jet stream and to mean meridional circulations.

Blackmon has also been studying the regional properties of the autocorrelation function of the 1000 mb height, 500 mb height, and 850 mb temperature fields. The regional distribution of the time between independent estimates has been calculated for each field. The results for the 1000 mb height compare well with the results of Roland Madden (ESG). The 500 mb field has similar structure to 1000 mb height, with the time between independent samples being approximately eight days in regions of blocking. However, in regions of short time between independent samples, the time for 500 mb height is approximately twice that for 1000 mb height. Finally, the time between independent samples for 850 mb temperature is distinctly different from that of the 1000 mb height, indicating substantially different dynamics for fluctuations of this field.

Air-Sea Interaction. Robert Chervin and Francis Bretherton (Oceanography Section) analyzed a series of ocean surface temperature anomaly experiments previously carried out with a version of the NCAR general circulation model to ascertain possible feedbacks from the atmosphere to the ocean. In particular, the simulated changes in net heat flux into the ocean surface, in wind stress, and in net water flux in response to the prescribed changes in ocean surface temperature have been examined with the aim of determining the properties of oceanic linear response matrices suitable as upper boundary conditions for climate sensitivity experiments with an oceanic general circulation model. These matrices would, to first order, contain the physical and dynamical properties of the atmospheric model and, as such, could replace the atmospheric model in "coupled" ocean/atmosphere experiments. Preliminary results indicate that so-called sensitivity coefficients which relate ocean surface temperature changes to net heat flux changes are highly dependent on spatial scale, model physical parameterizations (especially cloud/radiation interactions and vertical transports), and the local ocean surface temperature in the unperturbed base state. Outside the anomaly region the detailed spatial structure of sensitivity coefficients for the wind stress components leads to the conclusion that it may be difficult to construct these linear response matrices from a limited number of anomaly experiments.

LARGE-SCALE DYNAMICS SECTION

Overview

The strategy of the Large-Scale Dynamics Section has been to identify various sources of deficiencies in data analysis, initialization, and numerical models, with a view to understanding the behavior of large-scale atmospheric motions. While theoretical studies of atmospheric predictability indicate that the global-scale motions may be predictable up to a few weeks in advance, present deterministic forecast models have considerably less skill than these theoretical estimates, particularly in the planetary scales. Since planetary-scale motions contain a major portion of kinetic energy in the atmosphere, and act as steering currents for the baroclinic eddies, it is vital to understand the reason for the apparent lack of predictability in the planetary-scale motions.

This year, we made notable progress in identifying one important source of the forecasting deficiencies in planetary-scale motions. This particular source of deficiency seems to appear from an existing gap between observational data analysis and the use of such an analysis as the input to forecast models. In principle, observed data should be analyzed as faithfully as possible to given measurements, but in reality, because of observational errors and nonuniformity of observation points, the final product of analysis is a blend of observations and an initial guess provided by forecasts. In data-sparse areas, then, the analysis inherits the same deficiency as in the prediction model used. In data-rich areas, if the initial guess is very much modified by the observations, then this is an obvious indication that the forecast model will evolve differently from the actual atmosphere when the analysis is used as the model's initial condition.

In the past, it was difficult to provide a good initial guess from a numerical forecast because of shortcomings in the initialization procedure, being unable to control high-frequency oscillations produced by an initial imbalance between the wind and pressure fields. Two new initialization approaches, called nonlinear normal mode balancing and the bounded derivative method, have given us high expectation that we may be able to narrow the existing gap between data analysis and model forecast. This new development will not only contribute to improved short-range forecasts, but also provide a powerful vehicle to further explore real differences between the atmosphere and numerical models.

The forecast skill scores published recently by the European Centre for Medium-Range Weather Forecasts (ECMWF) indicate a significant improvement in their skill in short-range forecasts. Whether or not this improvement is a reflection of recent advances in our technical ability to measure the atmosphere in greater detail and to perform calculations at greater speed, there is no doubt that the progress toward our understanding the nature of large-scale atmospheric motions has contributed to their achievement.

Analysis of Data from the Global Weather Experiment

We began to analyze the data collected during the Global Weather Experiment, also referred to as the First GARP (Global Atmospheric Research Program) Global Experiment (FGGE), conducted during 1979. David Baumhefner acted as coordinator for the Working Group on Numerical Experimentation (WGNE), under the Joint Scientific Committee of GARP, in the selection of specific cases for numerical experimentation using the FGGE data set. Ten periods of study were identified from a large number of international requests. Selection was based on the presence of interesting phenomenological events and the availability of special data.

An extensive investigation of the Level IIa FGGE analysis during the first Special Observing Period (SOP), January-March 1979, was conducted by Baumhefner and Thomas Bettge. They examined in detail the structure of the planetary waves in the geopotential by evaluating the magnitude, latitudinal dependence, time continuity, and vertical structure of the flow. The quasi-stationary and transient features were identified and compared to climatological values. Three distinct latitudinal regimes are present in the wave patterns, which sometimes become phase-locked. The flow is highly barotropic and dominated by low-frequency components; however, on occasion, sudden shifts or transitions are present.

Baumhefner and Bettge examined the daily 72 h forecast skill of the National Meteorological Center (NMC) model during January - March 1979. Conventional skill scores and a newly developed normalized score were calculated from the error fields. They compared these results against other research and operational model forecasts for different periods. For the NMC model, planetary wave error represents nearly 50 percent of the average error variance. Systematic errors account for approximately 30 percent of the planetary-scale error. Peaks in the error magnitude coincide with transitions in observed large-scale structure. Comparison with other models indicate ECMWF forecasts are significantly better in the first four days.

Kamal Puri (Australian Numerical Meteorological Research Centre) examined three Southern Hemisphere cases during FGGE to check the sensitivity of the Australian spectral model to the specification of additional surface data from buoys near Australia. Preliminary evaluations show that the additional data provided a quite positive effect on the forecasts.

Diagnostic Analysis of Short-Range Forecast Errors

Baumhefner and Bettge collaborated with Puri in tuning, documenting, and testing the skill of the Australian spectral model in several real-data forecasts. The model has been updated with the addition of a nonlinear normal mode initialization procedure and nonlinear vertical diffusion. This model was used to evaluate the hypothesis that some of the planetary wave forecast error is caused by poor data analyses in the tropics (data) and/or by limiting integrations to a hemisphere (domain). Results from this model revealed that the data/domain errors are dependent in part upon the particular model being employed and upon the case being examined.

Roger Daley, Joseph Tribbia, and David Williamson completed investigating the problem of planetary-scale forecast error caused by tropical data deficiencies and/or equatorial walls previously noted by Baumhefner and Richard Somerville (University of California, San Diego). They discovered that the problem was largely due to the spurious excitation of large-scale free Rossby modes by the data or domain deficiencies. After excitation, the linear dispersion of these modes caused rapid transmission of error throughout the forecast domain. Procedures for controlling these large-scale Rossby modes were also investigated.

Previous work by Daley on determining the optimal design of a global observing system within the context of the shallow-water equations had shown that the correct initial specification of the geostrophic part of the flow was of fundamental importance in weather forecasting. These conclusions were generalized to the more realistic case of a baroclinic primitive equation model. It was found that the correct initial specification of the geostrophic flow was important for the larger vertical scales, but less important for the smaller vertical scales.

Further Studies on the Initialization Problem

One problem that has been noticed by all groups who have applied nonlinear normal mode initialization 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 Thomas Schlatter (Prototype Regional Observing and Forecasting System Program Office, Environmental Research Laboratories, National Oceanic and Atmospheric Administration) examined the relative importance of various sources of imbalance in analyses produced by multivariate optimal interpolation. Their experiments were done with shallow-water equations and thus consider only the horizontal aspects of the analysis-forecast system. Of the possible sources involving analysis and data quality they found that the multivariate optimal interpolation itself introduces systematic imbalances which result in relatively large changes when initialization is performed. However, even with these systematic errors, multivariate analysis is better than univariate. Random observational errors introduce imbalances which are consistent with the error variances themselves and which have a small-scale, random structure. Data-void areas do not affect the balance in neighboring data-rich regions.

Williamson and Daley began a project to incorporate more complete relationships between the mass and motion fields into the multivariate optimal interpolation. Preliminary results indicate that such relationships will eliminate a large part of the systematic error mentioned earlier.

Tribbia has developed an efficient and improved scheme for the implementation of variational nonlinear normal mode balancing. This technique is computationally more efficient than that proposed earlier by Daley. Also, the improved method partially corrects one of the major shortcomings of the previous scheme in that it obtains a more correct minimization of the prescribed data metric. Tribbia is currently investigating the properties of this technique when applied to observational data.

Akira Kasahara collaborated with Gerald Browning (Scientific Computing Division) and Heinz-Otto Kreiss (California Institute of Technology) in application of the bounded derivative method for the initialization of primitive equation models. Specifically, Kasahara compared the three procedures of initialization, i.e., nonlinear normal mode balancing, the bounded derivative method, and quasi-geostrophic formulation, using a baroclinic primitive equation model with beta-plane geometry in pressure coordinates. Since both new initialization approaches are more general than the classical procedure, these three-way connections will enhance our understanding of the dynamics of large-scale motions beyond the classical quasi-geostrophic theory. For example, the importance of the diabatic heating term and, to a lesser extent, the frictional effect for the initialization, particularly in the tropics, are elucidated.

Fredrick Semazzi (University of Nairobi, Kenya) and Kasahara are working on the initialization procedure for the NCAR limited-area forecasting model applying the bounded derivative method. Thomas Mayer and Williamson continued to develop the normal mode initialization procedure for the NCAR third-generation general circulation model.

Improvements in Numerical Prediction Models

One of the causes of planetary-scale model error is believed to be the incorrect specification of the upper boundary condition. This problem is thought to affect the partition between transient and stationary components, produce incorrect internal modes, and affect the model climate. Daley and Duane Stevens (Colorado State University) have constructed a special model to investigate this problem. It is a global spectral filtered baroclinic model in log pressure coordinates with 100 vertical levels extending above 100 km. It has simple physical parameterizations, but should be capable of successfully simulating such phenomena as stratospheric sudden warmings.

A Lagrangian formulation of the short-range prediction problem has been investigated by Philip Thompson. The methods of solving the equations for nondivergent barotropic flow or for "shallow-water" and adiabatic flow make explicit use of conservation of absolute vorticity or potential absolute vorticity. Those methods are to be contrasted with finite-difference or spectral methods of solving the Eulerian form of the conservation equations, which do not guarantee individual conservation of vorticity. The rotational part of the velocity of each element in an array of elements moving with the flow is completely determined by a Green's integral involving the current positions and initial vorticities of the elements. The divergent part of the velocity is calculated on a fixed grid, by solving the quasi-geostrophic equation for the vertical motions compatible with the known local changes of vorticity. This procedure automatically excludes gravity wave solutions, and has little effect on the predominantly rotational flow. The integration scheme does not require the use of elements of uniform size or shape, and is well-suited to variable horizontal resolution. Tests of this method will be carried out first for the nondivergent barotropic model and compared with the results of spectral integrations.

Kasahara and Puri have completed work to represent the wind and mass fields simultaneously using three-dimensional normal mode functions (NMFs). The NMFs are constructed from the eigensolutions of a global primitive equation model and they are orthogonal. The vertical parts of NMFs reflect the nature of the vertical structure of atmospheric motions in terms of the external mode and various internal modes. The horizontal parts of NMFs are Hough harmonics with zonal wave number and meridional modal index as two-dimensional scalings. The expansion of global data in terms of NMFs permits the identification of the nature of atmospheric motions in terms of various vertical modes and the two classes of modes--high-frequency gravity waves and low-frequency meteorologically significant motions (Rossby modes). There are wide applications of this representation technique and data analysis to numerical modeling which are being pursued.

Many questions still remain concerning the dynamical effect of mountains on large-scale flows. Hajime Nakamura (University of Tokyo), Grant Branstator, and Kasahara have begun to investigate the stationary and transient responses of a dome-shaped mountain on large-scale flows using a baroclinic primitive equation model. The results of calculations using finite-difference approximations applied to the model are being compared with those using spherical harmonics spectral approximations to the same model. From this comparison they hope to learn about the accuracy of numerical calculations related to the flow over and around mountains.

There is some suspicion in the numerical weather prediction community that climate simulations by spectral models may deteriorate at high resolution owing to a strong tendency toward an equipartition spectrum (energy distribution produced in the absence of sources or sinks). This phenomenon does not seem to have been observed in gridpoint models. The equipartition spectrum and relaxation time to equipartition have been previously determined for spectral models, but not for grid-point models. Daley, Jorgen Frederiksen (Commonwealth Scientific and Industrial Research Organisation) and Mayer have begun determining the equipartition spectrum of an enstrophy conserving grid-point shallow-water model of Arakawa.

The development and testing of a series of methods for transforming data between height and pressure coordinates were completed by Branstator and Donald Perkey (Drexel University). Recently, researchers at ECMWF noted that their vertical interpolation methods were having an adverse effect on the skill of their forecasts. However, Branstator and Perkey found that if treated carefully, the conversion of data from one coordinate to another should normally be only a small source of error in initial conditions.

Increasingly accurate lateral boundary specifications were applied in a regional model by Baumhefner and Bettge to determine the interaction with the interior forecast. They found that the specified structure at the boundary strongly influences the evolution of the large scale in the interior. The smaller scales in the center of the domain do not react to the increased accuracy of the boundary specification.

Bettge and Thompson tested a digital filter to decompose meteorological fields in a limited domain. The design of the filter, as suggested by Thompson, approximated the frequency response with the use of a Fourier series expansion. Much sharper response filters are allowed than with the former method, by Bettge and Baumhefner, which produced exact filter responses. The approximation error of the modified filter has been shown to not produce significant errors when the extraction of long and medium spatial scales is required.

Williamson extended his vortex representation to include storm track representation. The vortex representation mathematically describes individual local vortices in terms of a small number of parameters. After vortex representations are established for a series of data sets in time, the envelope of each feature over time is found. This field represents the storm track. In an example for one ten-day forecast and its verifying analysis, storm tracks appear to be more predictable than the instantaneous positions of storms.

Dynamical Studies of the Large-Scale Circulation Systems

Kasahara has worked with James Koermer (Air Weather Service, Scott Air Force Base) and Shih-Kung Kao (University of Utah) to formulate a primitive equation spectral model to study interactions between the troposphere and stratosphere in association with sudden stratospheric warmings. Using sigma coordinates for five tropospheric layers and log-pressure coordinates for 26 stratospheric and mesospheric layers, separate model equations for each system are combined to form single matrix governing equations. The gradual introduction of large-scale topography to an initially balanced state representative of observed mean winter conditions in the Northern Hemisphere is used for the generation of planetary waves. It was shown that by this orographic forcing, realistic major and minor stratospheric warmings can be simulated depending upon the intensity of the initial zonal wind in the stratosphere and that wave-to-wave interactions appear to be an essential part of the sudden warming process.

Branstator continued his study of dynamical mechanisms which may play important roles in the interannual variability of quasi-stationary atmospheric waves. This work, done in conjunction with J. Michael Wallace (University of Washington), is based on the assumption that such mechanisms can be found in simple barotropic models. In the past year, a global, steady-state shallow-water model which is linearized about a zonally symmetric state was used extensively in the study. One series of experiments which was carried out investigated the geographical distribution of forcing which is required to simulate observed 300 mb quasi-stationary waves in the model. Analysis of the model's linear operator showed most of this observed flow could be reproduced if just its slow (Rossby-type) modes were retained. These are the most easily excited states of the model and may be instrumental in describing the large-scale, slowly varying features of the atmosphere. Changes in local forcing, which in turn affect those sensitive modes which are excited at a given time, can have global effects on atmospheric flow.

An equally important mechanism in determining the quasi-stationary component of the atmospheric flow is the influence of the largest scales of motion on how energy propagates away from fixed, local sources. Branstator found that many features of certain midlatitude teleconnection patterns may be the result of changes in the energy-transmitting properties of the atmospheric fluid as the background flow changes. Further investigation of this was made possible by Branstator's new barotropic model in which a zonally varying basic state was allowed. In a zonal background current energy propagating away from a source follows a great circle route, but with a wavy background current the path becomes skewed so that new parts of the globe feel the influence of a local source region.

As another problem of examining the mechanism of atmospheric circulations, Tribbia has been investigating with Tsing-Chang Chen (Iowa State University) the spectral transfer of energy in barotropic and baroclinic flows. This study incorporates both observational analysis and numerical modeling. They have so far made an observational study of tropical spectral energetics and an analysis of the large-scale divergent wind spectrum. Work is currently proceeding toward a theoretical explanation of these results through the use of numerical experimentation.

At a much longer time scale, Bettge and Baumhefner, along with Robert Chervin (Climate Section), examined several seasonal temperature anomaly forecasts to investigate improved methods of verification. A scheme was suggested, employing empirical orthogonal functions, which allows the forecasts to be examined with respect to naturally occurring patterns within the atmosphere. Examination of the past forecasts revealed that standard point-by-point verification procedures were unsatisfactory compared to direct pattern comparison of the forecast and observed anomaly patterns.

Turning our attention to a localized circulation system, Tribbia has extended the analysis of solitary eddy solutions (modons) of filtered equations on the beta plane accomplished by James McWilliams (Oceanography) to spherical geometry, which is more appropriate for atmospheric motions. These modons have been proposed as a model of blocking patterns in the atmosphere and the primary objective of this study is to examine the robustness of these flow patterns in the presence of ageostrophic and topographic perturbations.

With Ernest Agee (Purdue University), Tribbia is developing a spectral thermal convection model to study the interaction between microscale turbulent thermals and large-scale organized cellular structures. They have obtained so far some results concerning the influence of exterior mechanisms on cell structure geometry. The work is proceeding to investigate internal nonlinear influences of cellular size and shape.

OCEANOGRAPHY SECTION

The research of the Oceanography Section in 1980 can be divided into four areas: large-scale ocean circulation studies, models of local eddy processes, analysis and interpretation of field data, and climate studies.

Large-Scale Ocean Circulation

During the last several years, William Holland and James McWilliams have carried out a number of numerical experiments with eddy-resolving models, examining the role of the eddies in the large-scale circulation in midlatitude gyres. These studies have, for the most part, been carried out with a highly efficient quasigeostrophic model, whose adequacy for midlatitude applications has been demonstrated by Albert Semtner and Holland through intercomparison with a primitive-equation model. Some studies have been also been done with a primitive equation model.

Various applications of such models have been made to study idealized closed-basin and channel flows, the North Atlantic circulation, the Antarctic Circumpolar Current, and the Southern Hemisphere ocean circulation. These studies have been designed to elucidate the nature of the large-scale dynamical balances that can exist in various circumstances. All of this work is continuing.

During the past year, Holland has continued the development of three-layer models of idealized basins as well as the Atlantic Basin. The focus of these efforts has been on understanding several aspects of the larger problem: (1) the role of eddy mixing in the redistribution of potential vorticity and of passive tracers in the basin; (2) the nature of instability processes in the Gulf Stream and far field regions that give rise to the eddy field; (3) the role played by thermal forcing and the nature of oceanic heat flux on the basin scale; and (4) the role played by frictional processes, bottom topography, and basin shape on the general circulation. In collaboration with Dale Haidvogel (Woods Hole Oceanographic Institution), Peter Rhines (WHOI), and Ed Harrison (MIT), Holland has completed studies of long-time-scale vacillation and of energy, potential vorticity, and heat budgets in simple ocean basins. In addition, a new model to study oceanic heat transport has been initiated with Y.J. Han (Oregon State University).

A study has been made by McWilliams and Julianna Chow of a numerical solution for wind-driven currents in a channel, which is a plausible idealization of the Antarctic Circumpolar Current. It was found that the turbulent eddies are efficient transporters of momentum, heat, and, most strikingly, potential vorticity (which is found to be uniform throughout the interior of the fluid).

For large-scale circulations a number of intermediate models--with physics intermediate between the primitive equations and the traditional quasi-geostrophic equations--have been proposed. In this category are the balance equations and the semigeostrophic equations, for example. An extensive theoretical analysis has been made by Peter Gent and McWilliams of the mathematical properties of these models, and an intercomparison of their solution characteristics is being made for a Lorenz severely truncated spectral representation where the solutions are readily obtained. Several of the models, in particular the balance equations, appear to have the highly desirable properties of simplicity relative to the primitive equations and accuracy relative to the quasi-geostrophic ones.

Work on trapped equatorial modes is continuing. Analytical studies are being carried out by Gent on forced, trapped modes when forcing is independent of longitude, oscillating in time, and applied only to the zonal momentum equation. In addition, Gent and Semtner are analyzing further the numerical free modes, trying to predict their frequencies in basins of arbitrary width, and analyzing the equatorial primitive equation numerical results for evidence of trapped standing modes.

Models of Local Eddy Processes

McWilliams, in partial collaboration with Glenn Flierl (MIT), Vatali Larichev and Gregori Reznick (Shishov Institute, Academy of Sciences, USSR), and Norman Zabusky (University of Pittsburgh), carried out several studies during the last year related to the theory of isolated vortices in order to explore further the self-consistency, generation, and durability of intense isolated vortices. In particular, their evolution in the presence of dissipation was examined, their ability to survive perturbations by a background field of turbulence was studied, and their mutual collision properties were tested. Such isolated vortices are of interest as models of Gulf Stream rings and certain types of atmospheric blocking.

Francis Bretherton, in collaboration with Brechner Owens (WHOI), has been using a mesoscale process model to understand the influence of local topography on the statistics of mesoscale eddies, in particular on why the eddies are apparently more baroclinic than over a flat bottom.

In collaboration with Andrew Bennett (Monash University, Australia), Holland began in 1980 a numerical study of simple laboratory flows in rotating, sliced cylinder geometry. Bennett is carrying out the laboratory studies and Holland the numerical simulations. Thus far, it is clear that, except for the very highest Rossby numbers, the numerical model reproduces the observed (laboratory) flow in great detail. Consequently the numerical experiments are being examined to understand the role played by eddy processes in establishing a mean circulation in statistical equilibrium. These interpretations will be helpful in choosing analysis techniques suitable for the much more complex three-dimensional numerical ocean model experiments.

Analysis and Interpretation of Field Data

In collaboration with Owens, Bruce Taft (University of Washington), and Colin Shen (University of Washington), McWilliams has made initial analyses of data from the 1977-1979 POLYMODE Local Dynamics Experiment. The central task is the compositing of many diverse types of measurements by optimal estimation theory in order to assess the balance of potential vorticity in the turbulent return flow region of the Gulf Stream gyre. An additional topic is the distribution and evolution of a number of small-scale, isolated patches of water distinguished from their surroundings by anomalous chemical properties and intense local circulations (i.e., they are isolated vortices). Their lifetimes appear to be as much as several years, and they may thus be a primary means of ocean mixing of scalar quantities horizontally along isopycnal surfaces.

An initial study has been made (Holland with William Schmitz, WHOI) comparing numerical results from large-scale eddy-resolving models with observations of the eddy field in the North Atlantic Basin. This comparison shows that, for realistic basin sizes and strength of wind forcing, the amplitude and meridional structure of deep eddy kinetic energy can be reproduced reasonably well by a two-layer quasi-geostrophic model. It seems necessary, however, to extend the vertical resolution to at least three layers to be able to reproduce the zonal pattern of eddy energy. Further comparisons are under way using three-layer models. The comparisons are being extended to Pacific data sets as well.

Climate Studies

Semtner has begun the development of a highly efficient, coupled ocean-atmosphere model. He has adapted the Held-Suarez atmospheric model to interact with a progression of dynamical ocean models on time scales ranging from seasons to many decades. With a constant-thickness oceanic mixed layer, the coupled model produces a reasonable seasonal cycle of atmospheric dynamics, including transport of heat and momentum by transient and standing waves. Allowing the mixed layer thickness to vary with time causes statistically significant effects on tropical and midlatitude winds and on high latitude atmospheric temperatures. Studies of the effects of adding three-dimensional ocean circulation as well, via a multilevel primitive-equation model, are under way, including the partitioning of heat transport between ocean and atmosphere and its seasonal variation.

This year saw the beginning of a collaborative program involving at present about ten scientists and engineers, including McWilliams, to develop and use better surface drifting buoys. The types of measurements desired are ocean currents and thermal structure and the fluxes across the air-sea interface. The initial activities have been primarily in planning.

Bretherton joined the Oceanography Section in August 1980. The central theme of his research is the role of the oceans in climate, both in the broader systems sense and in some of the specific mechanisms which need to be reflected in our numerical models. He has (in collaboration with Robert Chervin of the Climate Section) been examining the heat flux through the ocean surface as a function of sea surface temperature in atmospheric general circulation models and has proposed a generalized form of Newtonian cooling as the upper boundary condition for ocean models. This suggests that a global warming due to CO_2 should be delayed by at least 30 years and possibly as much as 300 years by the thermal capacity of the upper layers of the ocean. This inference focuses attention on the similarities and differences between additional heat and passive tracers in the general circulation of the ocean and prompts a review, now in progress, of the performance in this regard of present ocean circulation models.

With James Coakley of the Climate Section and Thomas Vonder Haar (Colorado State University), Bretherton has been devising new methods of classifying cloud structures over the ocean, with a view to the devising of climatological indices for surface temperature-cloudiness-radiation feedbacks.

In parallel with these research activities, Bretherton has been principal investigator on the UCAR project for NOAA (National Climate Program Office) on the Strategy for the Development of an Ocean Climate Monitoring System. This has required a broad overview of probable measurement needs and the potential of different observing systems, in conjunction with a group of consultants and other participants drawn from around the nation. A companion activity has been to serve as principal investigator for the National Ocean Satellite System Science Working Group advising NASA on the opportunities and requirements for oceanographic science from space.

STAFF AND VISITORS

AAP Division Office

Staff

Jackson Herring
Barbara Hill
Holly Howard
Cecil Leith (Director)
Ann Modahl

Visitors

Meg Carr, Oklahoma State University, January and March 1980.

Xiong-Shan Chen, People's Republic of China, December 1980 to August 1981.

James Curry, Massachusetts Institute of Technology, June to August 1980.

Jorgen Frederiksen, Commonwealth Scientific and Industrial Research Organisation, Australia, May to December 1980.

Uriel Frisch, Nice Observatory, France, December 1979 to January 1980, April 1980, August to October 1980.

Roland Grappin, Paris Observatory, France, August to September 1980.

Greg Holloway, University of Washington, July to August 1980.

Jill Jäger, Karlsruhe, Federal Republic of Germany, December 1980 to March 1981.

Robert Kerr, Cornell University, June 1980 to June 1981.

Ho Lin, Massachusetts Institute of Technology, March to May 1980, August to October 1980.

Maurice Meneguzzi, Center for Nuclear Studies, Saclay, France, December 1979 to February 1980, August to November 1980.

Annick Pouquet, Nice Observatory, France, September to October 1980.

Philippe Roy, Nice Observatory, France, September to October 1980.

Daniel Schertzer, Institution for the Study of Meteorological Research, Paris, France, December 1979 to January 1980.

Eric Siggia, Cornell University, May to August 1980.

Pierre-Louis Sulem, Nice Observatory, France, April to May 1980.

Shih-Yen Tao, People's Republic of China, December 1980 to April 1981.

Norman Zabusky, University of Pittsburgh, July to August 1980.

Mesoscale Research Section

Staff

Raymond Bovet
Richard Brost
John Brown (to 22 February 1980)
Chia-Bo Chang (long-term visitor)
Tzvi Gal-Chen (long-term visitor)
John Garratt (long-term visitor)
Dorene Howard
Joseph Klemp
Margaret LeMone (to 9 November 1980)
Donald Lenschow
Douglas Lilly (Section Head)
Rebecca Meitín
Dennis Miller (long-term visitor)
Katsuyuki (Vic) Ooyama (to 25 January 1980)
Donald Perkey (to 15 October 1980)
Nadine Perkey (long-term visitor)
Gary Rasmussen (long-term visitor)
Richard Rotunno
Doyne Sartor (to 22 February 1980)
Borislava Stankov
Patricia Waukau
Morris Weisman
Timothy Wilson
John Wyngaard
Edward Zipser (to 3 March 1980)

Visitors

Bruce Albrecht, Pennsylvania State University, June to August 1980.

Alan Betts, unaffiliated, January to March 1980.

William Boeck, Niagara University, June and July 1980.

Michael Bradley, University of Illinois, July to August 1980.

T.C. Chen, Iowa State University, June 1980.

Kerry Emanuel, University of California at Los Angeles, June to August 1980.

Lev Gutman, Tel-Aviv University, Israel, June to September 1980.

Carl Hane, NSSL/NOAA, June to August 1980.

Robert Heald, Oregon State University, March to May 1980.

José Melgarejo, Swedish Meteorological and Hydrological Institute, July to September 1980.

Robert Wilhelmson, University of Illinois, June to August 1980.

Climate Section

Staff

Eileen Boettner
Robert Dickinson (Section Head)
John Geisler (long-term visitor)
Christine Kingsland
Richard Wolski

Cloud-Climate Interactions Group (CCIG)

Bruce Briegleb
James Coakley
Patrick Downey (from 15 December 1980)
Laurence Goldberg (to 1 October 1980)
William Kellogg (to 1 October 1980)
V. Ramanathan (Group Leader)
Mary Rickel (to 1 October 1980)
Stephen Schneider (to 1 October 1980)
Warren Wiscombe

Empirical Studies Group (ESG)

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

Global Climate Modeling Group (GCMG)

Maurice Blackmon (from 1 October 1980)
Robert Chervin
Ann Gayton
Edward Gerety
Yen-Huei Lee
Gerald Meehl
Eric Pitcher (long-term visitor)
Lynda Verplank
Warren Washington (Group Leader)

Visitors

Bruce Albrecht, Pennsylvania State University, June to August 1980, CCIG.

Patricia Brown, Jackson State University, July to September 1980, GCMG.

Petr Chýlek, Massachusetts Institute of Technology, July and August 1980, CCIG.

Nüzhet Dalfes, Rice University, July and August 1980, CCIG.

Edward Friedman, MITRE Corporation, January to August 1980, CCIG.

Danny Harvey, University of Toronto, May to August 1980, CCIG.

Robert Kandel, National Center for Scientific Research, Paris, France, August 1980, CCIG.

Tamara Ledley, Massachusetts Institute of Technology, July to August 1980, CCIG.

Randi Londer, Columbia University, May to October 1980, CCIG.

Robert Malone, Los Alamos Scientific Laboratory, January and February, June to August 1980, CCIG and GCMG.

Alberto Mugnai, Plasma-Space Institute, Rome, Italy, July to October 1980, CCIG.

Sharon Nicholson, Clark University, July and August 1980, GCMG.

Moysés Nussenzweig, University of São Paulo, January and February 1980, CCIG.

David Randall, NASA Goddard Space Flight Center, June to October 1980, GCMG.

Jeffrey Rogers, Ohio State University, July and August 1980, ESG.

Haydee Salmun, University of Maryland, May to August 1980, GCMG.

Robert Schware, Aspen Institute for Humanistic Studies, January to October 1980, CCIG.

Peter Speth, University of Köln, Federal Republic of Germany, November 1980, ESG.

Starley Thompson, University of Washington, June to September 1980, CCIG and GCMG.

Large-Scale Dynamics Section

Staff

David Baumhefner
Thomas Bettge
Grant Branstator
Roger Daley
Akira Kasahara (Section Head)
Thomas Mayer
Mary Niemczewski
Thomas Schlatter (to 5 September 1980)
Richard Somerville (to 1 February 1980)
Philip Thompson
Joseph Tribbia
Joseph Wakefield (to 9 November 1980)
David Williamson

Visitors

John Barker, California Institute of Technology, June to August 1980.

James Koermer, University of Utah, February to March 1980, April to May 1980.

Hajime Nakamura, University of Tokyo, October to December 1980.

Fredrick Semazzi, University of Nairobi, Kenya, October to December 1980.

Akimasa Sumi, University of Hawaii, July to August 1980.

Oceanography Section

Staff

Mary Batteen
Francis Bretherton
Julianna Chow
Judy Fukuhara
Peter Gent
William Holland (Section Head)
Christine Kingsland
William Large
Michael McPhaden (long-term visitor)
James McWilliams
Albert Semtner

Visitors

Brechner Owens, Woods Hole Oceanographic Institution, October to November 1980.

Colin Shen, University of Washington, December 1980.

ATMOSPHERIC CHEMISTRY AND AERONOMY DIVISION

INTRODUCTION

In the summer of 1980 this division, formerly the Atmospheric Quality Division (AQD) was renamed the Atmospheric Chemistry and Aeronomy Division (ACAD). The former director of AQD, Paul Crutzen, left NCAR in August to begin work as professor and director of the Max Planck Institute for Atmospheric Chemistry in Mainz, West Germany. Crutzen was replaced as ACAD director by Ralph Cicerone, who previously served as a research chemist at the Scripps Institution of Oceanography, University of California, San Diego. Prior to that, Cicerone was a scientist and research faculty member at the University of Michigan. The organization and goals of ACAD remain those of AQD. Specifically there are six divisional projects as follows. Names of Project Leaders are in parentheses.

- In-Situ Measurements and Photochemical Modeling Project (Cicerone)
    - Chemical Modeling Group (Cicerone)
    - In-Situ Measurements Group (Heidt)
    - Global Halogen Group (Berg)
  - Biosphere-Atmosphere Interactions Subproject (Zimmerman)
  - Gas and Aerosol Aircraft Measurements Subproject (Delany)
- Precipitation Chemistry and Reactive Gases and Particles Project (Lazrus)
- Thermospheric Dynamics and Aeronomy Project (Roble)
- Global Observations, Modeling, and Optical Techniques Project (Gille)
- Stratosphere-Troposphere Exchange Project (Shapiro)
- Radioactive Aerosols and Effects Project (Martell)

In the text that follows we report the scientific progress from each of these group efforts in 1980.

The goals and strategies of ACAD's research program are as follows:

- To derive and explain the chemical composition of the earth's atmosphere, with particular concern for constituents that have global and regional significance because of their effects on the biosphere, climate, and the stratospheric ozone layer. This research requires the identification and quantization of the sources and sinks of atmospheric gases and 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 insitu 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. Examples are cycling processes of nutrient elements and those processes that control precipitation acidity.

Toward these goals, we employ a variety of experimental and theoretical methods of investigation. We consider a proper balanced scientific program of theory and measurement to be essential; without such a balance the classical scientific method loses potency. Finally, because of the nature of our investigations it is useful to draw ideas, methods, and scientific personnel from disciplines other than atmospheric science, e.g., physics, chemistry, biology, mathematics, oceanography, and soil science.

CHEMICAL MODELING GROUP

The research of this group included theoretical studies of the chemistry and dynamics of the mesosphere, thermosphere, and stratosphere and studies on tropospheric photochemistry. Because the open position for a Ph.D. scientist in this group was not filled, the work was carried on largely by Crutzen, NCAR visitors to ACAD, and ASP graduate students and postdoctoral fellows. In the fall, Cicerone replaced Crutzen.

In stratospheric photochemical modeling, Crutzen and Solomon reexamined the effects of the large solar proton event of 1972 on the stratospheric ozone layer. Their study added the effects of chlorine chemistry to the reactions considered previously and was performed with a time-dependent, one-dimensional model. With Solomon's extended version of Crutzen's two-dimensional model (see Thermospheric Dynamics and Aeronomy Project) they also studied the effects of precipitating particles on mesospheric ozone and D-region ion chemistry. Crutzen also employed this photochemical model in a tracer mode to predict stratospheric total chlorine-compound concentrations for comparison with the measurements by Walter Berg and others of total chlorine (see Global Halogen Group). Similarly, Crutzen and Louis Gidel calculated temporal trends in the latitudinal patterns of the fluorocarbons CF_2Cl_2 and $CFCl_3$ in support of the NASA Halogen Occultation Experiment (HALOE Satellite) Science Team research. Cicerone and Stacy Walters also began work with the intention of creating a generalized and improved two-dimensional model.

In tropospheric chemical modeling Crutzen and Gidel employed the NCAR two-dimensional time-dependent tropospheric model in calculations to deduce global source strengths of CH_4 and CO. These calculations first used NCAR measurements of CH_3CCl_3 by Leroy Heidt's group to test and adjust model-generated OH concentrations. The results show that there must be appreciable sources of CO in the tropics, probably contributions from natural emissions of CO and of hydrocarbons that are oxidized to CO but possibly also some that originate in biomass burning. Additionally in tropospheric modeling, Cicerone, Anne Thompson (visitor from Scripps Institution of Oceanography), Brian Heikes (visitor from University of Michigan), and Walters began work on gas scavenging in tropospheric chemistry. The temporal changes in background gas concentrations (e.g., HNO_3, H_2O_2, CH_2O) that result from simulated sporadic rainfalls appear to be large and interesting. Walters has achieved unusually high computational efficiencies and accuracies through application of advanced numerical techniques and CRAY assembly language programming. In other tropospheric modeling developments, Crutzen and Robert Chatfield (visitor from Colorado State University), investigated the regional effects of gas transport by large scale cloud-convective processes. Thompson and Walters incorporated cloud layers into a tropospheric optical multiple scattering computer code (patterned after that of Frederick Luther, Lawrence Livermore Laboratory). Walters also began work on a faster two-dimensional tropospheric model for accurate diurnal integrations. Most recently, Cicerone and several colleagues from elsewhere--Robert Turco (R & D Associates), Edward Inn (Ames Research Center), and Louis Capone (San Jose State University)--investigated the possibility of long-wavelength photodissociation of carbonyl sulfide in the troposphere.

IN-SITU MEASUREMENTS GROUP

The In-Situ Measurements Group began 1980 by completing the analysis of stratospheric samples collected in Brazil (at 6.5°S) in December 1979. Measurements of H_2O, H_2, CH_4, and CO_2 in 20 samples collected from 41.7 km down to the tropopause (20 km) indicate rather uniform inter-hemispheric mixing at the hemispheric junction. The concentrations of N_2O, $CFCl_3$, and CF_2Cl_2, however, decrease at a slower rate above the tropopause than at northern latitudes. These data, together with data from earlier flights, are being prepared for publication by Leroy Heidt.

With the eruption of Mt. St. Helens, the group participated in two sets of aircraft flights through the plume in an attempt to determine the contribution of volcanoes to the atmospheric concentrations of CH_4, H_2, and COS as well as other trace gases. Sampling equipment was installed on an NCAR Queen Air for the May flights by Richard Lueb and was operated by Richard Cadle (formerly of NCAR). He collected air samples in 4 ℓ evacuated flasks in the eruption cloud downwind of the volcano at altitudes varying from 0.03 km to 7.6 km and returned them to the Boulder laboratory for analysis. To sample the plume in October, Cadle and Lueb installed the same equipment on the twin-engine aircraft leased by the U.S. Geological Survey team for sampling.

Gas chromatographic (GC) analyses of these samples included the gases emitted either as fume or eruption clouds, both during the early stages of the eruptive cycle when the eruptions were largely or entirely phreatic and later following the magmatic eruptions. Among the conclusions drawn from these data and data from previous collections in Central America are: (a) Mt. St. Helens erupted various magmatic gases even during the phreatic stages, (b) the CH_4 often observed in volcanic gases is almost certainly of magmatic origin, and (c) volcanoes are only a minor source of COS in the atmosphere.

As a participant in the NCAR Summer Colloquium (CHON Photochemistry of the Troposphere) sponsored jointly by ACAD and the Advanced Study Program (ASP), Heidt directed the acquisition of background measurements of some of the long-lived trace gases which enter into the CHON photochemistry. James Johnson (University of Washington) and Mona Delitsky (University of Michigan) worked with the In-Situ Group to collect samples at the site and measure them in laboratory. GC measurements of CO, CH_4, H_2, CH_3CCl_3, CCl_4, and H_2O were performed to provide input into the photochemical model designed by other colloquium participants. The chlorofluoromethanes $CFCl_3$ and CF_2Cl_2 were measured as indicators of local air quality. Carbon monoxide measurements were performed on samples collected from the meteorological tower in conjunction with the OH^- measurements of Malcolm Campbell (Washington State University). Gradient measurements of the listed species were also attempted, but were not totally successful because of the influence of urban air from the Denver area. All data produced during the experiment, together with results of the other experiments, are being published by NCAR as a report, Grasslands.

A second major field expedition to Brazil to measure emissions from biomass burning was undertaken by the division in September. The In-Situ Group again provided measurements of some of the important trace gases for this project. Gas chromatographs, vacuum equipment, and air sampling equipment were set up at the Instituto Nacional de Pesquisas da Amazonia (INPA) near Manaus by Heidt, Lueb, and Walter Pollock. Samples collected both during surface sampling and with the NCAR Sabreliner aircraft were analyzed at the temporary laboratory for CO_2, CO, CH_4, N_2O, COS, and CH_3Cl. Samples were also returned to the NCAR laboratory for analysis of organic compounds by gas chromatography/mass spectrometry (GC/MS). Because of the large number of measurements completed, data reduction is still in process. Emphasis was placed on these gases because of their importance to the earth's radiation budget, to the global ozone balance, and to regional tropospheric inventories.

The design and development of a small cryogenically charged air sampler for use on rockets progressed substantially during 1980. Because the costs of completing the development and making flights of the sampler exceed available resources, however, a proposal for supplemental funding will be submitted to NASA and FAA to complete the project.

A major effort by Lueb, Heidt, and Dieter Ehhalt (now at Institute for Chemistry, Jülich, Germany) in recent years has been the modification of the group's balloon-borne cryogenic sampler to collect stratospheric water without contamination. In parallel, Pollock has developed an analytical technique to accurately measure the H_2O contained in those samples. The success of this project has produced a major contribution to the stratospheric H_2O data base (see Pollock et al., 1980, in the publications list of this report).

Heidt, Lueb, and Pollock will launch their system in late April 1981 in collaboration with six other organizations to produce intercomparisons of stratospheric H_2O measurements in the same air mass--a first in stratospheric experiments. Other participants in the experiment are Arthur Schmeltekopf and Dieter Kley (NOAA Aeronomy Laboratory, Boulder), Konrad Mauersberger (University of Minnesota), David Murcray (University of Denver), John Mastenbrook and Samuel Oltmans (Naval Research Laboratories), Wayne Evans, Henry Faust, and Clyde Midwinter (Atmospheric Environment Services, Canada), and Nigel Swann (National Physical Laboratory, England).

The addition of the GC/MS to the In-Situ Measurements Group has provided a powerful new analytical tool to measure atmospheric organic substances. In addition to the measurements of the Brazil biomass samples, Pollock has developed techniques to analyze the stratospheric samples collected with the cryogenic systems. He has also established a strong reference library in the computer data system of the GC/MS by running pure organic standards.

New measurement techniques are also being developed in the GC laboratory. James Shetter (formerly of Scripps Institution of Oceanography, La Jolla, California) is working with Heidt to develop new methods to measure H_2, CO, CH_4, and CO_2 using an electron-capture detector (ECD) and N_2O-doped carrier gas. Investigations are also under way by Heidt and Bruce Henry to improve the sensitivity of an ECD sufficiently to measure atmospheric concentrations of CH_3Cl, CH_3Br, and CH_3I.

Because of his concern for accurate measurements of the absolute concentrations of trace gases in the atmosphere, Heidt has continued to improve the calibration techniques used by the In-Situ Group. In addition to making improvements in his static dilution system, he has established routine exchanges of calibration mixtures with the Institute for Chemistry (Julich, Germany), the NOAA Aeronomy Laboratory of Boulder, the NASA Langley Research Center, the Oregon Graduate Center, and the Max Planck Institute for Chemistry (Mainz, Germany).

GLOBAL HALOGEN GROUP

The total chlorine research effort within the In-Situ Measurements and Photochemical Modeling Project (ISPHOM) has been continued and expanded as part of the Global Halogen Group (GHG). Currently the major atmospheric pathways in the halogen cycles are known only in the broadest sense, with key transformation processes and rates almost completely unknown. Reservoir magnitudes and cycle rates are not known, and predictive atmospheric models cannot be evaluated at present because most of the suspected key tropospheric halogen-containing species have not been detected in the atmosphere. Hence, a detailed examination of the global geochemical cycle of each halogen was initiated early in 1980, with particular emphasis on the movement of chlorine- and bromine-containing species from biospheric, oceanic, and anthropogenic sources through the troposphere and the stratosphere. The ongoing stratospheric total-halogen measurement effort was continued as part of this program during 1980 and is being treated as an integral part of the larger research effort designed to increase our understanding of the global movement of halogen-containing species.

A systematic approach to the study of global halogen pathways has been adopted in these studies, with initial research emphasis being placed on source/sink processes and on absolute reservoir magnitudes and rates. This has resulted in a two-pronged effort backed by one-dimensional model studies, with major field measurement efforts being focused on the low to midstratosphere and on the atmosphere immediately adjacent to the ocean surface.

In order to conduct atmospheric halogen sampling at the sea surface the total chlorine collection system that had been used in the stratosphere on aircraft and balloon platforms was modified for use as a trace-halogen sampling system in the marine atmosphere. Frank Grahek designed, built, and tested five complete tropospheric halogen sampling systems using a modular four-unit sampling head. Each unit provides sampling capabilities to the parts-per-trillion (volume) level or less for (1) the individual halogen total volume mixing ratio, (2) the inorganic halogen gas fraction, (3) the organic halogen gas fraction, and (4) the total halogen aerosol content. During 1980 these units were deployed in a series of coordinated coastal and open ocean halogen field studies.

Working closely with Wolfgang Seiler (Max Planck Institute for Chemistry, Mainz, West Germany), a mid-Atlantic field sampling program was launched using the NCAR-developed halogen sampling system (on board the German research vessel Meteor). During October and November 1980 a carefully selected series of individual halogen measurements was made employing a diurnal sampling scheme down the middle of the Atlantic Ocean in both the Northern and the Southern Hemispheres.

During this same period two additional field projects were launched on a coordinated basis. The first, led by Sonia Gitlin, consisted of the deployment of NCAR halogen sampling systems along the west coast of Chile in South America. A series of 96 four-unit modules was used in a diurnal sampling program judiciously carried out under remote and pristine marine atmosphere conditions. The second, led by Walter Berg, consisted of a series of East Coast halogen measurements at the experimental research pier in Duck Point, North Carolina. The field program was a joint NCAR-NASA effort, with Robert Harriss, senior marine scientist at the NASA Langley Research Center, working closely with GHG. This field project represents the first phase of an anticipated three phase cooperative research program on atmospheric halogen chemistry between NASA and NCAR.

The 385 samples collected as part of the GHG tropospheric field program are still being analyzed and tabulated. Most of the gas samples have been trapped on an ultrapure activated charcoal substrate. Typically six charcoal traps are positioned in line to insure a 100% collection efficiency. The inorganic halogen gas fraction is trapped on ultrapure nylon prefilters (or on tetra-butylammonium hydroxide treated prefilters). The halogen aerosol is collected using 0.4 μ Nuclepore prefilters. The key to this simple yet effective sampling system is the ability to prepare a charcoal sampling substrate with very low level chlorine, bromine, and iodine contaminants. Granular activated charcoal, selected grain by grain, is used following an extensive acid/base extraction procedure and a degassing process in which the charcoal is baked at 820°C under high vacuum ($<8 \times 10^{-5}$ torr) for a continuous period of 30 days. The elemental halogen determination in this matrix is made by nondestructive instrumental neutron activation techniques. Analyses are performed by counting the (1) 1,642 keV peak from the ^{38}Cl γ-ray ($t_{1/2}$ = 37.29 min), (2) the 617 keV peak of the ^{80}Br γ-ray ($t_{1/2}$= 4.5 h), and (3) the 443 keV peak of the ^{128}I γ-ray ($t_{1/2}$ = 25.4 min). A unique dual γ-ray detector system is employed in which a closed-end Ge(Li) diode is surrounded by a NaI annulus. By operating the annulus in anticoincidence, i.e., accepting a pulse from the Ge(Li) detector for pulse-height analysis only when it is not accompanied by a simultaneous (escape) pulse from the annulus, a very significant improvement in the peak-to-background ratio is realized. The coupling of these analytical techniques with a very low background sampling substrate has enabled GHG to make and report the first total halogen measurements in both the troposphere and the stratosphere. Initial results from these efforts for both chlorine and bromine were published in the November 1980 issue of Geophysical Research Letters.

In addition to the tropospheric work, a strong effort was made to continue the stratospheric total halogen sampling program. Observations of total chlorine (Cl_{tot}) as a function of season, latitude, altitude, and time of day made in conjunction with measurements of major stratospheric chlorine species are needed (1) to explore any chlorine species variability (e.g., Cl and ClO) at the same moment that all chlorine species (Cl_{tot}) are trapped and accounted for, (2) to carefully examine the stratospheric chlorine budget to insure that all significant chlorine species have been properly accounted for in considerations of chlorine-ozone photochemistry, and (3) to provide the necessary global limits on stratospheric chlorine for photochemical modeling efforts. Additionally, measurement of stratospheric total bromine (Br_{tot}) together with Cl_{tot} may prove to be very important because of the possible Cl-Br synergism involving reactions between BrO and ClO. Model predictions of a 5 to 20% enhancement of ozone destruction have been reported for Br_{tot} values of about 20 pptv, and recent stratospheric Br_{tot} values of up to 40 pptv at 20 km have been found and published by the Global Halogen research group. Hence, a strong research effort is being maintained to simultaneously measure Cl_{tot}, Br_{tot}, and I_{tot} up to 40 km over a wide range of latitudes.

During 1980 a dual sampling program was followed involving both balloon and aircraft total halogen sampling platforms. Two balloon flights to 25 km, utilizing the NCAR-developed 907 kg (2,000 lb) halogen sampling payload, were conducted back to back on 3 and 11 November 1980 from Holloman AFB, New Mexico. These flights yielded first-time data showing unexpectedly large variability in bromine total volume mixing ratios. Total chlorine values centering on 2.9 ± 0.6 ppbv chlorine were also observed.

Both of the stratospheric Cl_{tot} and Br_{tot} observed values were substantially higher than predicted by most one- and two-dimensional photochemical models. These data suggest that perhaps not all of the chlorine and bromine compounds have been properly considered and accounted for in the stratospheric halogen budget.

A series of 24 flights was also carried out during April, July, and November of 1980 employing the NCAR-built halogen sampling system on board a NASA WB-57F aircraft. Measurements of Cl_{tot}, Br_{tot}, and I_{tot} were made at 18.0 to 19.3 km (1) in the Southern Hemisphere from Montevideo, Uruguay, down to 52°S, (2) near the equator and ranging over the Yucatan Peninsula (18°N), and (3) up to 75°N near the Arctic Circle. These sampling missions were conducted as part of an ongoing joint research program between the Los Alamos Scientific Laboratory and NCAR. As part of this cooperative effort GHG has furnished all of the halogen sampling systems and the analytical expertise necessary to perform the halogen determinations. The Los Alamos research group, headed by Paul Guthals, has furnished the aircraft platform and the nuclear reactor needed for the halogen analyses. Results from the joint aircraft flights are still being compiled and tabulated.

For the global halogen research program in the coming year major emphasis will be placed on carefully combining both tropospheric and stratospheric halogen data. These data will then be used to develop a more coherent geochemical model of the global cycling of each halogen. As part of this effort, two long-duration balloon flights to 40 km are also planned for May and October 1981. These flights will be carried out simultaneously with other balloon sampling missions (i.e., conducted by the Anderson, Murcray, and Roscoe [Oxford University] research teams) in order to carefully explore the role that Cl, ClO, HCl, total chlorine, and total bromine play in the photochemistry of ozone in the stratosphere.

BIOSPHERE-ATMOSPHERE INTERACTIONS SUBPROJECT

The Biosphere-Atmosphere Interactions (BAI) Subproject is the NCAR focus for biogeochemistry as it relates to aspects of that discipline which are of consequence to the chemical balance and dynamics of the atmosphere. During the past year activities of BAI have emphasized extensive field work, laboratory and analytical development, and the development of cooperative research efforts.

The field work accomplished during 1980 included a one-week project in Guatemala in February of 1980, a four-week experiment during May and June near Ft. Collins, Colorado, and a four-week experiment in Brazil during the months of August and September. In addition, throughout the summer a cooperative experimental program with Donald Johnson (Colorado State University) was conducted.

One of the major BAI contributions to the experiment which took place in Guatemala was the collection of gas samples from the burning of tropical biomass. Samples were collected from sugar cane fires, agricultural residue fires, and fires used to prepare tropical fields for grazing. The experiment was an important field test for equipment which had been developed for the more extensive project planned for Brazil in 1980. The sampling conditions and the types of material burned could not have been easily duplicated in the United States.

In addition, in Guatemala BAI collected the first samples of volatile emissions from tropical vegetation and from a tropical swamp. Preliminary samples of the emissions from termite nests were also collected. All of the samples were analyzed for COS, N_2O, CO, CO_2, CH_4, and the C_2-C_{10} hydrocarbons. Although data reduction has not been completed for all of the samples, preliminary results indicate that termites may be a significant source of atmospheric methane. We are continuing our study into the potential of termites as sources of various trace gases. The data resulting from the Guatemala experiment will be published next year. Since the BAI involvement in the Guatemala project was a "tag-along" effort on a larger project of Cadle's designed to study emissions from volcanoes, it proved a cost-effective approach to the problem.

The experiment conducted at the Pawnee National Grasslands near Ft. Collins, Colorado, was sponsored jointly by ACAD and ASP. It occurred as a part of a summer colloquium and was designed to simultaneously measure carbon, hydrogen, oxygen, and nitrogen (CHON) species in the atmosphere and to model their interactions. The CHON colloquium included lectures presented by invited scientists on various aspects of atmospheric chemistry, laboratory and field work involving graduate students and scientists, and modeling of the data collected. BAI participated by making ambient measurements of C_2-C_{10} hydrocarbons for comparison with and corroboration of similar measurements made by researchers from the University of Colorado and Washington State University. The measurements provided a comparison of samples collected in stainless steel containers and on various solid adsorbents. The hydrocarbon data were critical to the photochemical modeling effort.

The BAI group also assisted graduate students in collecting samples of hydrocarbon emissions from the soils and slews at the grassland site so that the contribution of biogenic hydrocarbons to atmospheric photochemistry could be calculated. In addition, samples of CH_4 emissions from small ponds present at the site were collected so that the C_{12}/F C_{14} ratios could be determined. The C_{12} isotope is characteristic of "dead" fossil fuel carbon, while C_{14}, produced as the result of cosmic rays and nuclear bomb blasts, is of more recent origin. By determining the C_{12}/C_{14} ratio for biogenically produced methane, carbon cycling and organic matter lifetimes can be inferred and comparisons with the C_{12}/C_{14} ratio of atmospheric methane can provide insight into its origin.

The 1980 Brazil Brush Fire Experiment (Queimadas '80) included researchers from ACAD, as well as from Florida State University and the Max Planck Institute in Mainz, Germany. Persons involved are named in the Gas and Aerosol Aircraft Measurements Subproject section of this report. The research was primarily designed to aid in making estimates of the impact of biomass burning in the tropics on the chemistry of the atmosphere. The BAI personnel involved in the field work included James Greenberg and Patrick Zimmerman. The primary responsibility of BAI was the collection of ground level samples of the gaseous emissions from fires and the analysis of fire, aircraft, and background air samples for C_2-C_{15} hydrocarbons. Some hydrocarbons emitted by vegetation and some that are produced and/or released during biomass burning are highly photochemically reactive. They therefore have a substantial impact upon the photochemistry of the region. In addition, one of the most probable long-term decomposition products of biogenically emitted hydrocarbons (such as isoprene) is carbon monoxide. The composition of carbon monoxide is one of the primary factors that determine the steady state concentration of hydroxyl radical (OH) in the atmosphere. OH, in turn, is probably one of the most important oxidizers in the troposphere and its reactions with other trace gases dominate much of the chemistry that occurs. Therefore, hydrocarbon data are important in the determination of the regional photochemistry of the area and its impact upon global atmospheric chemistry.

An overview of the Queimadas '80 Project and the initial data generated as a result of that effort will be written jointly by ACAD and the Max Planck Institute and will be submitted during 1981 for publication in a Brazilian scientific journal.

A collaborative experimental program with the Animal Science Department of Colorado State University (CSU) was initiated in 1980. The animal metabolic laboratory at CSU contains sophisticated chamber systems which are used to study energy balances in ruminants. Cattle are put into chambers and fed carefully analyzed diets. Emissions of carbon dioxide, methane, and heat are then quantified as a function of weight gain. It has been widely reported that ruminants are responsible for up to one-fourth of the methane released into the atmosphere annually. In addition, new drugs are being developed to control energy loss by reducing the production of methane and thus increasing cattle weight gain. BAI scientific staff believed that this treatment also had the potential to alter the emissions of other trace gases. Air samples collected in the chambers were analyzed by the BAI staff for C_2-C_{10} hydrocarbons. Leroy Heidt was responsible for the analysis of COS, N_2O, CO, CH_4, and CO_2. Treated and nontreated steers were sampled. Tabulation of the results is proceeding and will be completed during 1981.

Visitors to BAI during 1980 included Takashi Yasuoka (Tokai University, Japan). Since his arrival in April of 1980, he has conducted extensive laboratory experiments on selected parameters which may potentially affect hydrocarbon emissions from vegetation. Experiments are being completed on relative humidity and CO_2. The species chosen for study were ponderosa pine and blue spruce. Both are common temperate zone species and are easy to obtain locally during the winter months. Ponderosa pine is a terpene emitter and blue spruce emits both terpenes and isoprenes. The data generated during the course of the experiments will be critical to the meaningful extrapolation of field measurements of biogenic hydrocarbon emissions to annual and global estimates. These estimates are necessary for regional air pollution inventories since terpenes and isoprene are photochemically active. They are also required inputs for most tropospheric photochemical models.

Another visitor, Bernard Bonsang from the Centre des Faibles Radioactivities, Laboratoire Mixte, Centre National (LNEXO), France, arrived in October 1980 to continue his study of sulfur emissions into the atmosphere. At NCAR he has been primarily involved in the development of an analytical methodology for the measurement of reduced sulfur compounds. Bonsang has been working with different methods of reduced sulfur species detection and he has tested flame photometric and photoionization detectors. He has also experimented with many types of chromatographic columns for the separation of organo-sulfur compounds which may be present in the atmosphere. Very few data are available about the importance of biogenic sulfur compounds in the atmosphere. They are important with respect to such varied questions as the cycling rates of sulfur through soils and wetlands and the origin of acid rain. It is hoped that the analytical and sampling methodologies will lead to meaningful atmospheric measurements and biogenic flux estimates.

During 1980 BAI also helped to initiate a one-year visit from a representative of an ad hoc group of researchers involved with forest meteorology. The representative will attempt to develop some long term funding sources for forest meteorology research and will pursue boundary layer research of mutual interest to BAI and other NCAR groups. In addition the representative will provide valuable micrometeorological assistance to BAI.

BAI made significant strides in improving its analytical capabilities during 1980. A room was remodeled for a laboratory and many new pieces of instrumentation were acquired and modified and made operable to satisfy specific research requirements. The laboratory is now equipped with nine flame ionization detectors located in three gas chromatographs. The BAI laboratory currently has the capacity to analyze C_1-C_{15} hydrocarbons in ambient air samples with a sensitivity of less than one part per billion.

The group is also developing techniques which can be used for non-cryogenic sample preconcentration and anlysis. These techniques include the development of chromatographic columns which do not require subambient programming for the separation of C_2-C_6 hydrocarbons and testing of solid adsorbents such as tenax and silicalite. Noncryogenic techniques are necessary since cryogens are usually very difficult (often impossible) to obtain in many field locations.

The BAI group also has the capability of chromatographically measuring reduced sulfur compounds, CO and CO_2. In addition the group has a gas chromatograph equipped with dual electron capture detectors for halocarbon analysis and dual thermal conductivity detectors for non-specific measurement of gaseous components present in air at high concentrations (e.g., N_2, O_2).

Plans were completed in 1980 for the expansion of the usable BAI laboratory space. The work will be completed in 1981. These facilities will greatly enhance the BAI's current research programs and future collaborative efforts.

Plans for the future include publication of the data generated in 1980. Some of the data generated as a result of the Guatemala project will be incorporated into a Ph.D. dissertation on biogenic hydrocarbon emissions to be authored by Zimmerman. The results of the CHON experiment will be discussed in an NCAR publication. The biogenic hydrocarbon emission data collected during the course of the CHON experiment will also be included in Zimmerman's Ph.D. dissertation. As mentioned above, the data resulting from Queimadas '80 will be published in Brazil jointly by ACAD and the Max Planck Institute. After the initial publication, the BAI staff expects to write papers on the detailed hydrocarbon composition of jungle air in the Amazon rain forest and on the hydrocarbon composition of the air near tropical biomass burning. The joint research with CSU concerning emissions from ruminants will be incorporated into a master's thesis by Daniel Benz (CSU). The implications of the research to atmospheric science and to animal science are expected to be published jointly with Donald Johnson (CSU).

The experiments conducted by Yasuoka will result in publications concerning the effects of relative humidity and CO_2 on hydrocarbon emissions from conifers. The data will also be used by Zimmerman in his dissertation to aid in extrapolating field measurements to global estimates of biogenic hydrocarbon emissions.

In the coming year, BAI will develop an experimental program with Shem Wandiga (University of Nairobi, Kenya) during his stay as a long term visitor to NCAR. The program will be designed to make preliminary estimates of the importance of various biomass decomposition processes to chemistry of the atmosphere. If the work proves to be fruitful, a long term cooperative program could develop.

The BAI staff also plans to participate in a project with Washington State University to develop better methods for measuring trace gas fluxes from biogenic sources. The research will compare trace gas fluxes measured with various enclosure, micrometeorological, and tracer techniques. It hopefully will result in the development of a simple, accurate method, one which is compatible with the limited level of logistic support available during many field projects in remote areas.

GAS AND AEROSOL AIRCRAFT MEASUREMENTS SUBPROJECT

The Gas and Aerosol Aircraft Measurements (GAME) Subproject of ISPHOM emphasizes two principal areas of independent research; the first of these concerns tropospheric ozone and oxides of nitrogen, and the second concerns tropospheric aerosols. Project members also provide a resource in leadership, expertise, techniques, and instrumentation for other divisional efforts. During the year 1980 a heavy emphasis on the latter responsibility is apparent, as GAME participation in the Pawnee Grasslands and Queimadas '80 projects will illustrate.

The 1980 NCAR summer colloquium was planned and organized by members of ACAD and ASP with Anthony Delany playing a leading role. The format employed for the colloquium was fairly unusual inasmuch as it was fashioned around the operational requirements of a research experiment (the Grasslands Project). This project involved the determination of a comprehensive set of photochemically active carbon, hydrogen, oxygen, and nitrogen compounds, together with a modeling effort aimed at reproducing and understanding the interactions of these species. It also involved establishing the experiment logistics and a good deal of work erecting towers and setting up the research site. This was done by Delany, Arthur Wartburg, Grahek, Gerald Dolan, Frank Melchior (all of ACAD), and Edward Barry (a colloquium student from Old Dominion University).

During the last few years great advances have been made in our ability both to measure atmospheric species and to understand their interactions. Although many studies of separate compounds and of simple sets have been carried out, no truly comprehensive study has been made to simultaneously measure the major tropospheric CHON species. In the Grasslands Project investigators from universities and government agencies were invited to join NCAR scientists in a cooperative program (for a list of the 37 participants please see the colloquium proceedings volume, which is available from the ASP or the ACAD office). The measurement program was complemented by modeling work, and an effort was made to effect a relatively rapid data turnaround in order that the closure between measurement and model could be examined during the period of the colloquium. In addition to the definition of the CHON photostate, the ground removal fluxes of O_3, NOX, and HNO_3 were to be measured.

In choosing a field site many aspects had to be considered. Although no attempt was to be made to investigate pristine air, the influences of strong local anthropogenic sources were to be avoided and as pollution-free an area as possible was sought. In order to investigate uptake fluxes of trace gases, it was necessary to be situated in a relatively flat area without pronounced orographic wind patterns. Finally, logistical support required that it be not too distant from NCAR.

The site selected was at the USDA Pawnee Grasslands Research Station 110 km northeast of Boulder, 20 km east of the foothills on the northern slope of the South Platte Basin. This short grass prairie region was removed from pollution sources and can be taken as representative of the extensive grasslands existing throughout the world.

In order to be able to carry out the comprehensive study, a fairly large crew of researchers was needed. The summer colloquium planned at NCAR permitted support through a group of graduate students who were able to maintain and operate the instrumentation, as well as work with the data reduction and programming. The colloquium was divided into two distinct periods; the first was an applied phase in which the colloquium investigators and students worked together to establish an experimental and modeling program. The second phase consisted of lectures covering the various aspects of the study. These lectures, together with the results of the experimental measurements and their comparison with model calculations, formed the basis of the colloquium proceedings which are now available. Further analysis of the Grasslands data is now proceeding, and it is expected that a colloquium supplement will be issued in a year's time comprised of research papers based upon the Grasslands data.

The investigation of the large scale vegetation burning begun in Brazil in the summer of 1980 was continued. This effort, titled Queimadas '80, was a cooperative program involving people from NCAR, including Delany, Wartburg, and Grahek of GAME; Zimmerman and James Greenberg of BAI; and Heidt, Pollock, and Lueb of ISPHOM. Foreign members contributing to the experiment included Crutzen and Seiler of the Max Planck Institute, Inacio Martin of the Instituto de Pesquisas Espaciais (INPE), Salati and Schubart of the Instituto de Pesquisas da Amazonia (INPA), Alistair Leslie and Louis Boueres of the Florida State University, and Celso Orsini of the University of Sao Paulo. A base was established at the INPA facility in Manaus, where a gas chromatography laboratory was set up. Aircraft flights were made both over the selva, or jungle, and to the south over the cerrado, or grasslands. Aboard the NCAR Sabreliner, ozone, oxides of nitrogen, carbon monoxide, water vapor, and meteorological parameters were monitored continuously, and can samples were taken at intervals for subsequent laboratory analysis for hydrocarbons and stable trace gases.

A series of flights was made over the selva to observe both clean uninhabited areas and forest clearing zones. Missions were flown through smoke plumes over the latter. On the series of flights to the south, fires were avoided; but given a subsidence inversion over the cerrado, the entire boundary layer contained elevated concentrations of oxides of nitrogen, carbon monoxide, and ozone.

Analysis of both the chemical and the meteorological data, which is being carried out by Delany, Philip Haagenson, and Walters, suggests that the two major atmospheric regimes which were encountered over central Brazil relate to the major vegetation regimes--the selva, with its generally well-mixed troposphere, and the cerrado over which, during the dry season, a strong subsidence inversion inhibits vertical mixing. The boundary layer itself is well mixed, and smoke and fumes from the fires quickly mix throughout the 4-5 km depth. This mixture of oxides of nitrogen, carbon monoxide, and hydrocarbons undergoes photochemistry and produces an excess of photochemical ozone. By contrast, the lower boundary layer over the selva shows a marked depletion in ozone. The mechanism of this depletion is not yet clear but may be efficient destruction within the forest canopy by biological surfaces or by reaction with unsaturated hydrocarbon emitted by the trees. Zimmerman's analysis of samples collected at different altitudes above the forest canopy for hydrocarbons should provide additional information which may enable us to decide which mechanism is most important.

Preparation for the Tropfold '81 spring Sabreliner flights intended to investigate the dynamics of tropopause folds and their contribution to stratosphere/troposphere exchange of chemical constituents has proceeded. This work is being done in cooperation with Melvyn Shapiro, Grahek, Wartburg, and Edward Stone (University of Michigan). It will involve an investigation of the dynamics of turbulent transfer and the measurement of ozone, water, and oxides of nitrogen.

PRECIPITATION CHEMISTRY AND REACTIVE GASES AND PARTICLES PROJECT

Volcanic Effects and Stratospheric Chemistry

For the first time a stratospheric aircraft capable of many simultaneous chemical and physical measurements was ready for deployment at the time of a major volcanic eruption. On 18 May Mt. St. Helens erupted; on 19 May through 17 June the U2 aircraft based at NASA Ames made five sampling flights through the stratospheric portion of the volcanic plume in conjunction with NASA's Aerosol Climatic Effects Program. Our recently developed Multiple Filter Sampler for collection of stratospheric trace gases and particles operated throughout these sampling missions. This sampler, capable of accommodating chemisorption beds, impregnated filters, and filter packs, was developed by Edward Lambdin (Research Systems Facility), Bruce Gandrud, and Allan Lazrus.

During the past year, samples from this instrument were used by Gandrud and Lazrus to measure gaseous hydrogen fluoride, hydrogen chloride, and nitric acid, and aerosol-phase ammonium and sulfate ions. In addition, polystyrene filters were used to collect samples for neutron activation analysis by William Zoller (University of Maryland), in order to determine enrichment factors of many elements in stratospheric aerosol. The sampling was conducted by Gandrud and William Sonnefeld (University of Maryland).

One of the fundamental problems addressed was the extent to which a major volcano injects hydrogen chloride into the stratosphere. This gas can react with hydroxyl radicals in the stratosphere, thereby producing chlorine atoms which have been shown to be effective catalysts for ozone destruction. During the U2 flights, no evidence was found for the enhancement of hydrogen chloride in the stratosphere. This appears inconsistent with two other sets of our measurements 1) large amounts of sulfate aerosol formed from sulfur dioxide injected by St. Helens were observed, 2) in cooperative flights with the U. S. Geological Survey, Lazrus collected samples of the tropospheric plume of St. Helens which contained comparable amounts of hydrogen chloride and sulfur dioxide. Clearly, a selective removal of hydrogen chloride must occur as the plume ascends and cools to stratospheric temperatures. This is probably due to the presence of copious amounts of water vapor in the plume, which must condense on particles and either precipitate out of the rising plume or fall out of the stratosphere as ice-coated ash particles. At 0°, the solubility of SO_2 is 300 times less than that of HCl in water. The solubility of SO_2 is further depressed by dissolved acids such as HCl, thereby accounting for the observed enhancement of volcanic sulfur in the stratosphere, and the absence of volcanic HCl.

During autumn, similar sampling was conducted by Gandrud on three more U2 missions flown between 55°N and 23°S in order to observe the concentration trends of volcanic sulfate and to provide confirmation data for aerosol measurements of NASA's Stratospheric Aerosol and Gas Experiment satellite experiment.

Sampling of the tropospheric plumes of Mt. St. Helens (for HCl, HF, SO_2, H_2S, HNO_3, $SO_4^=$, and NH_4^+) has also continued in cooperation with the U.S. Geological Survey and Cadle. Analysis of these samples is presently under way. The stratospheric and volcanic research was conducted by Gandrud and Lazrus (Gandrud and Lazrus, 1980; see the publications section).

Tropospheric Chemistry

The Acid Precipitation Experiment (APEX) continued throughout 1980. APEX, which is coordinated at NCAR and utilizes both NCAR's Research Aviation Facility and the Scientific Computing Division, is primarily a university project aimed at understanding the chemical and meteorological processes leading to acid rain. APEX is funded jointly by NSF and the Environmental Protection Agency.

Participants in APEX during 1980 included Volker Mohnen (State University of New York at Albany); Eugene Likens and John Eaton (Cornell University); Gregory Kok (Harvey Mudd College); Carl Kreitzberg (Drexel University); John Winchester (Florida State University); Barry Huebert (Colorado College); Lazrus, Haagenson, Paul Sperry, and Lawrence Beaman (NCAR), and Ronald Ferek (Florida State University and NCAR).

In 1979 two field missions were completed (one in spring and the second in late autumn) during which specific cases of warm frontal and cold frontal precipitation were studied. In summer of 1980, APEX concentrated on cumulus convective precipitation in the Ohio River Valley and the Adirondack Mountains. The analysis of these samples has recently been completed.

Sulfur species measured were SO_2 vapor, total sulfate aerosol, sulfuric acid aerosol (by titration and also by electron microscopic identification), elemental aerosol sulfur as a function of particle size, and sulfate in both cloud and rain water. Nitrogen species included HNO_3, NH_3, NO, and NO_2 vapors; NH_4^+ and NO_3^- in aerosol; and NH_4^+ and NO_3^- in cloud and rain water. Ozone vapor and hydrogen peroxide dissolved in cloud and rain water were measured. The metals Na^+, K^+, Ca^+, Mg^+, and others were measured both in aerosol and liquid samples. Acidity was of course also measured in a wide array of cloud and rain samples collected in the Midwest and the Adirondacks.

During 1980, the data analysis and interpretation for the 1979 missions were undertaken and are now being prepared for publication. These publications focus on the distribution of acids and acid precursors in nonprecipitating air and their relationship to acids found in cloud water condensed from the same air. Specific cases of warm frontal, cold frontal, and orographic precipitation were treated in light of chemical and meteorological analyses. The relative contributions of in-cloud and below-cloud scavenging processes were also examined.

Experimentally, two unique developments occurred. First was the design, construction, and testing, in cooperation with APEX, of the first efficient collector of cloud water from nonprecipitating clouds. The device was constructed by Mohnen and others at the New York Atmospheric Sciences Research Center, with the cooperation of Sperry and Lazrus. The second was the discovery by Beaman and Lazrus of unexpected complexities in the test for hydrogen peroxide vapor as developed by Kok. Further investigation of the chemistry involved has led to the study of a possibly important new mechanism for the transformation of sulfur dioxide to sulfuric acid in clouds.

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 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 atmosphere, 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 the effect of magnetospheric plasma convection at high latitudes on the global circulation and temperature structure of the thermosphere. This work is a collaborative effort between Raymond Roble, Robert Dickinson (AAP), and Cicely Ridley (Scientific Computing Division.) 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. Magnetospheric plasma convection is sun-aligned about the geomagnetic pole and there is also a tendency for the plasma to corotate about the geographic pole. The displaced geomagnetic and geographic poles give rise to a complex plasma motion with a universal time variation. An empirical model has been designed to parameterize the ion drift pattern over the polar regions. This ion drift pattern is appropriately mapped to lower altitudes, where the relative drift between the ion and neutral wind velocities are used to calculate the Joule heating and ion drag momentum source at each time step in the TGCM. The results show that Joule heating and ion drag both have a significant effect in altering the global circulation of the thermosphere. The ion drag momentum source primarily controls the wind and temperature structure at F-region heights whereas Joule heating is dominant at E-region heights. For enhanced levels of magnetospheric convection during moderate geomagnetic activity wind speeds of 400 m s^{-1} and temperature increases of about 400°K are calculated in the polar regions. In addition, a very complex circulation pattern is evident at high latitudes that varies with season.

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), who measure thermospheric winds and temperatures from ground-based optical observatories, and John Evans (Massachusetts Institute of Technology), Fred Herraro (University of Puerto Rico), and Vincent Wickwar (SRI), who determine winds and temperatures from incoherent scatter radar data at Millstone Hill, Arecibo, and Chatanika, respectively.

The TGCM produces diurnal variations of neutral gas temperature and winds at the stations of each observer and these predictions are compared to the measured properties. In addition to the ground-based data, the model wind predictions are also being compared to measurements made by Nelson Spencer (GSFC) from the Atmospheric Explorer Satellite.

In ionospheric modeling, work is continuing toward the development of a global ionosphere that will interact with the TGCM. This model is an outgrowth of the global dynamo model being developed in collaboration with Arthur Richmond (NOAA). The current version of the dynamo model uses the winds calculated by the TGCM and solves the appropriate dynamo equations on a sphere to determine the global ionospheric potential distribution, horizontal and field-aligned currents. The electric fields that are calculated are also used to determine their influence on the global ionospheric structure.

The winds and temperatures calculated by the TGCM are also used with a low-latitude ionospheric model to study the structure of the equatorial ionosphere. This work is being done in collaboration with David Anderson (NOAA) to evaluate the overall importance of thermospheric dynamics in controlling the low-latitude ionosphere.

The ionospheric model has also been used to calculate the global distribution of the thermospheric heating rate. This heating rate has been decomposed into the tidal Hough and associated Legendre modes for analysis of thermospheric tidal structure. The work being done in collaboration with Siu-Shong Hong (National Central University, Taiwan, Republic of China) shows significant differences in the heating distribution and tidal structure between solar cycle minimum and solar cycle maximum conditions.

The aurora model being developed in collaboration with Rees and Barbara Emery has been used to calculate the ionospheric effects and spectroscopic emission rates for several coordinated campaigns using ground-based, rocket, and satellite measurements. The model is also being used by Wickwar for a 24 h simulation over the Chatanika, Alaska, incoherent scatter radar station and by Chung Park (Stanford University) to study ionospheric effects of VLF radiofrequency-induced particle precipitation events from the magnetosphere.

In global electrical modeling, the global model of atmospheric electricity has been used to study the effects of solar-terrestrial events on the global distribution of currents and fields. The ionization rate variations associated with the Forbush decrease appear to affect currents and fields in the global electrical circuit. This work is a continuing collaboration with Hays, Israel Tzur, Richmond, and George Reid (NOAA).

In addition to the global modeling, a new one-dimensional model that solves for the ion distribution, electric field, and the charging of the earth simultaneously has been constructed. The time-dependent model resolves the electrode layer near the ground and it extends to an altitude of 100 km, properly accounting for the charge distribution of small and large ions and also the transition near 70 km between small negative ions and electrons. The model has been used to calculate the time-dependent electrical response to solar protons associated with the August 1972 polar cap absorption (PCA) event. The current carried by the solar protons is about 100 times larger than the fair weather air-earth current driven by worldwide thunderstorm activity. The positive space charge deposited in the atmosphere near 30 km is sufficiently large to reverse the normal fair weather field direction and affect the global circuit. The model has also been used to examine a number of other electrical effects near the earth's surface and in the middle atmosphere. This model is currently being extended to two dimensions to examine problems with horizontal spatial variability.

A two-dimensional chemical-dynamic model of the thermosphere and mesosphere has been developed in collaboration with James Kasting (ASP postdoctoral fellow, University of Michigan) to examine the mutual interactions between dynamics and the chemistry associated with the oxygen cycle. Dynamics has been shown to be very important for maintaining the atomic oxygen winter bulge and the seasonal distribution of molecular oxygen. It was also shown that the dynamic structure of the mesosphere also has an important effect on the thermospheric distribution of oxygen species.

A two-dimensional chemical-dynamic transport model has also been developed to study the complex chemical system involving NO, $N(^4S)$, and $N(^2D)$ in the lower thermosphere. This model has been developed in collaboration with John Gary (CU) and it is being used in collaboration with Jean-Claude Gérard (University of Liege, Belgium) to study the 5200 Å emission from $N(^2D)$ in the vicinity of the magnetospheric cusp and by David Rusch (CU) and Ian Stewart (CU) to determine the global distribution of NO and compare the results with observations from the Atmospheric Explorer Satellite.

A two-dimensional chemical dynamic model from the ground to the lower thermosphere has been developed in collaboration with Solomon and Crutzen. This model is being used by Solomon as part of her thesis to study the importance of thermospheric and auroral sources of NO in affecting the chemistry of the stratosphere and mesosphere. Her results show that the thermospheric and auroral sources of NO have an important influence on the mesospheric chemistry and that in the polar night region NO is transported to stratospheric heights where interactions with ozone occur. The model has been used to determine the global distribution of both neutral and ionized species and these distributions are being used to predict the infrared emission rates that are being used to design the CULER instrument on the UARS satellite. This latter effort is being done in collaboration with Gille, Mankin, and Coffey.

In addition to the above project activity, work is continuing toward participation in the NASA Dynamics Explorer Satellite activities with an expected satellite launch of 31 July 1981. Roble is a theoretician for the satellite team.

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 continued to center on the reduction of data from the Limb Infrared Monitor of the Stratosphere (LIMS) experiment on board the Nimbus 7 spacecraft. John Gille is coleader 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 (Rutherford and Appleton Laboratories, 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).

The LIMS operated very well from its launch on 24 October 1978 until the supply of solid methane cryogen was expended on 4 June 1979. The data appear to be of excellent quality, with very low noise levels.

The data reduction takes place in three steps. Initially, the raw data are converted to calibrated, located profiles of radiance. In the second step, the radiances from the six channels are converted to vertical profiles of temperature, O_3, H_2O, NO_2, and HNO_3, all registered on a pressure scale. In the third step, these profiles are analyzed to yield data from which maps and cross sections of these quantities can be prepared.

Paul Bailey, Douglas Roewe, and Gille developed algorithms to produce calibrated radiances, vertical profiles, and analyses. Bailey and Stanley Nolte have implemented these on a SEL 32/35 minicomputer. The production and distribution of calibrated radiance data are now complete.

In comparing the results of the initial inversion algorithm to correlative radiosonde and rocketsonde data, small but systematic temperature differences were discovered. Subsequent study showed that these varied from day to night, and appear to be due to atmospheric effects which were not incorporated in the initial algorithms. Corrections are now being developed.

Similar comparisons of trace gas retrievals have been compared to rocket and balloon measurements, and generally show reasonably good agreement. These algorithm developments should be completed early in 1981. Production of the inverted data is scheduled to begin in March.

Gille, Russell, and Fischer presented preliminary results from the LIMS sounder at the international Committee on Space Research meeting. Those authors, Remsberg and Harries also presented results of LIMS-related studies at the Ozone and Radiation Symposia.

Gille is team leader for two instrument definition studies for the Upper Atmosphere Research Satellite (UARS). The first of these is the Advanced Limb Scanner (ALS). He and associate principal investigator Russell are joined by Ralph Cicerone (formerly Scripps Institution of Oceanography, now NCAR), Paul Crutzen (formerly NCAR, now Max Planck Institute), and Marvin Geller (formerly University of Miami, now NASA Goddard Space Flight Center [GSFC]). Bailey is serving as data manager. This instrument builds heavily on the Limb Radiance Inversion Radiometer (LRIR) and LIMS technology and experience. It is designed to measure the LIMS gases, plus CF_2Cl_2, CH_4, N_2O, and NO. It is expected that these can be measured from about 10 km to 70 km.

The second instrument is the Cryogenic Upper-Atmosphere Limb Emission Radiometer (CULER). This is also a limb scanner, but employs cold baffles and optics as well as detectors to reduce the noise level to the point where signals can be obtained into the low thermosphere. In addition to the ALS gases, $CFCl_3$, CO, and several near-infrared auroral emissions will be observed, as will rotational temperatures. Joining Gille are William Mankin, Raymond Roble, Michael Coffey, and Bailey from NCAR, working with a team of co-investigators which includes Crutzen, Geller, James Holton (University of Washington), Virgil Kunde (GSFC), David Murcray (Denver University), Russell, and A. T. Stair Jr. (Air Force Geophysics Laboratory).

In other activities, Gille, Bailey, Coffey, and Mankin have been working with University of Colorado (CU) and Laboratory for Atmospheric and Space Physics (LASP) scientists on the calibration and testing of a limb scanning infrared radiometer for the Solar Mesosphere Explorer (SME) satellite, scheduled for launch in the 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 Crutzen, Julius London (CU), A. Ian Stewart and Gary Thomas (LASP), Robert Dickinson (NCAR), Shaw Liu and John Noxon (NOAA), and C. Barnard Farmer (Jet Propulsion Laboratory).

Analysis and Interpretation of Global Data

Global data analysis primarily concerns the interpretation of the Nimbus 6 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. These measurements were evaluated simultaneously for precision (1-2 K and 0.3 ppmv, respectively) and accuracy (less than 1 K and less than 0.3 ppmv above 30 km and about 1 ppmv lower below 30 km). The accuracy was determined by comparison with rocket soundings and the precision by internal comparison among LRIR determinations. These results were published in Science.

A comparison of determinations of equatorial mesospheric ozone obtained by both the OAO-3 (Orbiting Astronomical Observatory) satellite experiment and LRIR was completed. The data were obtained about one day apart near 2300 local time. The LRIR data agree with theoretical models in most of their observations, while OAO-3 is high by a factor of three to six. Thus, the deficiency in the understanding of mesospheric chemistry implied by OAO-3 measurements is not supported by LRIR results. This study was presented in Geophysical Research Letters.

Gail Anderson completed a preliminary study of the diurnal variations of ozone above 2 mb. The input data were a number of terminator crossings during Southern Hemisphere summer at the solstice. These results, while in general agreement with photochemical theory, display some features which are not completely understood at present. Anderson presented the results at the International Ozone Symposium.

A special interim data set of LRIR data for the months November and December 1975 has been prepared. The data include determinations of temperature, ozone, and geopotential height. William Kohri (NCAR graduate assistant from Drexel University) has used the temperature and height data to assess theories of propagation of planetary waves in the stratosphere. His results indicate that the refractive index picture provides a qualitatively correct indication of the location of maximum energy density for wave numbers 1 and 2, and the direction in which they preferentially propagate. For wave number 1, there are also sizable Eliasson-Palm flux divergence and convergence within the wave guide.

Gille used data from the same data set to study the interaction among ozone concentration, dynamics, and temperature. He and co-workers Anderson and Bailey found the ozone concentration to be inversely dependent upon temperature in the upper stratosphere, and directly in phase with geopotential variations in the lower stratosphere. In the intermediate region between these two limiting cases, maximum eddy ozone transport took place. These observations support the mechanistic model of Dennis Hartmann (University of Washington) and Rolando Garcia. Such data should provide detailed constraints on current three-dimensional models. These results were given at the International Ozone Symposium.

During an attempt to map LRIR data resulting from the revised inversion algorithm, some problems were uncovered. These are now in the process of being eliminated. It is expected to partially reinvert the LRIR data beginning early in 1981.

Gille, Garcia, and Kohri also used LRIR data in the zonally averaged thermodynamic and continuity equations to derive the mean meridional circulation. They found considerable temporal variability in the position and strength of the circulation features.

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

Modeling

Research on a mechanistic model of ozone transports by planetary waves was completed by Garcia in collaboration with Hartmann. The principal conclusion of this study was that wave ozone transports can play a significant role in the maintenance of the zonal mean ozone distribution, especially in the upper stratosphere. Detailed results were published in the Journal of the Atmospheric Sciences.

Further investigation into the chemistry of the stratosphere and mesosphere will be carried out using a zonally averaged model currently under development by Garcia and Susan Solomon (Advanced Study Program--ASP). At present, the model produces good simulations of the zonal mean temperature structure and mean meridional circulation of the stratosphere and mesosphere. Preliminary chemistry results are very encouraging.

The question of determining infrared cooling rates in the stratosphere has been pursued by adapting the radiation model of V. Ramanathan (Atmospheric Analysis and Prediction Division--AAP). Garcia incorporated this model into a program to compute the net stratospheric heating rates corresponding to LRIR observations of temperature and ozone distributions. These heating rate calculations were subsequently used, together with computations of eddy heat fluxes, in the estimation of the mean meridional circulation of the stratosphere during early winter 1975.

Finally, the forcing of traveling planetary waves and their effects on the zonal mean state of the stratosphere have been studied with a simple model by Garcia and John Geisler (visiting scientist from the University of Miami). They find that random fluctuations in the strength of tropospheric forcing are sufficient to excite traveling waves. Oscillating eddy heat fluxes arising from the superposition of these waves with a stationary forced wave can in turn produce oscillations in the zonal mean temperature gradient. A paper summarizing their results will be submitted to the Journal of the Atmospheric Sciences.

OPTICAL TECHNIQUES SUBPROJECT

The responsibilities of the Optical Techniques Subproject include developing new optical methods for atmospheric measurements, applying of optical techniques to scientific questions in atmospheric chemistry and related areas, and increasing our expertise in the use of optical techniques for global observations from satellites. One of the major activities in 1980 was the continued use of Fourier transform infrared spectroscopy for studies of the concentration and distribution of trace gases in the stratosphere. Mankin, Coffey, and Aaron Goldman (visitor from University of Denver) analyzed the distribution with latitude and season of the important nitrogen compounds N_2O, NO, NO_2, and HNO_3 in the stratosphere. Nitrous oxide (N_2O) was found to have a fairly uniform distribution with latitude and season, with a stratospheric column abundance of 8.1×10^{17} molecules cm^{-2}. Nitric oxide (NO) amounts were shown to decrease with increasing latitude in winter. A 50% decrease in high latitude winter amounts was observed as compared with low latitude values near 3.0×10^{15} molecules cm^{-2}. Nitrogen dioxide (NO_2) stratospheric amounts increase in summer with increasing latitude. Equatorial values are near 3.0×10^{15} molecules cm^{-2} above 12 km. An increase by a factor of three to four increase in higher latitude summertime NO_2, as compared to winter NO_2, was observed. Nitric acid (HNO_3) amounts showed a general increase toward higher latitudes and a marked increase in midlatitude winter as compared to summer. Winter amounts are highly variable with a mean value near 1.0×10^{16} molecules cm^{-2}.

This work, as well as previous work at NCAR and elsewhere (particularly measurements of NO_2 by Noxon), have shown that the NO_x compounds are strongly influenced by stratospheric circulation, especially at high latitudes in winter. In order to study this coupling in detail, it is necessary to have data covering a variety of meteorological situations. In the winter of 1979-80 Mankin and Coffey made a series of flights with the airborne Fourier transform spectrometer, covering the latitude range 40-55°N. The flight dates were selected to cover as wide a range of stratospheric meteorology as possible, particularly with respect to the location and stability of the polar vortex at the 10 mb level, near the peak of the NO_2 distribution. Spectra of primarily NO, NO_2, and HNO_3 were taken, although other spectral regions were covered as well. Substantial concentration differences were observed, as well as latitudinal gradients, but not the very steep gradients in NO_2 column near 50°N previously reported by Noxon. Detailed analysis of the correlation of NO_x concentration with stratospheric circulation has not been completed, but is expected to shed light on the origin of the observed distributions.

The major new initiative in the Optical Techniques Subproject is the development of infrared absorption spectroscopy using tunable diode lasers. This technique holds great promise as a very sensitive, species-specific tool for the identification and measurement of atmospheric trace gases down to levels of less than one part per billion, on samples of a few liters. The technology of tunable diode lasers made of lead salt ternary compounds has developed rapidly in the last few years, and appears to have matured to the point where its application to field measurements is feasible.

In 1980, commercial components--diode laser, temperature controller, and current controller--were purchased for construction of an airborne tunable laser system for measuring atmospheric CO concentration. Although the laser system has the potential for measuring many atmospheric gases, CO was chosen as the initial candidate because it is intrinsically interesting (for example in the Brazilian brush fire experiment discussed later) and because it is comparatively easy to measure. It is present in a fairly large concentration (around 250 ppb); it is characterized by a simple, intense infrared spectrum, and samples are easy to handle.

Mankin designed and built a system which uses both amplitude and frequency modulation of the laser output. Amplitude demodulation gives a signal proportional to the total laser power while demodulation at the FM harmonic gives a signal proportional to the absorbed energy, which depends upon laser power, CO amount, and FM modulation amplitude. A portion of the beam goes through a reference cell containing a known CO concentration. Signals from this beam are used to lock the laser frequency to the CO absorption line and to calibrate the system continuously.

The system has been assembled and tested in the laboratory. It measures the ambient CO level with a stability near 1 ppb. It will be flown on the NCAR Sabreliner in early 1981 for first flight tests.

The ultimate goal of the CO measurements is to measure CO fluxes, and hence tropospheric lifetimes, by the meteorological correlation method. In addition, numerous gases, such as HNO_3, H_2O_2, or NH_3, at low concentrations can in principle be measured by this method. Measurement of any of these gases in the clean troposphere would be important for tropospheric chemistry studies. The method can also be used to obtain accurate concentrations of more abundant gases, such as CH_4 and N_2O, in the vicinity of sources for determination of source strengths.

Another effort in 1980 was the analysis by Mankin and Coffey of spectra made in Brazil in the 1979 brush fire experiment. The most interesting of the spectral measurements were those of CO. The background levels in the lower troposphere, away from fires, were around 150 ppb, significantly higher than previous measurements in the Southern Hemisphere; this implies a large scale increase in CO background as a result of the burning. In the plumes of brush fires, the CO concentration increased by as much as a factor of 13 above background. Further analysis is necessary to convert these measurements to CO injection amounts from fires.

STRATOSPHERE-TROPOSPHERE EXCHANGE PROJECT

The Stratosphere-Troposphere Exchange Project (STEP) coordinates ACAD investigations into 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. Direct measurements are made with meteorologically and chemically instrumented research aircraft during tropopause folding events. Diagnostic and meteorological numerical simulation models are used to describe the mass circulations and temporal evolution of tropopause folds. 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.

Shapiro and Patrick Kennedy, in collaboration with Roland Madden (AAP), investigated perturbations on the observed January 1979 stratospheric-mesospheric meridional circulation that are forced by the interactions of stationary and transient (16 days) planetary waves. Meridional heat and momentum fluxes by these wave interactions were shown to give rise to periodic fluctuations in the convergence of the Eliassen-Palm wave energy flux vector, suggesting the presence of wave-mean flow interactions.

Total column ozone measurements from the Total Ozone Mapping Spectrometer (TOMS) on board the Nimbus 7 satellite were used by Shapiro and Arlin Krueger (GSFC) to demonstrate the application of these measurements to locating the position of the subtropical and high-latitude jet streams. The TOMS ozone maps will be used to reduce commercial airline fuel consumption and to aid in the avoidance of high ozone concentrations inside the aircraft cabins. This new application is to be tested by Northwest Airlines during March 1980.

An example of high ground-level ozone concentrations over Denver, Colorado, was documented by Haagenson and Shapiro, in collaboration with Paulette Middleton (ASP) and A. Rachael Laird (Colorado State University). Results showed that this unusually high ozone event was produced by a combination of low-level photochemical production enhanced by the transport of ozone from the stratosphere. The stratospheric transport component was diagnosed using three-dimensional isentropic trajectory analyses of observed synoptic upper air data. The photochemical production contribution was determined from chemical observations taken by the Denver air pollution monitoring network.

RADIOACTIVE AEROSOLS AND EFFECTS PROJECT

During calendar year 1980, the Radioactive Aerosols and Effects group, headed by Edward Martell, has shifted its attention to an assessment of the properties and dynamics of airborne radon progeny, the short-lived radioactive daughter products of radon and thoron in the atmosphere. These experimental studies are basic to the evaluation of health risks and remedial action for high levels of indoor radon progeny, problems of considerable concern to the Environmental Protection Agency (EPA) and to other federal agencies. Beginning on 1 July 1980, the main source of financial support for this project has been the EPA Office of Radiation Programs under Interagency Agreement #AD-49-F-078-0, NSF OA-186; R3046.

The specific objectives of the NCAR research effort under this interagency agreement are as follows:

(1) To evaluate the aerosol physical properties of radon progeny and the influence of humidity, Aitken particle concentration, and other meteorological parameters on such properties. The influences of the nature of the collection surfaces, air exchange rates, flow rates, and other factors will also be assessed.

(2) To assess the mechanisms of deposition and deposition velocities of the attached and unattached fractions of radon progeny on charged and neutral surfaces, including biological surfaces.

(3) To determine the accumulation of radon progeny on biological surfaces and the frequency of alpha emissions on such surfaces at known and/or controlled levels of radon and its attached progeny.

The experimental approach for the main objectives of this study involves the use of laboratory chambers in which the concentration of radon or thoron is maintained using solution standards and/or dry emanation sources of radium-226 and thorium-228. Experimental sources of small Aitken particles include cigarette smoke and particles generated by combustion of natural gas. Radium-226 and radon-222 are determined by standard procedures of radon gas counting in alpha scintillation counter chambers. Radon progeny determinations are carried out using either (1) absolute, low-level β^- counting in nearly 4Π geometry, using anticoincidence counting and steel shielding, or (2) alpha spectroscopy, using silicon solid state surface barrier detectors in vacuum chambers and associated electronic systems. Aitken particle concentrations are determined using a Rich-100 CN (condensation nuclei) Monitor designed by the Environment/One Corporation and modified as specified in an earlier NCAR study (Cooper and Langer, 1978). Size distributions of attached radon progeny are determined using a multistage cascade impactor with five impactor stages and a backup filter. For particles <0.25 μm in diameter the mean size will be determined using a diffusion-denuder in conjunction with the Rich-100 CN Monitor and with diffusion battery techniques.

Rates and mechanisms of deposition of radon progeny aerosols are also being investigated in natural surface air environments, using lead-210, the 10.6 h half-life radioactive daughter product of thoron, as a tracer. In addition, ^{212}Pb will also be used in laboratory chamber studies to assess the influence of particle coagulation and aging on the properties of airborne radon progeny.

Preliminary results of these studies are described in reports entitled The Dynamics of Airborne Radon Decay Products, prepared quarterly. Principal findings to date include the following:

(1) There is a remarkable dependence of the magnitude of the attached fraction of radon progeny on the indoor air concentration of Aitken particles, in accordance with the differential equation:

$$dZ/dt = -\gamma Z^2 - \lambda Z$$

where Z denotes the number of particles per cubic centimeter and dZ/dt is the rate of decrease in particle concentration. The term γz^2 represents the rate of decrease due to coagulation of airborne particles. The λZ term represents reduction in particle concentration due to diffusion to surfaces and to sedimentation.

(2) When the indoor Aitken particle concentration exceeds 10^3 to 10^4 particles per cubic centimeter, the attached fraction of radon progeny is maximized. When the particle concentration approaches or exceeds $10^6/cm^3$ (characteristic of smoke-filled rooms), the rapid rate of coagulation, which is proportional to Z^2, results in the association of radon progeny with particles approaching or exceeding 1.0 μm in diameter. Such a modified size distribution will, in turn, influence the distribution of inhaled radon progeny within respiratory systems and their effects.

(3) Studies of the deposition velocities for radon progeny on hairy surfaces yield values too high to be explained by the diffusion of neutral particles to surfaces. It has been proposed (Martell and Poet, in press) that radon progeny attached to small Aitken particles which carry a positive charge are selectively deposited on negatively charged surfaces. Results also indicate that hairy surfaces and electrostatically charged fibers are very effective in the accumulation of radon progeny.

Progress in the experimental work has been aided materially by helpful discussions with Delany, Jan Rosinski (Convective Storms Division), and Berg. These studies are complementary to related studies by Anthony Nero (Lawrence Berkeley Laboratory) and by Melvin First (Harvard School of Public Health).

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HIGH ALTITUDE OBSERVATORY

INTRODUCTION

The High Altitude Observatory strives to maintain a balance among theoretical, interpretive, and instrumental activities over a wide range of subjects, all within the general areas of solar and solar terrestrial physics. In this introduction, we illustrate the diversity of approach through several examples of recent work.

During the past year, theoretical investigations directed toward an understanding of internal solar structure and dynamics--which must ultimately drive the solar cycle and other aspects of the variable nature of the sun's output--have continued. Studies in the Solar Variability Section now include extensions of the models of solar convection and the dynamo to include compression and nonlinear effects. The predicted effects from such model calculations are being closely scrutinized and compared with current interpretations of observable parameters such as luminosity, differential rotation rates, and particularly with initial information on large-scale velocity fields.

The year has also seen substantial progress in the study of the energetics and dynamics of the solar corona and solar wind, processes that provide the direct link between solar conditions and terrestrial effects. Theoretical and interpretive research in the Coronal/Interplanetary Physics Section has centered on the structure of the corona, with particular emphasis on its relationship to the large-scale coronal magnetic field. Considerable progress in the physical interpretation of solar and interplanetary data sets has been achieved from the association of a "warped" neutral sheet arising from a tilted solar dipole with observed magnetic sector boundaries and solar wind parameters. Simplified magnetostatic models for the configuration of magnetic fields applicable to the corona are leading toward substantial progress in our understanding of the formation and stability of these coronal fields.

The interpretation of observational data on the polarization of radiation from various solar features, which in turn yields the configuration of the vector solar magnetic field, has received substantial emphasis during the past year within the Solar Atmosphere and Magnetic Fields Section. These studies promise stimulate movement into important new theoretical directions, encourage observational emphasis, and most importantly, give a better understanding of the nature of the solar atmosphere. The interpretation of the data sets obtained simultaneously from the upgraded Stokes II polarimeter and the Solar Maximum Mission coronagraph/polarimeter will receive heavy emphasis in the coming year, toward these goals.

Turning to experimental initiatives within the observatory, the Annual Scientific Report to NSF of last year emphasized the fact that a number of experimental programs successfully began operation then--including the Solar Maximum Mission coronagraph/polarimeter, the Mark III K-coronameter, the rocket-borne Lyman-alpha/white-light coronagraph, and an upgraded version of the Stokes II polarimeter.

Each of these experiments, in turn, has produced a new data set of high quality, thus giving rise to expectations that interpretation of these results will draw new perspectives and directions for future observatory research. Results from each of these experiments are discussed in the following sections.

Development continued throughout 1980 on two new observing instruments, both planned within the Solar Variability Section. The first instrument is a solar diameter monitor, a device to determine the solar diameter with high precision and to bring modern technology to bear on the question of possible changes in the solar diameter, which can currently only be inferred from historical data sets.

The second instrument, to be developed as a joint venture between HAO and SAO is a Fourier tachometer--a device to measure the large-scale solar velocity fields. Discussions concerning the technical and managerial approaches to the instrument were concluded during 1980, and initial steps to define the optical, mechanical, and electronic systems are being undertaken. This year will see intensive efforts at HAO toward the detailed definition and design of this new observational facility.

SOLAR VARIABILITY SECTION

The general goal of the solar variability effort continues to be to describe and understand the fundamental operation of the solar cycle over a broad range of time scales, from weeks to millennia. An understanding of the processes that give rise to variability in the sun must necessarily include studies of the ways in which the outputs of the sun that reach the earth--radiation, magnetic fields, and particles--are influenced and organized by the cycle of solar activity.

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. Research conducted in 1980 may conveniently be described in the following interrelated topics:

0 Modeling the Global Circulation and Dynamo

0 Observations of Global Circulation

0 Variability in Calcium II Flux

0 Variability of Luminosity and Diameter

0 Long-term Evolution of the Corona and Solar Wind

0 Geomagnetic Response to Solar Variability

Modeling the Global Circulation and Dynamo

During 1980, Peter Gilman and his student, Gary Glatzmaier (now an HAO postdoctoral visitor), have continued efforts to understand how compressibility affects the form taken by differential rotation in a rotating, convecting, spherical shell of fluid. The fully nonlinear computer code to study these effects has nearly been written, but in the meantime Gilman and Glatzmaier have been able to make preliminary estimates of what will happen, through the use of a second-order perturbation expansion technique. With this technique, complete solutions can be found for the profiles of differential rotation and meridional circulation that are induced as a result of the convection modes found at the onset of convective instability. In the case with a nonlinear incompressible shell studied earlier, the picture was rather simple: a broad equatorial acceleration required strong influence of rotation upon convection, as well as a deep convecting layer. Glatzmaier and Gilman's new results indicate that in the compressible case, a much more complex picture emerges, indicating it matters a great deal how the superadiabatic temperature gradient and diffusion of heat and momentum vary with depth. In particular, if the kinematic viscosity and thermal diffusivity are constant with depth, and (as a consequence) the superadiabatic gradient is much stronger near the top of the layer than the bottom, equatorial acceleration such as the sun has is much harder to produce in the model than in the incompressible case. On the other hand, if the kinematic viscosity and thermal diffusivity increase with depth (and as a consequence the superadiabatic gradient is more nearly the same at the top and bottom of the convection zone), equatorial acceleration is easier to obtain, and it is rather similar to the incompressible case. Unfortunately, it is difficult to decide on independent grounds which representation of viscosity and thermal diffusivity with depth is more reasonable. In fact, the results may indicate we need to abandon linear diffusion altogether and look for more realistic nonlinear formulations.

Gilman has also continued calculations with his hydromagnetic dynamo model. The 1979 Scientific Annual Report stated that first results were generally much different than the real sun, that is, the model contained no magnetic cycles, even though the model differential rotation profile was quite similar to the sun's. One of the reasons for this difference is that the global convection driving the model differential rotation is apparently considerably larger in amplitude than on the real sun. Gilman has since discovered new solutions, with reduced viscosity, in which considerably smaller amplitude convection drives the same amplitude and profile of differential rotation as before. He has begun new dynamo calculations based on this new hydrodynamic solution to see whether the earlier conclusions still hold.

Supergranule scale motions on the sun can be influenced by rotation and perhaps even contribute somewhat to global differential rotation and meridional circulation, through the action of Reynolds stresses. David Hathaway (ASP postdoctoral fellow) has been studying this problem using a modified version of a nonlinear incompressible convection code developed earlier by Richard Somerville (now at Scripps) and Tsvi Gal-Chen (now at Goddard Space Flight Center, Greenbelt). Hathaway has been able to demonstrate in detail how the tilt of the local rotation vector compared with the direction of gravity, which varies by 90° between equator and pole, will generate a differential rotation that increases with depth and a meridional circulation directed toward the poles near the outer boundary of the convecting layer. Comparison of magnitudes with the sun is difficult, but for convection amplitudes similar in size to supergranules, the differential rotation is a few percent of the average rotation, and the meridional circulation is of the order of 10 m/s. The former result confirms earlier calculations by Gilman and Peter Foukal (Atmospheric and Environmental Research, Inc.), and the latter is of the same sense but smaller in amplitude than current observational estimates.

Observations of Global Circulation

In the 1979 Scientific Annual Report we described an effort by Gilman and Glatzmaier for simulating the data reduction process used by Robert Howard and Barry LaBonte (Mt. Wilson and Las Campanas observatories) to look for global velocities on the sun. Gilman and Glatzmaier showed that this reduction technique could result in serious underestimates of the true magnitude of these velocities. During 1980, Gilman has been working with Howard and LaBonte to reduce the data again, taking into account changes recommended by Gilman and Glatzmaier. The result is that the upper limit on velocity power per longitudinal wave number has been raised by 40-50%, but the values are still quite small--no more than 12 m/s at low longitudinal wave numbers, and 3 m/s at high wave numbers. Furthermore, these still represent only upper limits, and the real solar velocities may be smaller still. These values were smaller by a factor of three or four compared with earlier computer model solutions found by Gilman for global convection driving an equatorial acceleration of the observed amplitude, but they are close to the new solutions described in the previous section now being used for dynamo calculations.

During 1980, Timothy Brown, in collaboration with Jack Evans and Alfred Healy (Sacramento Peak Observatory (SPO)), has made considerable progress with the prototype Fourier tachometer being operated at Sacramento Peak. This instrument is designed to measure global velocities of the solar plasma, ultimately with much greater stability and accuracy than has previously been obtained. Observations covering the full solar disk were obtained for most clear days from June through November 1980 (about 60 days total). From these data, it is now possible to make two-dimensional velocity maps at 4 x 16 arc s resolution. Brown has identified and eliminated several previously ill-understood sources of erroneous signals. These include inappropriate ways of reading the data array, blending of spectral lines in and around active regions, and changes in line width as a function of center-to-limb distance on the solar disk.

The experience gained from the prototype instrument is already proving to be very helpful in determining the best way to proceed with a second-generation instrument, which is to be built under a formal collaboration between HAO and SPO. Plans for this new version are approaching the stage of final instrument definition, at which point all the major building blocks of the device will be chosen and their interactions defined in some detail. The spectrum lines to be used have been chosen, the appropriate interferometers to analyze these lines are nearing completion, and a design is being developed for a new telescope to feed the device.

Recently Brown has initiated simulations of another data reduction technique used by Howard and LaBonte to demonstrate the existence of weak but persistent "torsional oscillations" in the solar differential rotation. Howard and LaBonte found alternating zones of fast and slow rotation that migrated toward the equator from very high latitudes, taking about 22 years to get there. This finding has generated considerable excitement in the solar physics community and is potentially very important for revealing internal workings of the solar dynamo. However, preliminary results from Brown's simulations indicate at least the high latitude portion of this oscillation may instead be simply an alias from the low latitude signal, introduced by the reduction procedures used by Howard and LaBonte. Study of this problem is continuing, and next year's report should contain much more definite conclusions.

Gilman has commenced another study with Howard, to measure sunspot rotation during the twentieth century using the Mt. Wilson white-light plate collection. The object of this study initially will be to compare sunspot and Doppler rotations for the period from 1966 to the present, for which both records exist, and then to work back in time from the sunspot record alone to 1915 to determine earlier changes. A detailed measurement program has been defined, and the necessary equipment with which to make the measurement is being purchased. Mt. Wilson and Las Campanas observatories have obtained an NSF grant to support its part of this joint study, with Howard and Gilman as Co-Principal Investigators.

Variability in Calcium II Flux

Earlier annual reports described a continuing collaboration between Oran White and William Livingston (Kitt Peak National Observatory (KPNO)) to measure chromospheric calcium II K emission throughout a solar cycle. They have now seen the apparent peak in this parameter for the present cycle, and the declining phase has begun. The observations indicate that throughout the observing period, the increases in calcium emission come almost exclusively from the increase in the number and extent of solar active regions. By contrast, similar measurements of 1 x 3 arc min areas taken in the quiet chromospheric network have shown no systematic rise with the approach to solar maximum. An important question to be answered in the near future is whether the same is true during the declining phase of the cycle, when the quiet network is augmented by many remnants of old active regions. If this happens, the full disk calcium emission should fall less rapidly than other measures of solar activity, such as sunspot number. During the rising phase, correlation of the Ca II emission with plage index, sunspot number, and 10 cm radio flux is very good.

White and Livingston observe a number of systematic changes in both the calcium K line width and its asymmetries as the level of solar activity changes. In general, changes in those spectral features that are formed in the solar atmosphere above the temperature minimum are well correlated with each other but are not clearly related to changes in line features of photospheric origin. Thus while calcium emission is clearly a good indicator of the level of solar activity and allows important comparisons with activity measures for other stars, it is doubtful such a measure can be used as an indicator of changes in total solar luminosity.

We continue to recognize the need for denser time coverage of the calcium emission in order to examine rotational modulation, and Richard Fisher has begun to develop a new monitoring device to be mounted on the HAO Mark III coronameter in Hawaii, so that daily measurements of Ca II emission can be made. These measurements will also allow comparisons between measures of chromospheric activity and coronal structure. Good correlations of these features could tell us more about coronal structures on other stars as well.

Variability of Luminosity and Diameter

Interest in making theoretical estimates of possible variations in solar luminosity has increased greatly in the last few years. Recent observations of luminosity changes with solar activity such as observed by the active cavity radiometer aboard the Solar Maximum Mission (SMM) satellite have highlighted the possible connections between luminosity and the solar cycle. Development of credible theories for such links is a difficult and subtle problem, particularly since full three-dimensional solutions representing the convective dynamics and dynamo action in the sun are not yet feasible. A number of simpler theoretical arguments have been put forward that claim to identify connections among luminosity, diameter, and solar cycle changes. For example, Edward Spiegel (Columbia University) and Nigel Weiss (Cambridge University, England) have argued that the build-up of a magnetic field at the bottom of the convection zone could increase the superadiabatic gradient required to drive the convection there. This change would be transmitted to the solar surface, resulting in a luminosity decrease at maximum in the cycle compared to minimum, together with a radius increase. Ronald Gilliland, an ASP postdoctoral fellow, has tested this idea using a stellar structure model, and shown that instead of the luminosity change being seen at the surface, there are compensating changes in the thermal and potential energy reservoirs at the levels just above where the magnetic field resides. This conclusion in turn has to be tested with an even more elaborate model that improves on the mixing length treatment of convection.

In the same study, Gilliland also tested a suggestion put forward by John Thomas (University of Rochester) that an increase in the number of magnetically buoyant flux tubes in the upper convection zone near solar cycle maximum could result in a solar radius increase and surface temperature decrease, without a corresponding change in luminosity. Gilliland found that in fact a luminosity change does occur, and that both the sign of this change and of the surface temperature change are sensitive to the location in the outer layers of the convection zone at which the flux tubes reside.

Both the above studies by Gilliland reinforce the need for much better models of solar convection zone dynamics and dynamo action in order to answer questions about variability in luminosity and radius.

Gilliland has also synthesized measures of solar radius from a great variety of sources over the past 265 years and found evidence for an approximately 76-year periodic modulation in radius, with a half-amplitude of approximately 0.2 arc s, or about 0.02%. This variation appears to be negatively correlated with the envelope of sunspot cycle amplitudes as measured by sunspot numbers, at approximately the 2-standard deviation (σ) level. Gilliland has also detected a variation in solar radius with an eleven-year periodicity that correlates at the 3 σ level with sunspot cycle. In this case the half-amplitude is about 0.1 arc s, and the phase is such that the minimum solar radius occurs near the maximum in sunspot number.

John Eddy, working with Aram Boornazian (S. Ross and Co.) has re-examined his estimates of solar diameter change, previously reported in the 1979 Scientific Annual Report. Eddy and Boornazian have now made more extensive corrections for changes in atmospheric transparency as well as observer personalities. When these effects are removed they find an apparent decrease in solar diameter of 1.2-0.6 arc s/century between 1880 and 1953 in the horizontal diameter. But this large a trend is not seen in other observatory data, and the distinction between this trend and the 76-year periodicity found by Gilliland remains to be sorted out.

Gilliland's and Eddy and Boornazian's results heighten the need for new measurements of the solar diameter taken over a solar cycle. As reported in the 1979 report, Brown is building such an instrument, which is now nearing completion: the mechanical, computer, and optical assemblies are essentially complete, while the electronics are in the final stages of fabrication. We anticipate being able to make first measurements of the solar diameter by the middle of 1981. The instrument will be installed in the new addition to the Mesa Laboratory. In a related effort, Gilman has begun a collaboration with Howard (Mt. Wilson and Las Campanas) to measure the solar diameter from the Mt. Wilson white-light plate collection, which extends from the present back to about 1915.

In the SMM measurements mentioned above, it was observed that the solar luminosity dropped by up to 0.2% with the passage of a large sunspot group across the central meridian. This new finding has motivated Eddy, White, and Douglas Hoyt to estimate possible past changes in solar luminosity from the Greenwich Observatory sunspot record. Such an estimate can be made by assuming that the change in luminosity is proportional to the projection of sunspot area in the direction of the earth. They are currently cleaning up the Greenwich record for measured sunspot areas and extending the record length up to 1976 and back to 1874. Thus, it should be possible to estimate the amount of luminosity change, at least from large sunspot groups, back more than a century.

Long-term Evolution of the Corona and Solar Wind

The mechanism by which galactic cosmic rays seen at the earth are modulated by the sun and interplanetary medium is not well understood. It is an important question for solar variability because terrestrial evidence of past solar activity is largely contained in deposits of radio isotopes that were first produced in the high atmosphere by cosmic rays.

Recent theoretical models of Jokipii (University of Arizona) and colleagues have stressed the role of particle drifts caused by gradients in and curvature of the interplanetary magnetic field in determining the motion of galactic cosmic rays in the heliosphere. One consequence of particle drifts as the primary mechanism of cosmic ray motions is that the trajectories of energetic particles are primarily across magnetic field lines, and they reverse direction when the sign of the field reverses. Thus, during the period 1969-1981, energetic protons are expected to flow into the heliosphere at high latitudes and out along the equatorial neutral sheet. During the previous cycle (1958-1968) and the one about to begin (1981-1992), protons would flow in toward the sun along the neutral sheet and out at high latitudes. As a result, the density of cosmic ray protons should increase away from the solar magnetic equator during 1969-1981 and decrease away from the equator in the previous and next cycles (the change of magnetic cycle here is determined not by occurrence of new sunspots at high latitudes but rather by the change in sign of the polar magnetic field). Gordon Newkirk, while on sabbatical leave at the University of New Hampshire, has collaborated with John Lockwood there to test this prediction, and he finds it fails. Newkirk and Lockwood found that by isolating periods in each solar cycle during which the global solar field was relatively stable and predominately in the form of a tilted dipole, they could estimate the cosmic ray flux density over a range of heliomagnetic latitude of $\pm 30^{\circ}$ from observations in the plane of the ecliptic. They found that both during 1965 and 1975 the cosmic ray flux density decreased with increasing heliomagnetic latitude. The theory predicted a decrease with latitude during 1965, but an increase during 1975. Furthermore the data Newkirk and Lockwood used to reach their conclusion were of higher quality for the later period. Therefore the theory of cosmic ray modulation needs to be revised again.

Arthur Hundhausen and Richard and Shirley Hansen have now virtually completed their study of evolution of the white-light corona over a solar cycle using Mark II K-coronameter data for the period 1965-1978. They find that large coronal holes at each pole seen in the beginning of a new cycle ($\sim$ 1965) shrink in size as the cycle progresses through its ascending phase and disappear for a two-year period just after sunspot maximum (1969-1970). New polar holes then reappear (near the end of 1970) and remain as prominent features of the corona through the entire declining phase of the cycle and into the ascending phase of the next one (1971-1978). During the sunspot maximum epoch the corona is dominated instead by midlatitude holes elongated in the direction parallel to the solar equator. During the other phases of the cycle, the polar holes often showed pronounced equatorial extensions, or they were accompanied by separate large equatorial holes. In most cases, these equatorial extensions and equatorial holes were the sources of high-speed solar wind streams, with maximum speeds in excess of 600 km/s at all phases of the cycle. Both the holes and streams lasted the longest during the descending phase of the cycle, around 1974-75.

This synthesis greatly extends the earlier work of Hundhausen, which concentrated on the Skylab period of 1974-75. It now needs to be tested against a second magnetic cycle, data for which are already accumulating from the operation of the Mark III coronagraph. The Mark II data have now also been made available to a number of research workers outside NCAR for their own parallel studies.

Geomagnetic Response to Solar Variability

Sadami Matsushita has continued his collaboration with Yohsuke Kamide (Kyoto Sangyo University) on the modeling of ionospheric current systems. They have found that how much low-latitude electric fields are predicted to be affected by high-latitude aurorae depends a great deal on the form assumed for ionospheric electrical conductivity. Previous models that assumed that the conductivity was constant with latitude greatly over-estimated the strength of electric fields penetrating to low latitudes. More realistic conductivity profiles that take the day-night asymmetry into account result in electric fields that are confined much more to high latitudes. This decay toward low latitudes becomes even sharper when field-aligned electric currents in the equatorward half of the auroral belt are added.

In the past, it has been difficult to analyze ground-based geomagnetic perturbations that result from the solar wind and to determine which part of the signal originates in the magnetosphere from field-aligned currents and which comes from ionospheric current. During 1980, Kamide, Arthur Richmond (National Oceanic and Atmospheric Administration), and Matsushita developed a method of separating these two effects. It involves a sequence of calculations starting with an equivalent ionospheric current function derived from the north-south and east-west surface magnetic field, followed by calculation of an electric potential distribution from the ionospheric current function using a simple model of ionospheric conductivity, from which, in turn, the field-aligned current is found by computing the divergence of the ionospheric current. Several examples were developed that agree well with observations from radar and satellites.

In previous annual reports we have described Matsushita's efforts to estimate the sign of the interplanetary magnetic field from anomalies in the horizontal geomagnetic field recorded at the ground. During 1980, he and Wen-Yao Xu (visitor from Academia Sinica, Beijing) have extended this approach and found a new anomaly near 70° magnetic latitude that reliably indicates interplanetary field changes from fall to spring seasons. The previous anomaly was centered near 80° magnetic latitude, and worked much better in the summer months. With both anomalies, the interplanetary field sign can now be predicted better for all seasons. Analogous anomalies in the geomagnetic field are also seen near the south pole, increasing the accuracy still further.

Connecting auroral events to the sun over the past several centuries may become much more feasible as a result of a new collaborative effort among Eddy, Matsushita, George Siscoe (University of California at Los Angeles), Samuel Silverman (self-employed), and Joan Feynman (Boston College). They have begun to organize and put on magnetic tape a comprehensive catalogue of auroral sightings over the past several hundred years. One object is to determine the shape and size of the auroral oval for each case and use this information to determine the relative frequency of solar flare-caused and coronal hole-caused aurorae. This is possible because it has been determined by others that high-speed solar wind streams from coronal holes produce a smaller and more poleward oval than do flares. If this distinction holds for all solar cycles, then from aurorae we can estimate how active the sun's magnetic structure was in previous cycles. Since cosmic ray modulation is likely to be different for magnetic cycles with different proportions of holes and flares, such estimates may also help us understand what mechanism predominates in cosmic ray modulation.

SOLAR ATMOSPHERE AND MAGNETIC FIELDS SECTION

Within the Solar Atmosphere and Magnetic Fields Section are addressed problems related to the energy balance and structure of the solar atmosphere. The interaction of the forms of energy in the solar atmosphere--heat, mass flows, and wave motions--with the structure of the solar atmosphere provides the solar conditions that we observe. Through studies of the detailed interaction between the solar plasma, radiation, and magnetic fields, we can hope to understand the atmosphere of the sun and the fundamental solar conditions that give rise to the heliospheric environment. In addition these studies benefit from 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 in the section to both the solar and stellar problems includes four general categories of effort: observational programs from ground-based and orbiting observatories; interpretative analysis of observational data; development of diagnostic techniques, and theoretical modeling.

During the past year, our primary data base was provided by the Stokes and KELP instruments operated by HAO at Sacramento Peak Observatory (SPO) until October 1980, by the data archive obtained from HAO observations with Orbiting Solar Observatory (OSO-8) experiments, by participation in the ultraviolet spectrometer/polarimeter (UVSP) experiment on SMM, and by collaborative observing programs with the large solar instruments at Sacramento Peak Observatory (SPO) and KPNO. Also, collaborative observing programs have been initiated with stellar astronomers.

The number of scientists working in the section continued to decrease during the year and is expected to return to normal during 1981. These staffing changes reflect partially the maturing of diagnostic techniques in radiative transfer, which in prior years have occupied a major fraction of the research effort. Future effort will concentrate more heavily on theoretical modeling and interpretation of data.

Solar Activity

Flares. Studies by Andrew Skumanich and Bruce Lites (now at SPO) using observations of two solar flares with the Laboratoire Physique Stellaire et Planétaire (LPSP) instrument on OSO-8 illustrate seemingly different dynamical processes in solar flares. In one case the measurements indicate a rather long lasting expansion of the chromosphere after the start of the flare. In the other case, rapid measurements of line profiles during the flash phase of the flare indicate a sudden and short-lived downflow in the chromosphere. Analysis of the flare spectra is being temporarily delayed pending improved calibration of the thermally induced shift of the spectrograph entrance slit, which otherwise could lead to spurious results.

Lites has completed an analysis of OSO-8 data from the University of Colorado experiment showing very rapid flarelike brightenings in the C IV line. The results show a number of cases of sudden downflow at the beginning of the brightening.

Large quantities of flare data in transition region and coronal lines have been obtained with the UVSP experiment on SMM. R. Grant Athay and Charles Hyder (HAO visitor from NASA) are participating in the UVSP experiment as co-investigators.

Sunspots. In collaboration with Skumanich, Lites has completed the reduction and analysis of sunspot spectra obtained with the LPSP instrument on OSO-8. These spectra provide profiles of ultraviolet lines from the chromosphere above a sunspot that are superior to any previously obtained. Magnetic field data from the HAO Stokes polarimeter are available for correlation with the spectroscpic data. The main goal of this program was to develop a semiempirical model of the spot chromosphere as a necessary step to the understanding of the energy balance and average dynamical state of the sunspot chromosphere, and eventually, to an understanding of the nature of umbral oscillations and energy deposition in active regions.

The sunspot observations, the semiempirical model, and the nearly simultaneous Stokes polarimeter measurements of the magnetic field of this spot are currently in the process of being correlated. The Stokes measurements should give some insight into the nature of the correlation of Mg II and Ca II line emission with very strong magnetic fields. This information will be useful for understanding chromospheric effects on stars that are suspected of having very large areas covered by starspots.

Asymmetries in the line profiles point toward a compressive chromosphere over the sunspot, i.e., most likely an inflow into the spot. The thermodynamic model appears to be similar to that in the quiet sun. The major difference is that the spot cooling mechanism penetrates as high as the middle chromosphere, dropping the temperatures below quiet-sun values. This causes the Mg II and Ca II line emission to be formed under "shell-like" conditions.

Athay has used the UVSP instrument on SMM to observe the flow properties surrounding sunspots at the level where C IV is formed (10^5 K). Preliminary analyses of these data indicate a predominant inflow toward the spot and downflow over the spot itself. Flow velocities are tens of kilometers per second.

Lites and White obtained data on chromospheric oscillations within sunspots using the tower at SPO. These data provide the clearest picture yet obtained of the relationship between the umbral motions and the running penumbral "waves." Phase and power spectra of the oscillations within the umbra contrast markedly with the quiet-sun phases and perhaps indicate that a larger fraction of the wave energy propagates into the chromosphere above spots.

Prominences. An effort undertaken by Lewis House and Raymond Smartt (SPO) in 1978 to measure prominence vector magnetic fields with He I D_3 polarimetry came to fruition in 1980. Egidio Landi Degl'Innocenti (HAO visitor from Arcetri Observatory) completed a solution of the equations of statistical equilibrium for He I including fully the effects of coherences between atomic levels and level crossings that occur in D_3 at field strengths greater than 5 G. Landi's solution is particularly important since it alone explains the observed circular polarization in D_3. Two prominence data sets, one obtained by House and Smartt in April 1978 and one obtained by Charles Querfeld and Smartt in August 1980 were interpreted using a linear polarization interpretation scheme devised by Veronique Bommier (Paris Observatory, Meudon) and the linear and circular polarization predictions obtained from Landi's scheme. The circular polarization proved crucial in eliminating vector magnetic field solutions that were consistent with the linear, but not the circular, data.

Unambiguous vector magnetic fields were obtained for the April 1978 prominence. Two families of polarimetrically indistinguishable solutions were obtained for the August 1980 prominence. The derived fields are approximately horizontal and normal to the prominence with a small component along the prominence. In the April prominence some solutions were found in association with D_3 loops embedded in the prominence which were strongly inclined upward and downward. Fields agree in direction with the polarity of the surface magnetic field and for April 1978 with the computed potential field configuration. The direction of the fields is consistent with magnetostatic models obtained by Boon Chye Low, Ellen Zweibel (now at the University of Colorado), and Hundhausen (see discussion under Coronal-Interplanetary Physics Section).

Solar Fluctuations and Structures

In a preliminary study of the solar cycle variability of the integrated disk Ca^+ emission, Skumanich has derived a three-component model--quiet sun, network, and plage--that appears to fit the Ca^+ data as well as the solar cycle Lyman-alpha flux variations observed by Vidal-Madjar (LPSP). Using the Ca^+ and Lyman-alpha data sets, Skumanich finds that the network-to-plage area ratio is essentially constant at 6.7, in good agreement with the value observed by Michel Herse (Service Aeronomie, Centre National de Recherches Spatiales), and a Lyman-alpha-to-Ca^+ network "size" ratio of 1.34, consistent with that derived from OSO-8. Such statistics are necessary for the comparisons of solar and stellar variability. This work is being pursued further in collaboration with White and William Livingston (KPNO).

Lites continued his investigation of the phase relationships of solar oscillations and discovered marked distinctions between cell (non-magnetic) and network (magnetic) features. The physical reason for these distinctions is now under study. Phase relationships among chromospheric lines provide excellent observational diagnostics for wave motions in the chromosphere.

Stokes Polarimetry

Both the Stokes II and KELP instruments at SPO were operated until the scheduled end of operations on 31 October 1980. The KELP operated synoptically to obtain Fe XIII 10747 and K-corona intensity and polarization maps in collaboration with the HAO Coronagraph/Polarimeter (C/P) experiment on SMM. The Stokes II operated the maximum allowed time under SPO scheduling rules to obtain rasters of Stokes spectral profile at modest resolution (5 s) in active regions and prominences in collaboration with SMM observers and Smartt (SPO). Quick-look data suggest that at least one set of five active-region rasters shows changes in the disk vector magnetic field structure during flaring. Several prominence rasters were obtained before and during prominence eruptions and simultaneous high-resolution (1 s) H-alpha and D_3 filtergram movies were made. After completion of SPO operations the KELP and Stokes II detectors and associated equipment were loaned to the University of Hawaii (John Jefferies and Donald Mickey) for installation on the Stokes polarimeter at Mees Observatory on Maui.

In 1977 Lawrence Auer (now at Pennsylvania State University), James Heasley (Institute for Astronomy, Honolulu), and House derived an algorithm for fitting spectral line profiles derived under certain conditions (according to a theory developed by W. Unno (Tokyo)--hence "Unno" profiles) to obtain the vector magnetic field from Stokes II disk observations in magnetically sensitive lines. This procedure was applied to Stokes II raster data, and it was found that the procedure works well with synthetic Unno-derived line profiles but fails when presented with real data. Iron lines used with Stokes II and by Heasley and Mickey have intensity profiles that are too wide to be consistent with the linear and circular polarization data. This leads to fields that appear to have a large transverse (to the line of sight) component and a reduced longitudinal component. Exhaustive tests by Landi and Querfeld at HAO and independently by Heasley confirm the integrity of the algorithm and find that the sun does not form lines in the way envisioned by Unno. The specific reasons for this remain unclear. The Mg 4571 intercombination line is formed in LTE and appears to be in better agreement with Unno theory, but it still is not interpretable. At present the Unno problem presents an interesting scientific dilemma, casting doubt on the interpretation of data from <u>all</u> existing solar and stellar magnetographs as well as Stokes polarimeters.

An important and unique set of magnetic field measurements in prominences with the Stokes instrument is discussed in the preceding paragraphs on solar activity. The interpretation of the prominence data is free of radiative transfer effects and does not encounter the inconsistencies found in the disk data, where radiative transfer effects become critical. Additional prominence observations with the Haleakala Stokes polarimeter (when the installation of the Stokes II detector is completed) and analysis of existing D_3 prominence data are continuing in a collaborative study.

The failure of the diagnostic program for disk data based on the Unno scheme has been brought into sharp focus by the Stokes data and presents a clear and important challenge to solar physicists. There appears to be no fundamental reason that a workable diagnostic for disk polarimetric data cannot be developed, and HAO is continuing a sustained effort to develop such a procedure.

Theoretical Models and Diagnostics

Models of the transition region between the chromosphere and corona began with an assumed balance between thermal conduction and radiation losses in a spherically symmetric, static case. It was later demonstrated by Allan Gabriel (Culham Laboratory, England) that network magnetic field structure strongly modified the model through its effect on thermal conduction and, in a separate context, by Gerald Pneuman and

Roger Kopp (Los Alamos Scientific Laboratory) that downflow within the network provided a major additional energy term.

Athay has initiated an investigation of computer-generated models incorporating the combined effects of thermal conduction, radiation, fluid flow, and network magnetic field geometry. The energy-balance models fall into two classes: one in which the primary energy input is downflowing coronal matter and a second in which the primary energy input is thermal conduction. The models driven by downflow are characterized by a large conduction flux at the base of the transition region, whereas the models driven by conduction flux are characterized by an outflow from the transition region to the corona and a small conduction flux at the base of the transition region. Further development of the transition region models together with their tie-in to chromospheric and coronal models is in progress.

Skumanich and Lites discovered during the course of their sunspot modeling that many of the published results using non-LTE line transfer codes to model the solar and stellar chromospheres contain serious errors. The process of verifying their own work, and of understanding the physical properties and asymptotic scaling of their transfer solutions, has led to new diagnostics for multitransition line transfer. These methods, under continuing development by Skumanich and Lites, are likely to be important in all future investigations that use optically thick spectral lines as diagnostic tools.

Work on diagnostics for polarized radiation is incorporated in the discussion of the Stokes program.

Stellar Chromospheres

An extensive review of the phenomena of the solar chromosphere and transition region, viewed in the context of a stellar chromosphere, was completed by Athay for a NASA/CNRS volume *The Sun as a Star* (currently in press), edited by Stuart Jordan (Goddard Space Flight Center).

Evidence that the solar dynamo and the erupted surface magnetic fields undergo a long-term secular variation has been reviewed by Skumanich and Eddy for the 1980 NATO Advanced Study Institute, "Solar Phenomena in Stars and Stellar Systems." Extant nonlinear calculations couple the strength of the dynamo to the dynamic properties of the convection zone and its rotation rate. Skumanich found that the calculations predict a linear dependence of the poloidal magnetic field on the rotation rate. This derived scaling relation for the nonlinear calculations agrees with the empirical relation between the magnetic flux inferred from the Ca^+ brightness and the rotation rate for main sequence stars. Extrapolation of the scaling law to the more evolved spectroscopic binaries would allow one to probe the nature of the dynamo mechanism in evolved stellar states.

Both the rotation rate and inferred magnetic flux (Ca^+ brightness) for main sequence stars are known to decay with the square-root of time as recently confirmed by David Soderblom (HAO visitor, Lick Observatory). Skumanich's analysis of extant models of nonspherically symmetric coronal winds demonstrates that the square-root braking law is consistent with a linear rotation-dynamo relation even under conditions of partially closed coronas as long as the magnetic flux in open regions is in constant ratio to the total erupted flux as inferred from the Ca^+ emission. A possible explanation for the sharp increase in angular velocity for stars more massive than the sun may be a sharp drop in the ratio of "open" to "closed" flux.

To further investigate the nature of the dynamo in spectroscopic binaries, Skumanich is collaborating with Arthur Young (San Diego State University) in a study of the Ca^+ infrared lines in such stars. In another collaboration with Robert Stern and James Underwood (both at the Jet Propulsion Laboratory) Skumanich is attempting to observe the X-ray emission from the unusual triple star system HD165590 with the High Energy Astronomical Observatory (HEAO-2) X-ray satellite (Einstein Observatory). The objective is to investigate the dependence of the X-ray/optical luminosity ratio on the angular velocity in extremely rapidly rotating stars.

CORONAL-INTERPLANETARY PHYSICS SECTION

As stated in last year's Scientific Annual Report, 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 coronal transients and their role in the transport of material and magnetic flux from the sun, the acceleration of the coronal and solar wind, plasma, the three-dimensional structure of interplanetary space, and the role of magnetic fields in both determining coronal structure and "modulating" the outflow of plasma. Our approaches to these problems range from an observing program involving both ground-based and space-borne instrumentation, through extensive efforts to interpret coronal and interplanetary data, to theoretical research aimed at the development of quantitative models of coronal and solar wind phenomena. Much of our work overlaps the interests of the two other scientific sections of HAO. Specifically, our studies of long-term changes in the corona and solar wind and their possible effects on the terrestrial environment are closely related to the HAO Solar Variability program, while the study of the relationship of coronal structure to that in the lower solar atmosphere brings us into contact with the Solar Atmosphere and Magnetic Fields Section. There is also a high level of collaboration with scientists from other institutions. The goal of our section is clearly centered on the NCAR theme of understanding solar processes and their influence on the interplanetary medium.

Coronal Transients

The observations of coronal transients--ejections of 10^{15} g of coronal material at speeds of several hundreds kilometers per second--made with the HAO coronagraph on Skylab in 1973 served to focus attention on this phenomenon and its role in the mass and magnetic flux balances of the corona. The physical mechanism driving this discontinuous component of the coronal expansion became a topic of considerable theoretical interest and debate, and several detailed quantitative models of transient initiation and propagation have been formulated. Analysis of the Skylab observations indicated that these events provided 5% of the mass and magnetic field carried away from the corona by the solar wind. The rate of transient occurrence was related to the level of solar activity, and the Skylab observations were made at a time of low activity (during the declining phase of sunspot cycle 20). It seemed possible that transients might play a more important role in the coronal mass and magnetic flux balances during periods of high solar activity.

Many of the coronal transients observed during Skylab had the appearance of bright loops and have thus been widely interpreted as rising magnetic flux tubes. Pneuman has examined the role of magnetic forces in driving an outward expansion of such a magnetic structure. He suggests that coronal transients result from the magnetic loops initially rooted, in the lower layers of the atmosphere. The lower part of the magnetic structure produced by the reconnection process remains so rooted, and the energy released by reconnection produces X-ray and H emission on these closed, low-lying magnetic loops. The upper part of the new field structure consists of loops detached from the dense lower layers of the sun, and it is accelerated upward by a magnetic pressure imbalance. Pneuman and Ulrich Anzer (Max Planck Institute in Munich) have computed the motion of the upper edge of these detached loops and find a rapid initial acceleration followed by nearly constant speed passage through the outer corona; this is similar to the behavior observed during the Skylab mission. They also predict that the width of the bright loop should increase with height in a fashion similar to that actually observed.

A major HAO program spanning the past several years has been directed toward a better observational understanding of coronal transients. A coronagraph/polarimeter has been designed, constructed, and in February of 1980 flown as one of the complement of instruments on the SMM spacecraft. This instrument observes the corona over the heliocentric distance range from 1.5 $R_\odot$ (solar radii) to 5 $R_\odot$ through a set of filters that can be used to distinguish the white-light coronal radiation (photospheric light scattered by coronal electrons) from radiation actually emitted from material in the corona, as in the normal coronal green line or in the H radiation from prominences. The SMM instrument is a significant improvement over the Skylab coronagraph in this range of coverage and filter selectivity as well as in spatial and temporal resolution. It has been operated in an interactive mode by the HAO team of House, Ernest Hildner (now at Marshall Space Flight Center), Rainer Illing, Constance Sawyer, and William Wagner, in close coordination with the other SMM instrument teams and with input from other ground-based and satellite-borne instruments. A new coronagraph and prominence monitor were constructed and installed under the direction of Fisher at the Mauna Loa Observatory (MLO) in time to participate in an SMM joint observing program. The new MLO coronagraph covers the heliocentric distance range from 1.1 $R_\odot$ to 2 $R_\odot$. It can thus detect coronal transients at altitudes lower than those accessible from SMM. This capability permits the study of the earlier stages in transient development and alerting of the SMM observers that a transient is rising into their field of view at a specified location.

Observations with both instruments spanned most of 1980. The SMM coronagraph/polarimeter collected more than 30,000 images of the corona before it ceased operation late in the year. The Mauna Loa instruments are still operating, and the coronagraph will continue long-term, synoptic measurements of coronal structure throughout the 1980s. Data from both sources have already extended and clarified our understanding of the initiation and outward propagation of coronal transients.

The Mauna Loa coronagraph has found a common class of transients to be first detectable as a looplike region of decreased white-light brightness (hence abnormally low coronal density) rising above the lower edge of the field of view. The eruptive prominence that is usually associated with a transient is seen by the Mauna Loa prominence monitor to rise well behind the deficit, at a significantly slower speed. Enhancement of the coronal white-light brightness (and hence a region of abnormally high coronal density) is observed around the edges of the deficit in the later stages of its passage through the field of view. It is clear that the material in the ascending prominence does not account for the "bright loop" characteristic of transients in the outer corona (as in Skylab or seen by SMM, as described below); it seems unlikely also that the bright loop is a compressed shell produced by a rapidly moving prominence. The motion of both the deficit in brightness and the prominence in the field of view of the Mauna Loa coronagraph is at nearly constant speed; the major acceleration of material must then occur below 1.1 $R_\odot$.

The SMM coronagraph/polarimeter has observed numerous coronal transients with the characteristic form familiar from Skylab--an outward moving bright loop. The SMM group and Hermann Schmidt (Max Planck - Munich) found that transients occurred over a wider range of solar latitudes than that during during the Skylab epoch, but that the range of observed speeds is similar. The rate of transient occurrence measured by SMM is consistent with that found during the Skylab epoch, despite the higher general level of solar activity in 1980. Again, these features move with constant or very slowly increasing speed through the field of view of the coronagraph/polarimeter. The eruptive prominence material has been clearly observed in H emission to heliocentric distances as large as 5 $R_\odot$; it appears well inside the bright loop.

An important facet of the SMM program is the great potential for studies combining the data from that spacecraft with simultaneous observations from other sources. Comparison with radio observations (in collaboration with Kevin Sheridan of the Commonwealth Science and Industrial Research Organization (CSIRO), and George Dulk (University of Colorado)) suggests that the mechanical and magnetic energy in a flare-associated transient far exceeded the radiative energy released in the flare. Several transients seen by the SMM coronagraph have also been observed with the SOLWIN coronagraph on the P78-1 spacecraft as far out as 10 $R_\odot$. Detailed examination of the motion of these transients by our SMM group and Neil Sheeley (Naval Research Laboratory) reveals a nearly constant propagation speed over the entire 1.5 $R_\odot$ to 10 $R_\odot$ range of heliocentric distance. Future correlative studies of this nature should clarify additional characteristics of coronal transients and their relationship to other forms of solar activity (such as X-ray emission) and the ground-based radio observations that have been traditionally interpreted as evidence for energetic particles, shock waves, and plasma motions in the corona.

The Quiet Corona and Solar Wind

The acceleration of coronal plasma to form the solar wind and the relationship between coronal conditions and the characteristics of the wind in interplanetary space have been topics of continuing interest at HAO. Recognition of the importance of coronal holes as sources of high-speed solar wind streams and the observation of the high-energy fluxes commonly associated with holes have provoked interest in the acceleration process in rapidly diverging flow tubes (coincident with the diverging magnetic flux tubes in holes) and in the role played by waves in adding momentum and energy to the plasma. Egil Leer (visitor from the University of Tromsø, Norway) and Thomas Holzer have developed several theoretical models combining these two ideas. They have examined a sequence of solutions to the fluid equations for mass, momentum, and energy conservation with parameterized momentum and energy addition terms under the boundary condition that the pressure at the base of the corona remains fixed. They show that the location where the momentum or energy is added is a crucial factor in determining the ultimate effect on the solar wind. If the addition occurs low in the corona, below the critical point where the flow becomes supersonic, the major effect is to increase the mass flux in the wind; the solar wind speed at large distances from the sun changes only slightly. An increase in the speed of the distant wind, the effect sought in adding momentum and energy, occurs only if the addition is in the outer corona, beyond the critical point. This result throws some doubt on the results of earlier solar wind models that hold the mass flux fixed as a boundary condition and obtain high solar wind speeds through the addition of momentum and energy in the low corona. Leer and Holzer have also applied these ideas to models of Alfvén wave acceleration of winds in stars other than the sun. The same doubt arises.

Other theoretical studies of solar and stellar wind formation have examined more specific mechanisms of momentum and energy addition (or dissipation). Pneuman has considered the possible role of discrete magnetic reconnection events in adding momentum to the expanding plasma. Xue-Pu Zhao (visitor from Beijing University) has considered the effects of Alfvén waves on the solar wind. Richard Wolfson (visitor from Middlebury College) and Holzer are studying the role of viscous dissipation in high-mass-flux stellar winds.

The ultimate test of any such model is its ability to predict observed solar wind properties given boundary conditions (e.g., density, temperature, or wave fluxes and frequency distribution) appropriate to the real corona. Existing models are poorly restrained by this test because of our fragmentary knowledge of the proper coronal boundary conditions, especially in the regions most important to the models described above, coronal holes. A joint Harvard-Smithsonian-HAO observing program is intended to provide much-needed measurements of coronal density, temperatures, and flow speed as a function of position in the corona. So far, we have flown a Lyman-alpha/white-light coronagraph package twice aboard a rocket. Analysis of data from the first flight by John Kohl and George Withbroe (Harvard-Smithsonian) and Richard Munro has yielded proton temperatures that vary from 2.4×10^6 K at a heliocentric distance of 1.5 $R_\odot$ to 7×10^5 K at 3.5 $R_\odot$ along a single radial "slice" through the corona. If this slice does represent a flow tube, such a rapid decrease in proton temperature with height in the atmosphere would imply a nearly adiabatic energy law. This behavior would be consistent with "two-fluid" models of the solar wind wherein the protons are assumed to be heated only by their weak collisional exchange of energy with the hotter electron population. The second flight of this instrument package achieved radial scans both in a coronal hole and along a coronal streamer. Analysis of these data is now underway.

Our studies of the characteristics of the solar wind in the interplanetary region emphasize the development of theoretical models of interplanetary phenomena and the interpretation of solar wind observations, often in the context of those models or in relationship to solar observations. For example, Victor Pizzo has spent the past several years working on a sophisticated numerical model of the interaction of steady solar wind streams of different speeds. The model has been carried to the point where it can deal with fully three-dimensional streams with a finite magnetic field provided that all fluid parameters vary continuously with position. Addition of an artificial viscosity will permit treatment of shock waves. While this model leads to general predictions of physical interest--for example, that even large-amplitude streams with steep gradients in the direction of solar latitude produce little transport of mass, momentum, or angular momentum in that direction--its full utilization should include direct, detailed comparison with observations. Pizzo has collaborated with Len Burlaga (visitor from NASA Goddard Space Flight Center) and Rainer Schwenn, Eckart Marsh, and Helmut Rosenbauer (Max Planck Institute in Lindau) in obtaining solar wind stream observations from three sources at different distances from the sun--Helios I and II measurements near 0.6 astronomical units (AU), IMP spacecraft near 1 AU, and Voyager I and II well beyond 1 AU. Data obtained at one location will be used as input to the model and the predictions compared with observations at the other locations.

Pizzo's collaboration with the Max Planck group has also led to a new determination of the angular momentum flux of the solar wind based on the Helios data. The He^{++} ions in the solar wind are now known to have a small average nonradial velocity component counter to solar rotation, and the Helios observations have yielded the first quantitative determination of the associated angular momentum flux. This value must be subtracted from the flux carried by the more abundant H^{+} ions in determining the total angular momentum flux carried by solar wind particles. This correction and the careful examination of systematic errors in the Helios measurements leads to a flux that is a factor of 4 less than given by several early solar wind data sets. The new value is in good agreement with simple models of angular momentum transport in the solar wind.

The three-dimensional structure of the solar wind is another topic of continuing interest at HAO. Examination of the long record of K-coronameter observations from the Mauna Loa Observatory has revealed a clear pattern of slow evolution in the spatial pattern of coronal holes during the past sunspot cycle; this work is described in the Solar Variability section of this report. Burlaga, Zhao, and Hundhausen have continued studies of the manner in which this coronal structure extends into interplanetary space. They hypothesized that a magnetic neutral line (at which the magnetic field reverses direction) encircles the sun directly above the line of maximum brightness in the corona. The predicted neutral line position was then compared with the observed locations of sector boundary crossings (i.e., magnetic polarity reversals) observed by Helios I and II. The agreement during an interval of four rotations of the sun in early 1976 was remarkably good. During a single rotation the two Helios spacecraft were separated by nearly 10° in solar latitude, with their orbits spanning the predicted location of the neutral sheet. Indeed, the two spacecraft observed different magnetic polarities, confirming that the maximum brightness line did predict the true neutral sheet location to within this 10° range. This comparison is of special interest because published neutral line locations based on potential field extrapolations for this same epoch have placed the neutral line 20° farther from from the solar equator. Zhao and Hundhausen have also shown that the solar wind speeds inferred from interplanetary radio scintillations are reasonably well organized around the predicted neutral line. Solar wind speeds are again low (near 400 km/s) at the neutral line and increase to 600 km/s at 30^{0} away from the line.

Magnetic Fields

It is widely recognized that the solar magnetic field is responsible for most of the spatial inhomogeneity (or structure) observed in the outer layers of the sun and for the temporal changes in that structure related to solar activity. Our earlier descriptions of research on coronal transients and the quiet corona and solar wind reflect this common belief. Yet it is no exaggeration to state that we have very little direct evidence concerning the strength or geometry of magnetic fields in the corona. Most of our knowledge of coronal magnetic fields stems from identification of such observed features as holes, loops, and streamers with distinct magnetic geometries (open regions, closed flux tubes, and neutral sheets, for example) or from the theoretical extension of fields observed in the photosphere to the outer layers of the solar atmosphere.

These theoretical extensions of photospheric magnetic fields have usually been accomplished by solving a boundary value stemming from some approximation to the equations of magnetohydrodynamics (MHD). For example, it has often been assumed that electric currents in the corona can be neglected and the field derived from the gradient of a scalar magnetic potential. The fields corresponding to any distribution of vertical (or alternately, line-of-sight) magnetic field components at the base of the corona can then be computed by standard techniques. Alternatively, it has been argued, the magnetic forces acting on the coronal plasma must be small, so that any currents in the corona must be parallel to the magnetic field lines. This yields a linear equation for the magnetic field B, namely that $\nabla \times B = \alpha B$ where α is a scalar function of spatial coordinates. Specification of the proper boundary condition requires knowledge of the vector magnetic field at the base of the corona. Neither of these approximations considers any coupling of the magnetic field to the plasma structure (other than that the currents flow in the plasma), as reflected by the purely magnetic nature of the boundary conditions given above.

There has been a recent upswing in interest in still another class of theoretical models that describe the extension of an ionized atmosphere above a lower boundary where conditions are specified--that of atmospheres in magnetostatic equilibrium. In this approximation to a full mhd problem, currents are allowed to flow in the atmosphere with the requirement that the sum of magnetic, pressure gradient, and gravitational forces is zero (and there is no motion of the plasma). The discovery of a family of analytic solutions for the magnetostatic equilibrium of infinitely long magnetic arcades by Zweibel and Hundhausen was described in the last annual report. This work has now been extended by Joan Rohrer Hundhausen (Colorado School of Mines), Hundhausen, and Zweibel to a spherical geometry with an inverse-square gravitational force, a set of assumptions far more suited to the study of coronal fields than the simpler Cartesian geometry with constant gravity used in the earlier study. The magnetic field is assumed to be a function of solar latitude and distance from the sun. Again, a family of analytic solutions was found, corresponding to arcades of closed magnetic loops encircling the sun parallel to its equator. For a dipole-like radial field at the base of the corona, these solutions describe the distortion of the well-known dipole field, obtained if there are no currents in the atmosphere, by a concentration or depletion of plasma at the equator. An equatorial plasma concentration, as observed in the corona during those phases of the sunspot cycle when the sun does have a strong dipole general field, inflates the closed magnetic field lines spanning the equator, producing more nearly vertical fields at the base of the corona. The general appearance of the calculated field lines resembles the shapes of the helmet-like structures actually observed in the corona far better than the very "flat" closed loops commonly obtained in potential field theory.

All of these solutions to the magnetostatic equilibrium problem have been derived under the assumption of very simple distributions of plasma on magnetic field lines that yield a linear problem. More general pressure distributions lead to nonlinear problems. Boon Chye Low, who has also worked extensively on magnetostatic atmospheres before recently joining our staff, has found analytic solutions to a single nonlinear case in Cartesian coordinates. Work is now under way on numerical solutions to still more general atmospheres with less simple distributions of plasma with respect to the magnetic field.

Vladamir Osherovich (visitor from Pulkoua Observatory) has worked on a related formulation of magnetostatic equilibria in a cylindrical geometry with a most obvious application to the sunspots. He has found a self-similar solution to this problem that allows the return of field lines radiating from the spot to the surface of the sun. This model describes the observed orientations of the sunspot field far better than earlier solutions to this problem.

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Len Burlaga, NASA Goddard Space Flight Center, June 1980 - September 1980.

E. Landi Degl'Innocenti, Arcetri Observatory, Florence, Italy, September 1979 - September 1980.

Soren Frandsen, University of Aarhus, Denmark, October 1980 - September 1981.

Gary Glatzmaier, University of Colorado, October 1980 - October 1981.

Shaddia Habbal, Harvard College Observatory, August 1980.

Charles Hyder, Marshall Space Flight Center, January 1980 - present.

Egil Leer, University of Tromso, Norway, June 1980 - August 1980 and December 1980.

Vladimir Osherovich, USSR Academy of Science, Pulkovo, USSR, October 1980 - October 1981.

Jean-Pierre Picat, Paris Observatory, Meudon, France, October 1979 - January 1980.

Eric Priest, University of St. Andrews, Scotland, September 1980 - December 1980.

David Rees, University of Sydney, Australia, December 1980 - February 1981.

David Soderblom, Lick Observatory, California, October 1980 - October 1981.

John Streete, Southwestern at Memphis, June 1980 - June 1981.

Wen-Yao Xu, Academia Sinica, Beijing, China, September 1979 - October 1980.

Richard Wolfson, Middlebury College, Vermont, September 1980 - September 1981.

Xue-Pu Zhao, University of Beijing, China, October 1979 - October 1981.

ADVANCED STUDY PROGRAM

In its major role as a center for collaborative research throughout the atmospheric research community, NCAR strongly supports interactions among its own staff, university researchers, and graduate and postgraduate students in the atmospheric sciences. Much of this collaboration is facilitated through the Advanced Study Program (ASP). ASP administers a visitor program consisting of graduate research assistantships, post-doctoral fellowships, and scientific colloquia, all designed to foster new and continuing cooperative work between NCAR scientists and university investigators. In its role as initiator of experimental research, ASP also contains an Environmental and Societal Impacts Group (ESIG). ESIG explores the social context and implications of atmospheric research and phenomena through interdisciplinary studies within NCAR and in collaboration with university, governmental, and other non-governmental agencies.

VISITORS PROGRAM

Graduate Research Assistantships

ASP awards a limited number of graduate assistantships to students pursuing master's or doctoral degrees in the atmospheric sciences. While in residence at NCAR, graduate assistants carry out research based on their thesis proposals, which must be endorsed jointly by a university scientist and an NCAR scientist. These scientists serve as advisers for the thesis and as members of the student's thesis committee. The students work directly within NCAR research projects in such areas as atmospheric dynamics, climate, cloud physics, atmospheric chemistry and radiation, atmospheric physics, environmental and societal impacts assessment, solar physics, and oceanography. Their length of tenure has been from one to three years. In 1980 two new appointees were named, eight assistantships were continued, and one assistant received the doctoral degree. Selected examples of work by ASP graduate research assistants are given below.

A one-dimensional time-dependent photochemical model of the atmosphere from the earth's surface to an altitude of 120 km has been constructed by Susan Solomon, a visitor from the University of California, Berkeley. The model includes all the relevant chemistry of the stratosphere, such as chlorofluorocarbon chemistry, NO_x chemistry, etc. In the D-region, ion chemistry is also included. This model has been used to study the neutral and ion chemistry of solar proton events and, particularly, their effects on atmospheric ozone.

Solomon has also constructed a two-dimensional model of the same altitude region. This model has been used to study thermospheric production of NO. In the polar night region, NO produced at thermospheric altitudes can be transported downward to reach the stratosphere. The impact of this process on stratospheric NO concentrations is an effect not considered in other models of the stratosphere, and it has been found to be substantial. In the stratosphere, NO interacts catalytically to destroy atmospheric ozone. The enhanced NO densities at stratospheric altitudes which result from thermospheric processes therefore yield considerable decreases in atmospheric ozone. This coupling between the thermosphere and the stratosphere is an important process which has been examined theoretically for the first time in this work.

In another example, the work of William Kohri, visitor from Drexel University, had essentially two objectives. The first was to test and implement a statistical filtering algorithm for obtaining "synoptic" estimates of the distribution of atmospheric field variables from "asynoptic" satellite measurements. This procedure was used to determine daily fields of temperature and geopotential height in the stratosphere during November and December 1975 by operating upon temperature data obtained from the Limb Radiance Inversion Radiometer (LRIR) experiment. This instrument was flown aboard the Nimbus 6 spacecraft launched in June 1975. The output of the filtering algorithm was composed of daily zonal Fourier coefficients representing temperature and geopotential height at latitude intervals of 4° between 64°S and 84°N and at 18 pressure levels extending between 100 mb and 0.1 mb. A comparison of the daily LRIR and National Meteorological Center Northern Hemisphere analyses at levels between 100 mb and 10 mb verified the validity of the filtering technique.

The daily Northern Hemisphere temperature and geopotential height coefficients were subsequently used in the computation of the structure of the monthly zonal mean temperature and zonal wind as well as of stationary waves one and two in the latitude/height plane. These data were then used in an evaluation of the results produced by theoretical one-dimensional and two-dimensional models which were designed to explain the structure and propagation of the stationary planetary waves present in the Northern Hemisphere's stratosphere. The satellite data served to emphasize the importance of the two-dimensional distribution of the mean zonal wind in determining the manner in which stationary planetary waves propagate.

Postdoctoral Fellowships

The fellowship program seeks to provide opportunities for talented Ph.D. scientists with less than four years of experience to continue pursuing their recent research objectives and to allow them the opportunity to take advantage of NCAR's intellectual and physical resources to gain expertise in other areas as well. The program also serves to enrich atmospheric science research efforts by inviting a limited number of Ph.D. physicists, chemists, applied mathematicians, engineers, biologists, social scientists, and specialists from other appropriate fields to apply their training and experience to problems in the atmospheric sciences. A primary long-range goal of the program is to help ASP fellows form associations with NCAR that will extend well beyond the terms of their appointments through continued use of NCAR's research facilities and through ongoing work with NCAR staff.

The one-year fellowship appointments (including stipends and NCAR benefits) may be extended for a second year. During the first year, fellows are encouraged to pursue individual interests, including exploration of new areas of research. For reappointment, however, interaction with NCAR staff is stressed, as fellows are expected to participate in the large-scale, coordinated research projects being conducted at NCAR in climate studies, large-scale dynamics, mesoscale meteorology, oceanography, geophysical fluid dynamics, severe storms, atmospheric chemistry, atmospheric physics, solar physics, or environmental and societal impact assessments. Fellows have direct access to the NCAR CRAY-1/Contol Data 7600 computer system and to the main research library; use of other facilities--aircraft, radars, and laboratory and field observing systems--is by mutual agreement with the appropriate project or facility.

During the past year, ASP awarded eight new fellowships and gave second-year renewals to nine other appointees. Some highlights of the research of a few fellows is given below to exemplify the contributions they typically make both to the specific goals of NCAR and to atmospheric research in general.

In order to correctly model solar variability, it is necessary to first have an adequate deterministic model of the solar convection zone. This requires a three-dimensional computer code capable of including the complex physics appropriate for any level of the solar convection zone. Ronald Gilliland pursued the possible application of a noniterative, alternating-direction-implicit (ADI) algorithm to this problem. His work included generalizations of previously published noniterative ADI schemes to allow for: (1) spherical geometry, (2) cyclic boundary conditions, and (3) fourth-order compact spatial differencing. The two-dimensional algorithms can be extended to three-dimensional spherical coordinates in a straightforward manner.

The subject of solar radius and luminosity variability has recently become a very popular subject with several (often conflicting) studies of causal mechanisms and their effects appearing in the literature. Some authors have claimed that a model-independent relationship exists for relative radius and luminosity fluctuations on the sun. If they are correct, then a measurement of radius variations, coupled with current theory, implies a definite corresponding luminosity variation. Gilliland argued that the resulting variations are highly model dependent. Furthermore, the physics (deterministic magnetohydrodynamics) required to predict solar variability has not yet been included in the models. Other authors have predicted solar variations by examining in a linear sense one consequence of an assumed perturbation. Gilliland showed that with a more detailed treatment (fully time-dependent, one-dimensional, stellar-structure computation) the stated surface variations either do not occur or require major modification. His calculations have shown that the simpler models are probably in error. However, a reliable modeling of solar radius and luminosity variations will require deterministic and physically realistic models of the solar convective and photospheric regions.

Concurrent with the proliferation of simple theoretical models of solar variability is the appearance of several (often conflicting) studies of the historical records of solar radius indicators. (Unlike the debate over appropriate theory, the debate over interpretation of observational evidence for solar radius changes extends back about a century.) This recent upsurge of interest is in large part due to the claim of John Eddy (of NCAR's High Altitude Observatory) and Aram Boornazian (S. Ross and Company, Boston) that meridian circle transit-timing data indicates a large ~0.1% century decrease of solar radius. This trend has been disclaimed by other authors based upon historical Mercury transit timings. Gilliland undertook an analysis of several different data sets with the intention of investigating both possible secular trends and periodic variations. An objective analysis of all available data implies a small negative secular trend ($\gtrsim$0.01%/century). Of greater significance is the evidence in all data sets of a periodic variation of solar radius (P = 76 $\pm$ 8 yr, Amp = 0.02 $\pm$ 0.01%, max phase = 1911 $\pm$ 4). Evidence of an 11-year cycle in the solar radius at half-amplitude of 0.01% is also found. The radius variations at all discernible time scales are significantly anticorrelated with observed sunspot frequency.

Research by Thomas Phillips entailed the use of a modified version of the Held-Suarez climate model, in collaboration with Bert Semtner of the Atmospheric Analysis and Prediction Division. They studied two cases: (1)prescribed tropical and midlatitude anomalies superimposed on a seasonally varying, but prescribed, ocean; and (2) empirical orthogonal function (EOF) analysis of a 30-year integration of the model with an active oceanic mixed layer whose temperature and depth are prognostically determined. In the first case, Phillips' results were in accord with those of analogous general circulation model experiments performed over much shorter periods of integration. Prescribed tropical anomalies forced an extensive statistically significant downstream response in all seasons, whereas midlatitude anomalies had a statistically significant impact only on the atmosphere above and immediately downstream of the anomaly. While Phillips has only done a preliminary analysis of the results with an interactive oceanic mixed layer, it appears that particular EOFs of atmospheric temperature and geopotential height correlate significantly with certain EOFs of ocean temperature, assuming that oceanic data two years apart can be treated as statistically independent.

In a related piece of work using a quasi-geostrophic model, Phillips examined the effects of longitudinal shifts (with respect to a forced planetary wave number two pattern) of prescribed sea surface temperature anomalies under different conditions of vertical shear and static stability. He found that the climatic response is quite sensitive to the changes in longitudinal position of the anomaly, but is even more sensitive to changes in vertical shear or static stability. Lower values of vertical shear or higher values of static stability are associated with relatively low-amplitude transient waves, and correspondingly less "climatic noise." Statistically significant downstream responses in most atmospheric fields are evident in these cases.

Phillips also worked with Maurice Blackmon (chairman of ASP until 1 October 1980) in analyzing six Southern Hemisphere winters using the "Australian" data, probably the most reliable data set now in use for the Southern Hemisphere. They obtained winter means and variance fields for different atmospheric fields at standard levels in the vertical. They also examined high-pass filtered data in order to separate the variance due to synoptic storms from the total variance. A preliminary analysis reveals some analogues with Northern Hemisphere winter climate; namely, a seeming tendency for the jet stream to spiral inward toward the pole in moving from west to east around the hemisphere, a jet stream with several "centers of action" which appear to be related to land/sea contrasts and/or orography, and a relationship of these jet centers and the centers of variance associated with synoptic storms. There are also expected differences, principally, the much more zonal character of the Southern Hemisphere winter means of all atmospheric fields.

Summer Colloquium

In addition to sponsoring various lectures, seminars, and scientific conferences throughout the year, ASP attempts to maintain a program of summer colloquia for graduate and postgraduate students. The colloquium series, begun in 1965, comprises lectures and seminars centered on a selected topic of significant contemporary interest to atmospheric researchers. The colloquium summaries are typically published collectively as a volume; they are widely used as references both at NCAR and in university courses.

In 1980 a summer colloquium entitled "The CHON Photochemistry of the Troposphere," was conducted jointly with the NCAR Atmospheric Chemistry and Aeronomy Division (ACAD). For the first time it involved student field work as part of the process of measuring, assessing, and numerically modeling data on the fluxes of trace gases and of photochemical interactions of "CHON" species (i.e., carbon, hydrogen, oxygen, and nitrogen compounds) in the troposphere. Colloquium participants included 15 graduate students and a dozen scientists from 11 universities, NASA, the National Oceanic and Atmospheric Administration (NOAA), and NCAR.

The field site, located in northeastern Colorado on the Pawnee Grasslands preserve, was chosen partially for its remoteness from human influence and partially because of its level terrain and correspondingly uncomplicated airflow patterns. Two instrumented towers were erected for measuring standard boundary-layer parameters (vertical fluxes of heat, momentum, and moisture); fluxes of ozone, NO_x, HNO_3, H_2O_2, and hydrocarbons; concentrations of the principal tropospheric CHON species; and ultraviolet radiation (which provides the energy for photochemical reactions). The NCAR Queen Air aircraft also made boundary-layer flux and ozone measurements in flights over the towers; during the second week of the field phase it flew to the Gulf of Mexico, collecting ozone flux data over different kinds of terrain along the way and above the ocean surface in the Gulf to be used for intercomparison with the Colorado data.

As the field work was going on, other participants were refining two computer models of photochemical processes. The first, a zero-dimensional model, uses measured values of long-lived atmospheric species to predict the amounts of short-lived species that will be present at photochemical equilibrium. The experimenters compared the model's predictions with the actual measurements of short-lived species made in the field. The second model is a one-dimensional model that takes both vertical diffusion and chemical reactions into account. One of the chemical models was contributed by ASP postdoctoral fellow James Kasting. As data from the grasslands became available, the colloquium investigators conducted studies to project the effects of boundary-layer data on the rest of the troposphere.

The final two weeks of the summer program were devoted to seminars and to subsequent student-written reports. During the meeting sessions, five major topics were addressed: boundary-layer meteorology, the photochemistry of the troposphere, the chemical and micrometeorological instrumentation used in the field phase, laboratory measurements of species collected in the field, and models of photostates and removal fluxes for atmospheric constituents. These discussions have been published as Grasslands, notes from a colloquium on the CHON photochemistry of the troposphere, summer 1980.

ENVIRONMENTAL AND SOCIETAL IMPACTS GROUP

The passage of the National Climate Act in 1978 and the establishment of the U.S. National Climate Program Office has heightened interest in assessing the impact of atmospheric phenomena on society as well as the impact of societal activities on atmospheric phenomena. ESIG has expanded its research efforts on the value to society of such climate-related information as: climate-related forecasts; drought and desertification and their relation to land use in arid and semiarid areas; climate variability and its impact on agricultural and fisheries productivity; water resource planning in developed as well as developing regions; as well as on the social considerations of urban air pollution and the CO_2 issue. Several of these efforts are described below.

The first stage of a research effort by Michael Glantz, the analysis of the impact of the Yakima streamflow forecast, was completed in 1980. Glantz, along with university visitors (Richard Katz, Oregon State University; Barbara Bintliff, University of Denver Law Library; Benjamin Schoepfle, graduate student at Indiana University), has been conducting a study to evaluate the impact of a February 1977 estimate by the Department of Interior's Bureau of Reclamation (now the Water and Power Resources Service) of the total water supply available in the Yakima River Valley for the year's irrigation season. The estimate projected that less than half the long-term average water supply would be available to irrigators. Allocations were made by the Bureau of Reclamation accordingly, with "senior" water rights honored first and "junior" rights awarded at 7% of the normal share. Responses to the estimates and to the allocations based on those estimates included expensive well drilling, the pumping of dead storage from a major reservoir, the relocation of crops outside the Yakima basin, and considerations of transbasin water diversions. During succeeding months, allocations were revised in response to changing estimates of available water. In May 1977 the Bureau of Reclamation admitted that errors had been made in calculating water supplies, and Yakima Valley farmers took legal action in an attempt to recover expenses incurred as a result of those projections. The Yakima case raises questions about the possible benefits and costs to society of such forecasting as well as about the responsibilities associated with certain types of forecasts. Some of the findings of this study (and of other studies) were presented at lectures given by Glantz at two separate United Nations Environmental Programme/USSR World Land Resource Project courses, at the World Meteorological Organization's Technical Conference on Climate in Gwuangzhou, China, and at various Canadian univerities and government offices from British Columbia to Newfoundland.

New projects for future studies have been developed in the area of climate-related impacts in 1980. These include plans for a possible co-operative research effort on societal aspects of acid rain, which would involve some members of NCAR and John Lewis of the Geography Department at McGill University. Glantz was on collaborative leave at McGill in February and March 1980. A cooperative research effort on "Government Response to the mid-1970s Drought" between Glantz and Norman Rosenberg and Donald Wilhite of the Center for Agrometeorology and Climatology at the University of Nebraska is being considered. In progress is the development of a multidisciplinary project with the University of Nebraska concerning the use of the Ogallala aquifer and related policymaking processes at the local, state, and federal levels.

In 1980 work continued on several important aspects of the Denver Regional Air Quality Study. The goal of this multi-year, interdisciplinary team study is (1) to develop a set of models which project, for the next 20 years, the quality of the air of the metropolitan Denver area and which show the effects on air quality of a number of possible management policies; and (2) to link (via the Symmetrical Linkage Systems) these quantitative predictions to a model developed by behavioral scientists, which analyzes the trade-offs involved between effectiveness and acceptability of various management options.

Robin Dennis has coordinated the overall project, integrating three new people (Mary Downton, Colleen Keeling, Thomas Stewart) into the group, as well as initiating and continuing major technical analyses for use in the various components of the scenario model. He also worked on the linkage between the technical and social value components of the study.

Paulette Middleton worked on the development of urban visibility index and urban ozone indices to be used in the scenario models. The ozone work was done in collaboration with A. Rachel Laird and Richard Miksad from the University of Texas at Austin. In addition, she completed a study with Melvin Shapiro and Philip Haagenson of ACAD documenting the fact that the highest ozone event on record in Denver from 1974 to 1979 was due primarily to stratospheric intrusion of ozone rather than to pollution. The aerosol measurements for the visibility field studies were carried out in collaboration with NCAR's ACAD, NOAA/Environmental Research Laboratory, the Solar Energy Research Institute, and Hal Rosen, Anthony Hansen, and Tihomir Novakov of the Lawrence Berkeley Laboratory. Two projects to collect summer and winter field observation data for the study of visual air quality were organized and supervised by Stewart and partly funded by the Environmental Protection Agency (EPA). The above work of the ESIG group in the area of urban visibility has received national attention, exemplified by an invitation to participate in the design and execution of similar studies in other regions and by invitations to present the work at national meetings.

Other aspects of the project are also continuing. Two workshops were conducted, one on social-value modeling and one on the hierarchical structuring required by social-value models. Both included ESIG members and a dozen or so planners from the Denver Regional Council of Governments (DRCOG), the Regional Transportation District, the Department of Highways, and the Department of Health. Aided by a grant from the EPA Region VIII, a technical analysis of emissions reductions due to high-altitude inspection/ maintenance programs was carried out, and, in part through a grant from the Colorado Department of Health, the data from the 1980 State Legislative Study on mobile emissions were analyzed (work done by Dennis and Keeling). The Systems Applications, Inc., (SAI) airshed model was brought to NCAR through the cooperation of the Colorado Department of Health. Dennis, with William Lord (an economist from the University of Colorado), developed a more detailed economic analysis which was included in an updated version of the scenario model for use in the workshop held in the fall of 1980. Stewart examined the hierarchical structure of public values regarding air quality, with the goal of developing methods for obtaining social-value information that can be integrated with the output of the physical/economic/environmental models.

The methods and models of the Denver project have been presented to the Clean Air Task Force, a citizens advisory committee to DRCOG, which the project personnel determined was the appropriate user. Consequently, DRCOG has agreed that the ESIG group should participate in the public workshops planned for the summer of 1981 and hence in the process of developing the Denver element of the Colorado State Implementation Plan for air pollution regulation, whose aim is to bring the Denver region into compliance with federal air quality standards.

In October 1980, William Kellogg, formerly with the Atmospheric Analysis and Prediction Division, joined ESIG. His work since then has been in the area of environmental and societal impacts of a potential CO_2-induced climate change. Kellogg, along with Stephen Schneider, who also transferred from AAP to ASP in October 1980, has concentrated on gathering a wide variety of inputs for the development of "climate scenarios." These are detailed descriptions of climate that could occur on a warmer earth. They serve as a first step in the study of possible impacts of a global climate change due to increasing CO_2. Kellogg also organized and participated in the American Geophysical Union's session on "Carbon Dioxide and Climate."

An interdisciplinary project has been started by two visitors to ESIG, Derek Winstanley, a climatologist formerly with Environment Canada, and Donald Borock, a political scientist on sabbatical leave from Gettysburg College under an NSF Faculty Development grant. Their project examines societal impacts on world food systems of climate variation, concentrating on how national and international policy and decision-making interacted with climatic effects. Specifically, climate-related issues of the world food crisis of the early 1970s, the U.S. policy during that crisis, and the World Food Conference of 1974 are being investigated. Preliminary results suggest that deliberate policy decisions more than climate-related variations in food supply are the major forces of influence on global food systems. They suggest that a more detailed examination of the interactions between climate variability, food supply, and the political process can contribute to increased food security in the face of climatic events.

Richard Warrick, a geographer, joined ESIG in late December. He will continue his research on problems related to society-climate interactions, such as drought in the Great Plains and the societal effects of CO_2-induced climatic change. Robert Schware, an ASP postdoctoral fellow working with ESIG, began a trip in 1980 to gather field information on the societal effects of floods on inhabitants of the Ganges lower region.

OTHER ASP STAFF RESEARCH

In October 1980 three senior scientists, John Firor, William Kellogg, and Stephen Schneider, transferred into ASP. Kellogg's research in the fall of 1980 is described under ESIG. Firor has assumed the directorship of ASP; he plans to evaluate various impact assessments methods for ESIG projects when he returns from his sabbatical with Resources for the Future in the spring of 1981. Schneider, who is deputy director of ASP and head of the Visitors Program, has been working with Firor and Glantz (the head of ESIG) to define appropriate research topics, methods, collaborators, and staff for ongoing and future ESIG projects. He also is pursuing his interests in climate modeling. In the fall of 1980, Schneider worked with Starley Thompson (a visitor from the University of Washington) and ASP postdoctoral fellow Eric Barron on an energy-balance model simulation of the Cretaceous climate (100 million years ago). They found that external factors such as paleogeography, combined with plausible internal factors such as cloudiness variations, can "explain" the equable Cretaceous climate. However, they concluded that nondiffusive heat-transport parameterizations will need to be developed if more successful Cretaceous climate simulations are to be achieved with economical, highly parameterized models.

Schneider and Thompson worked with H. Nuzhet Dalfes (an ASP graduate research assistant) to complete their study of the sensitivity of an energy-balance model in response to stochastic-forcing parameterizations. They found that the form of the stochastic heat-flux parameterization (e.g., additive versus multiplicative) had a large effect on simulation skill, and thus cautioned that all previous results from highly parameterized "stochastic models" should be re-examined to determine the consequences of the assumed form of the stochastic parameterizations.

STAFF AND VISITORS

Division Staff

Maurice Blackmon (transferred to AAP 30 September)
John Firor (Director)
Bernhard Haurwitz
Verlene Leeburg
Mary Rickel
Ursula Rosner
Stephen Schneider (Visitors Program Head)
Sharon Vieyra
Betty Wilson

Environmental and Societal Impacts Group (ESIG)

Robin Dennis
Mary Downton
Michael Glantz (Head)
William Kellogg
Maria Krenz
Paulette Middleton
Suzanne Parker
Jan Stewart
Thomas Stewart

Graduate Assistantships

Nuzhet Dalfes, Rice University
Russell Dickerson, University of Michigan (to 17 April)
Dale Durran, Massachusetts Institute of Technology
Ronald Ferek, Florida State University
Laurence Goldberg, University of Colorado (to 30 April)
Brian Heikes, University of Michigan
William Kohri, Drexel University
Paul McKenna, University of Colorado
Robert Rasmassen, Drexel University
Susan Solomon, University of California at Berkeley
Bruce Wielicki, University of California at San Diego (to 6 December)

Visitors

Tommy Augustsson, NASA Langley Research Center, May 1980 - June 1980, Summer Colloquium.

Peter Bannon, University of Colorado, November 1978 - August 1980, Postdoctoral Fellow.

Edward Barry Jr., Old Dominion University, May 1980 - June 1980, Summer Colloquium.

Thomas Blackburn, University of Michigan, May 1980 - June 1980, Summer Colloquium.

William Blankenship, Washington State University, May 1980 - June 1980, Summer Colloquium.

Donald Borock, Gettysburg College, September 1980 - August 1981, ESIG.

Byron Boville, University of Washington, August 1979 - August 1981, Postdoctoral Fellow.

Malcolm Campbell, Washington State University, May 1980 - June 1980, Summer Colloquium.

George Carnevale, Harvard University, September 1979 - September 1981.

Ching-Sen Chen, University of Illinois, June 1980 - May 1981, Postdoctoral Fellow.

Jorgen Christensen-Dalsgaard, University of Cambridge, September 1980 - September 1981, Postdoctoral Fellow.

Mona Delitsky, University of Michigan, May 1980 - June 1980, Summer Colloquium.

Paul Dusenbery, University of New Hampshire, August 1978 - March 1980, Postdoctoral Fellow.

Daniel Ely, University of Colorado, June 1980 - May 1981, ESIG.

Ronald Errico, Massachusetts Institute of Technology, October 1979 - October 1981, Postdoctoral Fellow.

John Gaynor, NOAA, Boulder, May 1980 - June 1980, Summer Colloquium.

Alex Gholson Jr., Washington State University, May 1980 - June 1980, Summer Colloquium.

Ronald Gilliland, University of California, September 1979 - September 1981, Postdoctoral Fellow.

Richard Grotjahn, Florida State University, June 1979 - May 1981, Postdoctoral Fellow.

David Hathaway, University of Colorado, June 1979 - May 1981, Postdoctoral Fellow.

Alan Hills, Willamette University, May 1980 - June 1980, Summer Colloquium.

Barry Huebert, Colorado College, May 1980 - June 1980, Summer Colloquium.

James Johnson, University of Washington, May 1980 - August 1980, Summer Colloquium.

J.C. Kaimal, NOAA, May 1980 - June 1980, Summer Colloquium.

James Kasting, University of Michigan, September 1979 - September 1981, Postdoctoral Fellow.

Richard Katz, Oregon State University, July 1980 - August 1980, ESIG.

Marta Kowalczyk, University of California at Berkeley, May 1980 - June 1980, Summer Colloquium.

Eric Kraus, University of Miami/NOAA, June 1980 - August 1980, Ad Hoc Faculty.

Glenn Long, University of Texas, May 1980 - August 1980, Summer Colloquium & ESIG.

William Lord, University of Colorado, October 1979 - September 1980, ESIG.

Edward Lorenz, Massachusetts Institute of Technology, June 1980 - August 1980, Ad Hoc Faculty.

Thomas Lundgren, University of Minnesota, June 1980 - August 1980, Ad Hoc Faculty.

Barbara Mihalas, University of Colorado, September 1979 - December 1980, Postdoctoral Fellow.

Barry Moore, Washington State University, May 1980 - June 1980, Summer Colloquium.

Jeryl Mumpower, University of Colorado, June 1978 - June 1980, ESIG.

Edward Niple, Ohio State University, June 1979 - June 1980, Postdoctoral Fellow.

Tracy Nishikawa, Humboldt State University, June 1980 - September 1980, ESIG.

Joyce Nuttall, Harvey Mudd College, May 1980 - June 1980, Summer Colloquium.

Richard Pearson, University of Michigan, May 1980 - June 1980, Summer Colloquium.

John Pflaum, University of California at Los Angeles, September 1978 - August 1980, Postdoctoral Fellow.

Thomas Phillips, University of Wisconsin, September 1979 - September 1981, Postdoctoral Fellow.

Murry Salby, Georgia Institute of Technology, July 1978 - July 1980, Postdoctoral Fellow.

Robert Seivers, University of Colorado, May 1980 - June 1980, Summer Colloquium.

Janet Smith, Colorado College, May 1980 - June 1980, Summer Colloquium.

Donald Stedman, University of Michigan, May 1980 - June 1980, Summer Colloquium.

Thomas Stewart, University of Colorado, June 1980 - August 1980, ESIG.

Val Veirs, Colorado College, January 1980 - February 1980, ESIG.

James Ward, University of Colorado, October 1979 - January 1980/June 1980 - August 1980, ESIG.

William Watt, University of Michigan, May 1980 - June 1980, Summer Colloquium.

David West, University of Michigan, May 1980 - June 1980, Summer Colloquium.

Hal Westburg, Washington State University, May 1980 - June 1980, Summer Colloquium.

Diane Kay Willmarth, Scripps College, May 1980 - June 1980, Summer Colloquium.

E. Deniz Yalvac, University of Michigan, May 1980 - June 1980, Summer Colloquium.

James Yarbrough Jr., University of Georgia, August 1979 - May 1981, ESIG.

CONVECTIVE STORMS DIVISION

INTRODUCTION

Clouds are scientifically interesting for many reasons. For example, they influence radiative transfers, and play a role in the scavenging of trace constituents from the atmosphere, so that they are important in the planetary energy balance and in atmospheric chemistry. One of the most obvious roles of clouds is as a link in the hydrologic cycle; this aspect of convective clouds is the focus of research in the NCAR Convective Storms Division (CSD). Earlier work has led to the conclusion that in order to understand precipitation formation and growth, it is necessary to describe not only how the embryos of precipitation particles grow in a given cloud environment, but also how that environment came to exist, and how the embryos arrived there. Studies of this scope call for an understanding of the interactions between the dynamics of a cloud and the microphysical processes occurring in it. This "whole cloud" approach is characterized by the need to collect well-coordinated measurements with the aim of arriving at a description of the storm which extends over a significant part of its life history and is comprehensive enough to depict how precipitation forms and grows. To achieve this result, substantial resources must be deployed in observational field programs. Because these cannot be available very frequently, and because such intensive programs collect a large amount of data which will require extensive analysis, field episodes must be spaced several years apart. During this year, a major concern has been planning for the next field program--the Cooperative Convective Precipitation Experiment (CCOPE), to be conducted in Montana in the summer of 1981. This experiment will be sponsored by the Department of Interior's Water and Power Resources Service and NSF/NCAR, with the cooperation of the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Canadian Atmospheric Environment Service.

In accordance with the mission of NCAR, CSD provides opportunities for scientists from universities and elsewhere to become involved in large field programs such as CCOPE. This is achieved in part by consulting regularly with the relevant scientific community in planning the future directions of research. The initial plans for CCOPE were discussed at workshops held in November 1978 and December 1979, and the resulting recommendations provided the basis for the Preliminary Experiment Design published in March 1980. A final workshop involving all investigators was planned for January 1981 after which a detailed operations plan was to be published in April 1981.

In addition to planning for CCOPE, CSD has continued the analysis of data from earlier field seasons in northeastern Colorado and from GATE, and has proceeded with the preparation of a final report on physical research carried out during the National Hail Research Experiment (NHRE). A number of chapters from this report are summarized here.

PLANNING FOR CCOPE

The Cooperative Convective Precipitation Experiment (CCOPE) is a major research program scheduled to begin in May 1981 at Miles City, Montana. The project is sponsored by CSD and the U.S. Department of Interior's Water and Power Resources Service. CCOPE's objective is to observe the life cycle of summertime cumulus clouds so as to better understand their precipitation-forming processes.

The latest of several workshops was held in Boulder on 5-7 January 1981. This was the initial step in developing the detailed operation plans for the summer field experiment. Scientists from universities, government agencies, private companies, and foreign countries (Canada, Great Britain, and Italy) who plan to participate in the field project took part in these discussions.

The actual field season will be 11 May-7 August 1981 and will encompass a 150 km radius area near Miles City. Coordinated observations will be made by 14 aircraft, 8 radars, 7 rawinsondes, and 125 surface stations. Convective clouds will be studied from the initiating events in the planetary boundary layer to the final fallout of precipitation and dissipation of the clouds. The earliest events must be understood before prediction of convective activity can be improved, and the later events within the clouds themselves must be understood better before precipitation can be predicted or influenced.

In order to organize the field operations, three storm stages are somewhat arbitrarily designated: prestorm, early storm, and mature storm. Each stage will be treated separately below, but it is worth pointing out that there is no distinct separation between the three and that the names can be misleading. Some classification is necessary for the sake of practical field organization, but any breakdown of stages of cloud development is bound to be imperfect.

The prestorm stage is concerned with the heating and/or convergence in the boundary layer that start vigorous convection in the first place, and also with mechanisms of continuance or regeneration of storms. These mechanisms involve several possible interactions of a storm with the boundary layer. Thus this aspect of the prestorm stage really continues throughout a storm's evolution. Prestorm stage studies include the storm's interaction with its large-scale environment, both in terms of standard meteorological variables and aerosols, because these factors are preexisting, and influence storm behavior.

The early storm stage involves study of clouds up to the large cumulus congestus or early cumulonimbus stage. The end of this stage may be defined operationally as the time when a cloud becomes too severe for most cloud physics aircraft to make unrestricted penetrations. The

Table 1. CCOPE Aircraft

Organization	Aircraft Type, Registration Number	Operational Period	Research Flight Hours
South Dakota School of Mines and Technology	T-28, N510MH	18 May - 7 August	55
University of Nevada	Aero Commander, N37BW	22 June - 7 August	55
University of North Dakota	Citation II, N77ND	1 May - 7 August	150
University of Wyoming	Queen Air, N10UW	15 June - 7 August	110
	King Air, N2UW	18 May - 7 August	190
Atmospheric Environment Service/ National Aeronautical Establishment, Canada	Twin Otter, CF-POK-X	25 May - 8 July	80
National Aeronautics and Space Administration	WB57F, NASA 926	26 May - 9 June	36
	Convair 990, NASA 712	14 July - 24 July	10-20
National Center for Atmospheric Research/ National Oceanic and Atmospheric Administration	Schweizer 2-32, N9929J	20 May - 7 August	—
National Center for Atmospheric Research/ Research Aviation Facility	Queen Air, N304D	1 June - 7 August	127
	Queen Air, N306D	15 May - 7 August	127
	Sabreliner, N307D	15 May - 7 August	69
National Center for Atmopsheric Research Sponsored	Cessna 182, N50TH	7 May - 7 August	—
	Cessna 180, N52032	20 May - 7 August	—

Table 2. CCOPE Participants

UNIVERSITIES

A. H. Auer
University of Wyoming

M. B. Baker
University of Washington

V. N. Bringi
Ohio State University

W. A. Cooper
University of Wyoming

J. G. Hudson
Desert Research Institute
University of Nevada System

J. Metcalf
Georgia Institute of Technology

V. A. Mohnen
State University of New York at Albany

D. J. Musil
South Dakota School of Mines & Technology

H. D. Orville
South Dakota School of Mines & Technology

R. E. Orville
State University of New York at Albany

R. Pearson
University of Michigan

J. R. Scoggins
Texas A & M University

T. A. Seliga
Ohio State University

P. L. Smith
South Dakota School of Mines & Technology

R. C. Srivastava
University of Chicago

G. Vali
University of Wyoming

T. H. Vonder Haar
Colorado State University

W. P. Winn
New Mexico Institute of Mining & Technology

FEDERAL GOVERNMENT AGENCIES

R. J. Curran
NASA/Goddard Space Flight Center

G. H. Fichtl
NASA/Marshall Space Flight Center

R. A. Kropfli
NOAA/Wave Propagation Laboratory

F. Pasqualucci
NOAA/Wave Propagation Laboratory

STATE GOVERNMENT AGENCIES

T. Engel
Montana Dept. of Natural Resources and Conservation

D. B. Johnson
Illinois State Water Survey

E. A. Mueller
Illinois State Water Survey

FOREIGN

G. A. Isaac
Atmospheric Environment Service, Canada

J. Latham
University of Manchester Institute of Sciences & Technology

P. Mandrioli
FISBAT-CNR

R. S. Schemenauer
Atmopsheric Environment Service, Canada

OTHER

R. K. Crane
Environmental Research & Technology, Inc.

flight plans in the early storm stage all involve multiple penetrations in single cells, though groups of cells will no doubt often be studied in this stage also.

The mature storm phase takes over as the storm (or "convective complex") intensifies. In the severest mature storms, only the armored T-28 aircraft penetrates the storm interior; other penetrating aircraft may operate in feeder cells.

Topics studied in CCOPE will include:

- The origins of ice in clouds
- Mechanisms of entrainment
- Evolution of hydrometeors
- Precipitation efficiency
- Storm initiation processes
- Airflow structures
- Atmospheric chemistry processes
- Storm electrification.

Table 1 lists the aircraft which are expected to be used, as of April 1981. Investigators other than staff members of NCAR and the Water and Power Resources Service are listed in Table 2.

MODELING

The CSD modeling effort involves two major areas of numerical modeling. The first area considers the modeling of the dynamical processes of such phenomena as convective clouds and airflow over topography, and to a lesser extent fluid dynamical topics such as understanding the details of forced gravity wave theory. The models used to pursue such activities are nonhydrostatic finite-difference models in both two and three spatial dimensions. The second area considers the modeling of microphysical processes within convective clouds--the various moist and ice processes leading to rain, snow, graupel, and hail. Clearly there are many problems where the interaction of cloud physics and dynamics is important and neither can be ignored, but it seems easiest to describe the modeling effort using these two general categories.

Small-Scale Dynamics

One of the major problems of a field observing program lies in understanding the errors involved in obtaining the wind fields derived by multiple Doppler radars. Certain aspects of this complex problem can be addressed through numerical modeling. A paper published by Clark *et al.* (1980) on multiple Doppler error analysis describes a basic technique to simulate radar scans through a known set of "data" obtained through three-dimensional time-dependent numerical modeling of severe storms. The main errors analyzed were the temporal errors caused by the asynchronous time sampling by three or more Doppler radars. Scan rates and the number of radars were varied to determine the character of the temporal errors of the three wind components. As a basis for error comparison, the temporal errors were compared with the better known random-noise type errors. The results of this particular error analysis showed that for 3 min scan times the temporal errors were typically smaller than the errors due to random errors. Future research in this direction may consider horizontal spatial scales much smaller than the current 1 km and may aid in assessing the need for rapid-scan radars with improved resolution.

Another area of importance for the cloud modeler is the subgrid-scale parameterization of cloud processes for general circulation models (GCMs). In this vein, an analysis of horizontal eddy fluxes of vertical vorticity was performed on cloud simulated data in collaboration with Dr. Han-Ru Cho of the University of Toronto. Typically, the GCMs assume that cloud-scale horizontal fluxes of vertical vorticity can be ignored. However, the current work with Dr. Cho suggests that the combined effects of deep convective clouds in the midlatitudes could contribute an effect equal to that already considered due to the large-scale mean structure of the wind fields. A paper was submitted for publication on this topic and should be forthcoming.

Dr. Hsiao-Ming Hsu (University of Wisconsin-Milwaukee) was a summer visitor with CSD for a period of one month in 1980. His area of interest is in the modeling of wintertime Lake Michigan storms. For a given land/lake temperature difference his results suggest a strong relationship between wind direction and character of lake storms. Satellite observations appear to confirm many of his model results.

Airflow over mountainous terrain appears to be one area of modeling where direct comparison of model results with observations should be quite promising, due to the local casuality of the flow. Collaborative research in this direction has progressed with Robert Gall and Kenneth Young from the University of Arizona in Tucson. Our work compares model simulations with the dynamical fields observed by aircraft and cap cloud microphysical characteristics with surface observations. Two wintertime cases of airflow around Elk Mountain in Wyoming and one springtime case of flow around Mount Withington were considered. The results of the simulations are being compared with the observations of Elk Mountain by a University of Wyoming group (Theodore Karacostas and John Marwitz, among others) and with the observations over Mount Withington by David Raymond and Marvin Wilkening of the New Mexico Institute of Mining and Technology (Socorro, New Mexico). This research is progressing and the dynamical field comparisons are currently being written up for publication.

Studies of forced gravity wave theory, conducted with Richard Peltier of the University of Toronto, are continuing on such topics as three-dimensional lee waves and breaking gravity waves, as well as on other related topics. These types of studies are useful to CSD in at least two ways. From a technical point of view, comparisons of model simulations with observations and with linear theory supply good tests of the fidelity of performance of the dynamics of the CSD "cloud" model. Secondly, the studies contribute to the general understanding of small-scale dynamical processes.

Microphysical Processes

The major goal of the microphysical modeling effort is to develop suitable numerical treatments of the cloud microphysical processes leading to the formation of precipitation which can be incorporated efficiently into multidimensional cloud models. While detailed "brute-force" numerical treatments of cloud microphysical processes have been established by numerous authors for more simplified frameworks, these methods require large amounts of variables to describe adequately the spectra of water and ice. Their direct application to three-dimensional models is not feasible due to the large computer core and central processing time they require. Thus, parameterization methods based upon the physical equations governing cloud microphysical processes must be used.

The microphysical processes of interest include condensation of cloud droplets on cloud condensation nuclei, coalescence of water droplets, diffusional growth ice particles, riming growth of graupel, aggregation of snowflakes, and hail growth. The basic approach we are following in order to develop suitable parameterizations of these processes is to first study these processes using existing brute-force techniques in a two-dimensional dynamic framework. Parallel computer runs are then computed using proposed microphysical parameterization schemes which are based upon the same physical equations and contain minimum numbers of variables to describe the spectra of each hydrometeor class. These parallel runs are then compared with the detailed model runs to test the accuracy of the proposed parameterizations for the physical processes of interest.

The results so far are very encouraging for the nucleation and condensation growth of cloud droplets. The cloud water parameterization assumes that the cloud water spectra are represented by two variables: number concentartion and liquid mixing ratio. This gives one the ability to estimate mean properties of the droplet spectrum which are needed in order to apply directly the basic cloud microphysical equations governing the cloud droplet growth rate and supersaturation field. With the knowledge of the supersaturation field, cloud condensation nuclei characteristics are then incorporated according to field observations or idealized air mass types. The fields of supersaturation, number concentration, and mixing ratio compare extremely well with detailed calculations. This type of parameterization allows one to capture a few essential details of cloud droplet number concentration and mean radius that are very important in determining the collection efficiency with ice particles and sensitivity to warm rain coalescence.

Continued development of the parameterization to include the ice phase is currently in progress. A similar approach to the ice parameterization of Randall Koenig and Frank Murray (1976) is currently being tested. Preliminary results indicate that certain observed features, such as the weak radar echo or vault region and the anvil or outflow region, compare qualitatively with the detailed model. However, the behavior of the largest growing particles that form the precipitation embryos has not yet been fully parameterized.

Two main problems remain extremely important. The first is the source of nucleation characteristics of ice particles and the second is the spectra representation of the ice spectra. These problems can be greatly simplified through the use of field observations. If the observations can describe the sources of ice particles, particle concentrations, and characteristics of shape and density, one can make simplifying assumptions on what determines the mode of precipitation formation (i.e., via the graupel process or via snowflake production).

The remaining process of interest is hail growth. Jia-Liu Xu from the University of Lanzhou in China, a visitor at NCAR for the past year, has been working on this subject with the CSD modeling group. He is using model data from the three-dimensional cloud model to perform kinematic trajectory studies of growing hailstones. The goal of his work is to understand preferred location of hail embryos in the storm structure and to relate his findings to the NHRE data set of observed hail events.

WIND TUNNEL TESTS

During this past year the high-speed icing tunnel of the National Research Council's Low Temperature Section in Ottawa, Canada, was used to calibrate and evaluate the performance of a number of cloud physics instruments, particularly Johnson-Williams (J-W) hot-wire liquid water content meters. CSD collaborated in these tests, which were coordinated and sponsored by the Cloud Physics Research Division of the Atmospheric Environment Service of Canada. A central objective of the tests was to obtain absolute calibrations and intercomparisons of the J-W probes, which will be flown on aircraft in CCOPE this summer. Other objectives included testing two Particle Measuring Systems axially scattering spectrometer probes, a constant temperature hot-wire liquid water device developed in Australia, a Ruskin evaporator liquid water probe which incorporates a Lyman-alpha water vapor sensor, and an impactor slide cloud gun. The droplet characteristics and distribution of liquid water content inside the icing tunnel were also studied. Individuals from ten organizations representing four different countries participated in the tests.

Although the J-W liquid water content meter has become the most commonly used device for the measurement of liquid water since it was developed almost 30 years ago, there have been few direct calibrations of the instrument. As with other airborne cloud physics instruments, proper calibration of the device is a difficult problem because it requires producing a cloud of known water content, with a known particle size distribution at aircraft speeds and at temperatures <0°C, and independently determining what the properties of the cloud are. The icing tunnel in Ottawa, which has been developed over the past 20 years for various studies, including aircraft icing, has proven to be particularly valuable for these calibration studies. Airspeeds can be varied from 80 kt to over 200 kt, and temperatures from 20°C to -25°C, while producing a cloud of known and controllable droplet size distribution up to 2 g m^{-3}.

Operational characteristics and problems of individual instruments, many of which had been suspected but could not be confirmed from airborne data, were documented during the tests. For some of the probes the calibrations agreed reasonably well (± 20%) with the manufacturers' recommended calibrations, while others were off by as much as a factor of two. The tests demonstrated conclusively that a wet calibration of each and every J-W sensing head and electronics package is necessary before measurements from that device can be used with confidence. This is particularly true for older units where problems frequently arise due to corrosion and resistance changes in connector contacts. As well as calibrations and documenting problems in individual units, technicians conducted studies to determine the general characteristics of the J-W device, such as its sensitivity to variations in the angles of attack and yaw, characteristics of the signal when icing of the sensor occurs, and the influence of the heaters on the measured value.

These tests and similar intercomparisons and calibrations of other microphysical instruments, which will be conducted prior to and during CCOPE, will help assure some uniformity in the large number of microphysical measurements which will be made from different aircraft during CCOPE. Additionally, the intercomparisons will be important in their own right because they will add considerably to the understanding and reliability of the instruments themselves--a problem which currently is of great interest to the cloud physics community.

CONVECTIVE STORM CASE STUDY

Several more of the NCAR Technical Notes describing sets of measurements on convective storms were completed during this year. The latest one (Case Studies on Convective Storms, Case Study 9, 13 June 1974: Mature Storm Study/A Small, Isolated "Steady State" Convective Storm, Charles Knight) concerned an unusual storm with an unusual suite of observations. The storm was isolated in a cloudless sky. It traveled into the NHRE experimental area from the northwest at 17 m s^{-1} and disspiated within the observation network after having had a steady intensity (reflectivity factor and radar top height) for at least an hour. It extended to (and somewhat beyond) the tropopause, had a cloud base temperature of about +2°C, and produced neither a measurable amount of precipitation at the ground nor any significant manifestation of outflow at the surface. The observations of the storm included a detailed radar echo history, vertically pointing Doppler radar data, excellent time-lapse photo coverage, and circumnavigations by the three NCAR Research Aviation Facility aircraft (but no measurements from penetrating aircraft).

The active convection in the storm was on its back (northwest) side and the storm moved slower than, but parallel to, the cloud layer winds. It was preceded by a large visible plume of cloud and/or virga blowing downwind. Aircraft measurements indicated marked subsidence below this midlevel wake (ahead of the storm with respect to the earth, but behind it with respect to the cloud level winds), presumably caused by evaporative cooling of the air blowing past the storm, and mixing with cloud material. The subsidence ahead of the storm carried air with momentum appropriate to the middle levels down into the boundary layer, where the environmental wind was such as to produce convergence at the edge of the wake. It is argued that this is probably the mechanism of maintenance of this completely isolated, long-lived storm, and it also provides an explanation of its direction of movement.

Some of the older "cells" of the storm attained maximum radar reflectivity values slightly above 45 dBZ, but in at least one case a vigorous new cell a few kilometers distant from the main storm only barely attained 30 dBZ in spite of reaching a visual height over 13 km MSL. (Virtually all of the precipitation evaporated before reaching the ground.) The evidence suggests that the storm produced its radar reflectivity primarily by reingesting embryonic precipitation particles that had blown downwind ahead of the storm, descended below cloud base, and been caught up again in the inflow. With the exception of the new cell mentioned above, the entire active part of the storm contained radar echo at or above 20 dBZ.

The vertically pointing Doppler radar data revealed very complicated velocity spectra, with two or three distinct peaks being rather common. In the cross-section data there were three marked updraft maxima, with the appearance of rising "bubbles," in the cloud's upper levels. Each was accompanied by a local echo maximum, supporting the recycling hypothesis. The maximum updraft revealed was above 20 m s^{-1}, and the maximum visual cloud-top rise rate was about 11 m s^{-1}.

The radar reflectivity structure changed little throughout the storm's lifetime, but was not easily explainable. The storm might make an interesting case for model simulations, inasmuch as it achieved an overall steady state and appeared to have little interaction with the earth's surface as a boundary. It was interesting that it produced an anvil only as it was dissipating. The primary interest of the case, however, was the evidence for large-scale, systematic recycling of precipitation.

MESOSCALE ORGANIZATION OF CUMULONIMBUS CLOUDS: A TROPICAL CASE STUDY

It has been recognized for some time that most significant precipitation from convective clouds, whether in the tropics or in midlatitudes, falls not from isolated storms but from those which are organized into mesoscale systems or complexes such as squall lines. What are the differences between isolated and organized convective storms, and how can we understand them better? We know that these are important questions. The fact that convection is organized on the mesoscale makes a difference in water and energy budgets. Neglect of the fact of mesoscale organization of convection contributes to the acknowledged poor performance of cumulus parameterization schemes in numerical prediction models. However, these are long-term problems. A more immediate question is how the convective and mesoscale circulations interact to produce the major precipitation systems which are observed.

Studying such questions over tropical oceans with the comprehensive data set obtained during the Global Atmospheric Research Program's Atlantic Tropical Experiment (GATE) has certain advantages. The tropical convective clouds are generally weak and without hail, so they can be penetrated safely by research aircraft. The fact that the maritime tropical air mass is everywhere warm and moist, in near-equilibrium with the underlying warm ocean surface, means that deep convection is thermodynamically possible almost everywhere. Therefore, the intrinsic growth and decay of mesoscale convective systems can be studied without undue concern that changes in air mass properties are responsible for controlling the evolution of a given system.

Edward Zipser, Rebecca Meitín, and Margaret LeMone selected the particular GATE convective band of 14 September 1974 for intensive study on the basis of the following: It was nearly linear, so that it was reasonable to approximate its mesoscale structure as two-dimensional; it was reasonable to approximate its mesoscale structure as two-dimensional; it was penetrated by research aircraft a total of 41 times in 3 h, covering eight different altitudes; and it was centered in the dense observing array, within range of quantitative radar throughout its lifetime.

The analysis emphasized quantitative description of this relatively weak, slow-moving (2-3 m s^{-1}) band of cumulonimbus clouds, with one focus being the question of how it was similar to or different from squall lines, which are also present in the GATE area but which tend to be stronger and which move much more quickly (10-15 m s^{-1}).

An important finding was that the fields of normal, tangential, and vertical wind, and of equivalent potential temperature, reveal <u>mesoscale</u> features 10-40 km in horizontal extent normal to the band. They are recognizable on successive aircraft passes over a period of several hours, whether or not the aircraft encountered a convective scale event such as a strong updraft core. This fact may seem obvious, but it is of fundamental importance. The existence of mesoscale fields of kinematic and thermodynamic variables signifies that convective clouds go through their life cycle in an environment that is not the same as the large-scale environment. There is every indication that the same conclusion applies to most squall lines.

Environmental winds relative to the system can be obtained by subtracting the band's motion, eastward at 2.5 m s^{-1}, from the observed winds. The relative winds ahead (east) of the band are thus directed with a component from front to rear at all levels. This is also true for tropical squall lines as well as for a GATE convective line observed on 2 September. Only in limited regions to the rear of most squall lines is the relative environmental wind directed from the rear toward the front, usually with a small magnitude, and only in the 500-700 mb layer. In the 14 September case, all environmental winds are directed from front to rear. Relative flow from rear to front does exist in the rain area below 4 km, but in such a restricted area that one is forced to conclude that this feature is induced by pressure gradients internal to the convective band itself.

The cloud and precipitation structure of the convective band consists of deep cumulonimbus clouds along the leading edge only, with extensive, thick, precipitating stratiform clouds covering the rear portion of the system, with bases near 4 km and tops near 12 km. This is the same as squall-line cloud structure as well as that observed in a number of non-squall mesoscale convective systems.

A well-defined gust front exists, separating ambient subcloud-layer air from cooler near-saturated air in the heavy rain area. It is similar to squall-line gust fronts. However, the 14 September gust front is less well-marked than most squall gust fronts in terms of vector wind change and temperature drop, and the change in equivalent potential temperature is extremely small.

There is evidence for a mesoscale sinking region in the stratiform rain area to the rear of the system, derived from two-dimensional divergence computations and from the cloud distribution. In the composite, the sinking rate averages about 5 cm s^{-1} at a height of 500 m, at the low end of the 5-25 cm s^{-1} range given by Zipser in an earlier paper for squall lines. Thermodynamic evidence for mesoscale sinking also exists, in the form of a shallower mixed layer, and unsaturated downdraft air in the stratiform rain area, but these features are far weaker than in squall line cases.

In summary, the GATE convective band of 14 September differed from many squall lines by moving more slowly, having weaker winds and less mass flow through the system, and showing considerably less drying in the rain area. Again, these are all differences in degree, not in kind.

In other respects, such as the cloud and precipitation distribution, the sense of the relative wind, the sense of the wind and thermodynamic changes across the band, and the evolution of the system with time, there seem to be no fundamental differences from squall lines. However, one possibly significant difference not discussed above is that the 14 September band is oriented parallel to the shear of the horizontal wind from the low to middle troposphere while squall lines tend to be oriented perpendicular to the shear. This issue deserves further study.

As the convective band matures, the fraction of the total rain falling in the stratiform area increases. Most convective rain falls at rates greater than 8 mm h^{-1}, while most stratiform rain falls at rates less than 8 mm h^{-1}. The intensity of convective rain changes little with time. Stratiform rain contributes about 30-35% of the total rain produced by the system. Upward mass flux continues to be associated with the convective region as the system ages, but in the lowest kilometer, the downward mass flux increases, so that net mass flux decreases toward zero with time, likely becoming negative during the decay phase.

The zone containing most convective updrafts slopes at 60-70° from the vertical, or about 1:3. This is consistent with the observed ratio of vertical velocity w to horizontal velocity change u in the convective clouds (3 m s^{-1}:9 m s^{-1}). The time scale for ascent thus can exceed 1 h. An independent observation supporting the slow ascent rate is the rapid decrease of radar reflectivities with height in radar echo cores. The large slope of the system is helpful in its maintenance, by permitting much precipitation to fall into the downdraft area.

Downdraft mass flux is about half updraft mass flux up to about 3 km, above this altitude, it is likely to be a smaller fraction. This is somewhat smaller than the comparable fraction in squall lines. The total mass flux in the mesoscale updraft region, about 10^9 kg s^{-1} per 200 km length of the band at an altitude of 1 km, is weaker by a factor of 2-5 than that measured in most tropical squall lines.

The Importance of Organized Mesoscale Ascent

Despite their relative weakness, the mesoscale regions of downward and upward mass flux control the development of new cumulonimbus clouds. In the 14 September case, cumulus congestus clouds existed everywhere east of the gust front, but they developed into cumulonimbus only in the mesoscale ascent zone near the gust front. Why did they fail to do so elsewhere? The thermodynamic stratification could support deep cumulonimbus development everywhere in the vicinity. However, in nature, it appears that cumulonimbus have a difficult time growing from random initial impulses, and much prefer to grow in zones where upward impulses follow each other in rapid succession. A mesoscale ascent zone can be visualized as a place where many such impulses can be directed in an organized manner, without leaving time for much descent between rising plumes before the next plume arrives. Further, the mesoscale ascent itself is an agent of strong destabilization.

Thus, a closely interactive process of positive feedback seems to be taking place. Some initial mesoscale forcing is often required to initiate a mesoscale cumulonimbus band. Once formed, the organized downdrafts interact with the environmental flow field to intensify the mesoscale convergence field and maintain the system, perhaps by local destabilization but mainly by providing the large flux of warm moist air from the boundary layer which is so important to the sustained growth of cumulonimbus clouds. Still unanswered is the question of why this positive feedback works well on some occasions and not at all on others.

TROPICAL CUMULONIMBUS CLOUDS: WHY SO MUCH WEAKER THAN THEIR MIDLATITUDE COUNTERPARTS?

The updrafts and downdrafts within a cumulonimbus cloud are the fundamental units or building blocks of the cloud. The strength and organization of these vertical velocity events are of crucial importance in determining the nature and intensity of the precipitation from that cloud, the nature and intensity of severe weather, and the contribution made by that cloud to mass and energy transports in the vertical. Despite the great advances in measurement capability in recent years, there have been few systematic studies of cumulonimbus draft statistics by direct measurement of internal properties. The most complete such study was the very first: the venerable work by Horace Byers and Roscoe Braham in the U.S. Weather Bureau's Thunderstorm Project, undertaken in 1946 and 1947. Outside of hurricanes, there has never been such a study of clouds over the oceanic tropics. Now LeMone and Zipser have filled this gap in the literature by completing a two-part study of GATE cumulonimbus clouds.

The data used for this study are collected from three aircraft, each equipped with an inertial navigation system and instrumentation to measure speed and attitudes of the aircraft themselves, as well as a host of dynamic, thermodynamic, cloud physics, and radiation parameters at a rate of 1 s^{-1}. Six days are studied which represent a range of convective activity and synoptic forcing.

The events are divided into two types. To be called a draft, the vertical velocity must be continuously positive (or negative) for 500 m and exceed an absolute value of 0.5 m s^{-1} for 1 s. Cores are the stronger portions of the stronger drafts, defined by requiring that upward (or downward) vertical velocity be continuously greater than an absolute value of 1 m s^{-1}. The diameter of an event is defined as the product of the duration of the event in seconds and the true airspeed.

Perhaps the most striking result is the rarity of really strong drafts and cores compared to those observed in cumulonimbi over land. No core in the entire data sample has a mean vertical velocity as great as 8 m s^{-1}, or a maximum 1 s vertical velocity as great as 15 m s^{-1}. In all of GATE, the greatest vertical velocity was measured in a cumulonimbus in the tropical depression of 15 July 1974, and was only slightly stronger than the maximum in the above data set, with $\overline{w}$ of 9 m s^{-1} and w_{max} of 17 m s^{-1}.

The properties of the statistics of the GATE cores and drafts can be summarized as follows:

1) Their diameter, average vertical velocity, maximum vertical velocity, magnitude, and mass flux are approximately log-normally distributed within each altitude group.

2) Above cloud base, downdrafts are somewhat larger than updrafts, and considerably weaker than updrafts. Near and below cloud base, downdrafts are nearly the same size as updrafts, and only slightly weaker.

3) Downdraft cores tend to be smaller than updraft cores at all altitudes, and are about two thirds as frequent.

4) Vertical velocity and mass flux in downdraft cores are less than those in updraft cores, except near cloud base where updraft and downdraft cores are about equally strong.

5) In the middle troposphere, only 10% of the GATE updraft cores have diameters in excess of 2 km, and only 10% of updraft cores have mean vertical velocities as great as 5 m s^{-1}.

6) Compared to Thunderstorm Project statistics, GATE cores peak at somewhat lower altitudes, are about the same size, and are a factor of 2.5-3.0 weaker. Compared to hurricane cloud statistics, GATE cores are about the same size and intensity.

7) Total mass flux in updraft cores is in approximate agreement with large-scale requirements. Together with other consistency checks, this suggests that the data sample is representative of GATE conditions.

8) Mass flux in both updraft and downdraft cores is distributed over a wide range of diameters and vertical velocities.

9) Fractional area covered by updraft cores on the 100 km scale is 1.5% at cloud base, increasing to over 4% coverage in the middle troposphere. Downdraft cores occupy about half the area of updraft cores at all levels. Drafts occupy a much greater area--15-18% for updrafts, 25-30% for downdrafts.

10) Vertical velocity and diameter are positively correlated, although rather weakly for updraft cores and insignificantly different from zero correlation for downdraft cores.

11) Vertical velocity profiles through drafts and cores resemble "triangles" more than "top hats."

12) If one-dimensional steady-state cloud models are applied to GATE soundings, cloud diameters chosen to represent the correct cloud-top height result in overprediction of vertical velocity. Alternatively, if smaller diameters are chosen so that the model gives realistic vertical velocities, cloud-top heights are greatly underpredicted.

13) A crude analogy can be drawn between the vertical velocity profile of GATE cumulonimbus clouds and that of thermals in the Air Mass Transformation Experiment (AMTEX) boundary layer, further emphasizing the weakness of the GATE clouds in a nearly moist-adiabatic environment.

14) The draft, cores, and clouds in GATE are typically part of a larger, organized mesoscale system. Cores are found only in close association with active convective clouds, while a large number of drafts are the decaying turbulent motions which were generated in more convective regions.

15) For the 90% of GATE convective cores with mean vertical velocities less than 3-5 m s^{-1}, the time scales for convection are quite large, perhaps in excess of 1 h for air starting at cloud base to reach cloud top. Such time scales are consistent with a large rainout from the warm part of the cloud, the presence of ice at relatively warm temperatures, and rapid decrease of radar reflectivity with height above the 0°C level.

In a typical GATE cumulonimbus, therefore, the predominance of weak updrafts implies an inability to form either hail or significant liquid water concentrations in the form of large raindrops above the 5-6 km level, where the temperature would be colder than -5 to -10°C, because much rain would fall out of the ascending air below the freezing level, and there would be ample time for most of the remaining liquid water to be converted to ice above that level. If that is true, the radar reflectivity in most GATE cumulonimbus should decrease rapidly above the freezing level, because of the sixth-power dependence upon drop diameter.

Zipser and Edward Szoke are currently working on the problem of comparing GATE and other radar data sets. Thus far, the radar observations are completely consistent with these deductions.

One may well ask why the GATE convective cores are so much weaker than those in middle latitudes. We thought at first that there might be much less available potential energy on the sounding to convert into vertical kinetic energy, i.e., the GATE soundings might be nearly moist-adiabatic or neutrally buoyant compared to a midlatitude sounding. This hypothesis does not stand up to the facts. In a specific comparison with the NHRE storm of 22 July 1976, for example, the typical GATE sounding has about 70% of the available potential energy of the sounding from northeastern Colorado, but the typical GATE updraft core has, at most, 30% of the vertical velocity of the NHRE core. The indications are that it is not simply the energy available on a sounding that matters, but the efficiency with which that energy can be realized in an actual updraft.

NHRE FINAL REPORT SUMMARIES

A sizable fraction of CSD's efforts in 1980 was devoted to writing the final report of the National Hail Research Experiment, for which NCAR and groups from universities and federal agencies gathered data in the years 1972-74 and 1976. The purpose of NHRE was twofold: to ascertain whether a particular cloud seeding technique could produce a statistically verifiable effect on the amount and size of hail produced by hailstorms in northeastern Colorado; and to further understanding of the life cycles of such storms--why some produce hail but not others, and why the experiment did or did not demonstrate the efficacy of hail suppression by cloud seeding techniques.

While NHRE did not produce statistically significant evidence that the cloud seeding technique was effective in suppressing hail, the experiment produced findings that have altered our view of the mechanics of large thunderstorms on the high plains of the United States and have influenced the view of scientists and policy makers interested in hail suppression.

Much of the data from NHRE have already been exploited and many findings have been already been published in scientific journals and in NCAR Technical Notes. A final report, written by scientists who participated in NHRE, will summarize findings already published and not yet published. This report will be in two volumes; the first, comprising 12 chapters dealing with various aspects of storms, is expected to be published in the late summer of 1981; the second volume will include three detailed case studies, and is expected to appear in the late fall.

Chapters 2-12, which follow an introductory chapter in Volume 1, are summarized below. These chapters were the work of the following scientists:

Stewart W. Borland[a], Daniel W. Breed, Terry L. Clark, Edwin L. Crow, James E. Dye, James C. Fankhauser, Richard D. Farley, Charles A. Knight, Griffith M. Morgan, Ilga Paluch, Ronald E. Rinehart, and Charles G. Wade (all of NCAR); William A. Cooper, David C. Rogers, and Gabor Vali (University of Wyoming); and Harry D. Orville and Paul L. Smith (South Dakota School of Mines and Technology).

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Chapter 2: The Environment of the Storms

The purpose of this chapter is to provide the physical setting within which NHRE was conducted and to describe some of the general meteorological conditions favoring development of convective storms over the central High Plains. Some comparisons between long-term regional climatology and precipitation characteristics observed during NHRE, summarized in the 1980 annual report, indicate that the decade of the 1970's, during which the experiment was conducted, was anomalously dry. The effect was to reduce the number of storms below the statistical expectation.

In a stratification of NHRE storms according to type and intensity, it was found that moderate to strong multicellular storms and the so-called "supercell" variety formed in equally unstable conditions. But, in keeping with thunderstorm studies conducted elsewhere in the central United States and Canada, the more persistent unicellular phenomena were more apt to form when the vertical wind structure exhibited strong vector shear. In general, however, the influence of large-scale synoptic forcing mechanisms responsible for storm development was more subtle and difficult to identify on a daily basis. For example, synoptic features usually associated with active weather regions, such as fronts and low pressure regions, were found to play a subordinate role, and while upper level dynamical mechanisms such as positive vorticity advection, divergence, and vertical wind shear were identifiable precursors in some instances, large-scale influences were frequently rather obscure.

The most important single factor in the development of significant convection was the existence of surface airflow with a strong easterly component capable of advecting moisture into the NHRE region at low levels. The presence of low-level easterlies may be beneficial in two ways: first, by increasing the potential instability through increased water vapor content; and second, by setting up the favorable wind shear profile discussed above.

Four basic synoptic patterns conducive to convective development over the Central High Plains were identified. These were closely related to the normal seasonal summertime progression of anticyclones from their origins in western Canada southeastward into the North Atlantic states of the United States. The initial northeasterly airflow pattern over the High Plains gradually shifts to the east and then southeast as the anti-cyclones make their way into the central and eastern United States. The resulting sequence of days having easterly winds can be straightforwardly related to similar daily sequences found in surface precipitation records.

Chapter 3: Aerosols and Nuclei

A concerted effort to characterize the spring and summer climatology of the natural aerosol and nucleus populations of the atmosphere in northeastern Colorado was carried out in the 1976 NHRE field season. A variety of measurements of aerosols and nuclei were made at two permanent group sites, operated by NHRE and the University of Wyoming, and aborad several of the research aircraft. The purposes of this chapter are to report the results in a climatological sense--typical values and ranges of variability--and to examine the question of whether nucleus measurements made at the ground are appropriate to use in studies of convective clouds, which typically draw their inflow air from the top of the boundary layer.

An intercomparison program was performed to check the compatibility of the results from the different instruments and/or procedures of the two groups. While differences were found in certain instances, in general the measurements do form a consistent set for drawing climatological conclusions.

The results of the aerosol size spectrum, Aitken nucleus, and cloud condensation nucleus (CCN) measurements show that northeastern Colorado in the late spring and summer months is an extremely "continental" area in terms of the dichotomy between continental and maritime air masses. The continental CCN spectra contribute, along with the cold cloud bases, to inhibiting rain formation by liquid coalescence, as is shown to be the case in Chapter 7. Seasonal trends of all measured quantities during the summer months are relatively small, and, within the limits of data, vertical gradients of aerosol and nucleus content in the planetary boundary layer are small enough that surface measurements taken with appropriate precautions can be used to represent cloud inflow conditions.

The ice nucleus measurements yield no surprises as regards average conditions. However, some striking short-term variations do occur, especially in the ice nucleus content. Some of these are related to well-defined meteorological events, such as thunderstorm outflows. However, it still remains an open question whether these fluctuations are of significance in precipitation formation.

Chapter 4: Precipitation at the Ground

This chapter summarizes what was learned about convective precipitation, principally hail, and the problem of measuring it in the climatic setting of northeastern Colorado. Distributions are developed from the observations of the hailpad and raingage networks which show how the mass depositions of rain and hail are distributed (a) among days, and (b) over area. The principal characteristic of these distributions is that the preponderance of the precipitation of either type falls on a very small fraction of the number of days or over a very small fraction of the precipitation area. The ratio between the masses of hail and of rain falling on the NHRE experimental area were determined, day by day, and show hail to be a very small contribution, typically by only a few percent to the water arriving at the ground as precipitation.

The hailstone size distribution is made up mostly of small stones, the largest stone observed being less than 3 cm in diameter in three years of observation. Larger, even catastrophic, events do occur but are extremely rare over any fixed network of the size employed (1700 km^2).

The size distributions of raindrops are markedly flatter (i.e., show relatively more large drops) than the exponential Marshall-Palmer distribution observed in other, more humid climatic regions. This may be due to evaporation of the smaller drops, or to the presence of recently melted hailstones in the rainfall.

Photographic measurements of hailstone fallspeeds indicate that hailstones fall about 20% slower than ice spheres of equal volume.

Comparable measurements have not been made elsewhere, so it is not known whether this apparent anomaly is peculiar to this area. However, other properties of hailfall in Colorado appear similar to those in other regions. These are: short average durations of hailfall at a point; an average range of numbers of hailstones falling on a unit area per hailfall; and large small-scale variability (tenfold variations in hail intensity over distances of a few hundred meters).

Attempts to measure hailfall with radar were less successful in Colorado than has been claimed in other regions, although high reflectivities in storms are a good indicator of hailfall from somewhere in the precipitation areas of the storms. Suggestions are offered for further research on surface hailfall measurements, as would be needed for future hail suppression experiments.

Chapter 5: Storm Types and Some Radar Reflectivity Characteristics

In the analysis of the NHRE randomized seeding experiment results, published in 1979, a great deal of effort was spent in trying to classify the storm types encountered in NHRE and in characterizing the experimental days in terms of objective radar reflectivity factor statistics. The storm type study was done for the purpose of stratifying the days, since there were ideas that seeding might influence different types of storms in different ways; and the radar reflectivity studies were done in the effort to uncover a direct effect of seeding. Inasmuch as the entire seeding analysis revealed no effect of seeding, the data from the 57 "hail days" over the 1972-74 period can be treated as a storm climatology of the region, and this chapter presents the data in such a framework.

The distinctions made among the various storm types--the supercell, organized multicell, squall line, disorganized multicellular complex, and single, ordinary cell--are subjective and inexact, at least in part because the fundamental definition of the thunderstorm cell is not a quantitative one. For the purposes of the NHRE analysis, a largely objective definition of the cell was implemented on the basis of continuity and longevity of a discrete 45 dBZ radar reflectivity in the midcloud level. In terms of this definition, there were a total of about 1100 cells on the 57 days, with a mean area of about 15 km^2 (from <2 to >200 km^2) and a mean duration of about 20 min (from about 7 to over 100 min). Only four of these cells could be termed supercells in terms of having long-lived (>15 min) radar echo vaults, but five more had short-lived vaults. The vaulted cells did tend to be much larger and much more long-lived than average. It was found that cell motion tended to be markedly to the left of the mean cloud layer winds, but was very well coordinated with the average wind direction between the surface and the altitude at which a lifted boundary layer parcel would have a temperature of -5°C. Statistics of radar reflectivity factor quantities--such as maximum values attained--are also presented.

Chapter 6: Air Motion and Thermodynamics

Following a description of NHRE mesonetwork designs, operational procedures, and data analysis techniques, a discussion is given of surface observations, emphasizing the effects of thunderstorms. Topics discussed include the distribution of surface convergence and thermodynamic properties. General aspects of thunderstorm outflows are also summarized and some gust front statistics are presented.

In a section concerned with properties of updrafts observed in the inflow sector of thunderstorms, data from three aircraft platforms are investigated. In the first study, based on qualitative information logged by seeding aircraft crews flying in updraft regions during randomized seeding activities in 1972-74, the positions of over 800 individual seeding events were related to nearby radar echo features. It was found that nearly all of the seeding was carried out in the east and southeast quadrants of the storms. This result is consistent with the observed predominantly northeastward storm motion combined with primarily southeasterly subcloud airflow, which would tend to concentrate relative inflow in an eastern quadrant.

A similar result with regard to the relative locations of storm radar echoes and cloud base updrafts was obtained in the analysis of the more quantitative updraft measurements provided by the air motion systems aboard the NCAR Queen Air aircraft. Additional information on mean updraft breadth and strength were also provided. Results indicate that at cloud base, the updraft zone has on the average dimensions similar to the storms themselves (of the order of 10 km), and that the average strength of cloud base updrafts was about 5 m s^{-1}. The NCAR Queen Air results on updraft intensity are in agreement with independent measurements made by the University of Wyoming Queen Air (N10UW).

Measurements made inside northeastern Colorado storms by penetrating aircraft reveal faster vertical motions. Updrafts as strong as 30 m s^{-1} and downdrafts of 27 m s^{-1} have been observed. Typically, the observed updrafts in Colorado cumulonimbus are comparable to those found in Florida and Ohio during the Thunderstorm Project (Byers and Braham, 1949), but are considerably stronger than the updrafts observed in tropical oceanic cumulonimbus during GATE (LeMone and Zipser, 1980).

Intense storms, however, are rather rare compared to those of lesser intensity. Also, strong convection is limited to a relatively small region, as is evident from the predominance of weak updrafts and downdrafts in the aircraft measurements. This is particularly the case in the measurements near cloud base collected along a straight flight path by the University of Wyoming Queen Air. There, the cloud air was found to be for the most part neutrally buoyant, with little vertical motion or turbulence. In tropical storms studied in GATE (Zipser and LeMone, 1980) also, strong convection has been found to be limited to regions which are small compared to the whole cloud.

While it has long been thought that intense hailstorms have unmixed cores (Ludlam, 1958; Fujita and Byers, 1960), the present measurements show unmixed cores also in storms of weak to moderate intensity. In such unmixed cores, updrafts were occasionally as strong as those predicted by the nonentraining parcel model.

Vertical velocity measurements in developing storms of weak to moderate intensity indicate that these storms do not usually go through the classic cumulus stage characterized by updraft throughout the cell, as described by Byers and Braham (1949). In these storms, cold downdrafts were observed in their early stages of growth, before significant numbers of particles of precipitation size had formed. The cold temperatures in these downdrafts could only be attributed to evaporative cooling resulting from the mixing of cloud air with dry environmental air.

The thermodynamic properties of mixed cloud air in downdrafts and in the weaker updraft regions nearby often indicated that the source levels of the entrained air were 1 or 2 km above the observation level. The deduced entrainment levels were found to be related to the negative buoyancy of the mixed air. Calculations show that in the moderately intense storms chosen for sailplane penetrations, strong negative buoyancies can result from mixing of cloud air with the cold dry mid-level air typical of Colorado soundings. In more intense storms, mixing generally creates less instability because the cloud temperature excess is higher. Little instability is also produced when mixing takes place at cold temperatures (-30°C or colder) because then little evaporation is required to reach saturation.

The observations of penetrative downdrafts and large well-mixed cloud volumes near buoyant equilibrium with the environment in the lower and middle cloud levels support the idea earlier proposed by Squires (1958) and Telford (1975) that local buoyancy differences are the primary source of energy for mixing in these clouds.

Chapter 7: Microphysics

Data from NHRE aircraft that made extensive storm penetrations, especially in 1976 when the instrumentation was more advanced than in previous years, are summarized and presented mostly as frequency diagrams. The three aircraft were the South Dakota School of Mines and Technology armored T-28, which typically penetrated severe storms through their inflow sectors at levels between -10 and -15°C; the University of Wyoming Queen Air, which made weak echo region penetrations and cumulus congestus penetrations to about the -5°C level; and the NCAR/NOAA instrumented sailplane, which typically spiralled upward in the updrafts of large cumulus congestus to medium-sized thunderstorms, spanning 0 to -20°C, and occasionally to above the -30° level. The results from individual aircraft are interesting both in themselves and in contrast with each other.

1. The clouds are very continental, with droplet concentrations usually on the order of 1000 cm^{-3}.

2. There is no convincing evidence of liquid coalescence being an important factor in precipitation formation. The relatively scarce liquid drops of precipitation size that are found within clouds can be explained plausibly by the recycling of melted ice particles in the updrafts.

3. The Bergeron-Findeisen ice process of precipitation growth is overwhelmingly predominant: nucleation and vapor growth of snow crystals followed by riming to graupel and eventually to hail.

4. Precipitation water content (in the form of ice) within the cloud rarely exceeds 1.5 g m^{-3}.

5. A great deal of the precipitation growth must be on particles that did not originate within the updrafts in which they accomplish most of their growth. This is shown both by simple numerical estimates and by observations of updrafts with adiabatic liquid water content and no precipitation content at all at middle cloud levels. All aircraft provided observations of precipitation particles too large to have had time to grow in the updrafts in which they were found. Transport of preexisting precipitation particles into updrafts at low and middle levels is generally a very important process in these storms.

6. The T-28, penetrating usually older storms than the sailplane, encountered average ice particle concentrations higher by more than a factor of ten.

The other data presented in the chapter concern radar first echo heights and hailstone observations. The first echoes occur at a mean height of about 6.5-7.0 km MSL, some 3 km above cloud base, at a mean temperature of about -16°C. The hailstones mostly form on graupel embryos and their growth structure is consistent with adiabatic and subadiabatic liquid water contents.

The chapter concludes with the observation that, using the size spectra of precipitation-sized particles measured from the T-28, the growing graupel particles in the 1-3 min diameter size range deplete the cloud water considerably more than do the hailstones, which are present in much lower concentrations. This observation has implications regarding attempts to suppress hail by inducing "beneficial competition."

Chapter 8: Microphysical Modeling

Several microphysical models were developed during NHRE. The models were limited in scope and mostly focused on specific problems related to hail growth and concepts of hail suppression. The microphysical processes were treated in some detail but not coupled to cloud dynamics.

A model for ice formation within a one-dimensional parcel framework was developed by Young (1974a, 1974b, 1975). The model results support earlier estimates that AgI seeding to suppress hail by updraft glaciation is not likely to be practical. The model shows that in continental storms moderate seeding rates can significantly increase the number of ice particles that form. However, in the strongest updrafts typical of hail-producing storms, ice particles do not have enough time to grow to precipitation sizes, and thus the hail embryo formation must be limited to the peripheries of the main updraft region or to the weaker updrafts in feeder clouds. Furthermore, rapid ice particle growth by deposition requires cold temperatures (around -15°C) so that the region of hail embryo formation through the ice phase can be expected to include the upper cloud levels.

How the precipitation-size ice particles that form through the ice phase are transferred from the upper cloud regions and the weak updrafts into the strong updrafts where they may grow into hail is presently not well understood. The available Doppler-derived storm velocity fields were too limited in space and time to allow simulation of the early stages of ice particle formation and their transfer into the main updraft. In the hail growth simulations the hail trajectories were studied assuming that ice particles in the 100-1000 μm size range are present in the inflow regions at the periphery of the Doppler velocity field.

Assuming that seeding does produce sufficient numbers of precipitation-size ice particles in the main updraft, the hail trajectory simulations (Paluch, 1978) suggest that the results of seeding may vary depending on the altitude at which the precipitation-size ice particles enter the main updraft. If the ice particles enter the updraft in the lower levels where updraft strength and cloud liquid water increase with height, those ice particles that follow lower trajectories grow to smaller sizes than those higher up. Artificially increasing the initial ice particle concentrations can therefore be expected to favor the production of the smaller ice particles (because they are first in space to encounter undepleted cloud water) and suppress the growth of hail higher up. If the ice particles enter the updraft in the upper cloud levels only (above ∿-15°C, where cloud liquid water and vertical velocity are nearly constant with height), the ice particles that follow the lowest trajectories could grow into large hail. Increasing the initial ice particle concentrations in such situations could produce more large hail unless there is sufficient turbulent mixing among the growing hailstones so that they compete for cloud liquid water on a more or less equal basis. Young's (1978) numerical experiments, however, indicate that moderate levels of turbulence, such as typically observed in updrafts of Colorado storms, are not likely to produce sufficient mixing to reduce hailstone size significantly. These results suggest that the effectiveness of seeding to suppress hail may depend on whether seeding can produce sufficiently large ice particles in sufficient quantities in the lower updraft regions where competition for cloud water favors the growth of small graupel or rain.

Chapter 9: Two-Dimensional Modeling

This chapter describes the two-dimensional time-dependent dynamical/microphysical numerical modeling work performed as part of NHRE by the modeling group of the Institute of Atmospheric Sciences at the South Dakota School of Mines and Technology. Two types of models, both based on the dynamic framework of earlier work by Harold Orville and his associates, were used in this study. These models differ in the amount of detail used in treating hail. The first model uses conventional microphysical parameterization techniques for all hydrometeors; the second model is hybrid in nature in that hail and ice are treated in more detail by using 20 size categories to define the ice spectra, while parameterization techniques are still used for water drops.

The highly parameterized model has been applied to two NHRE cases, one a supercell case the the other a multicell case. The tendency for a long-lasting cloud to form occurs with the supercell storm sounding of 21 June 1972 (the "Fleming Storm"). A characteristic sloping updraft, with attendant rounded storm top, radar overhang, and moving gust front, all occur in the simulation. The creation of secondary cells by accelerating updraft cells is evident. A general picture emerges of a large storm-scale circulation upon which smaller scale cells are superimposed. These smaller buoyant cells travel up the main sloping updraft, periodically intensifying the storm.

Simulation of a multicell storm has not been so successful. The thermodynamic structure of the simulation differs from the observations, indicating that the evaporation rate from the surface in the model may be too large for northeastern Colorado storms. Although multicell characteristics begin to show up late in the integration, the limited domain of the model precludes following the storm evolution further.

The 20-category hail model has been exercised on the supercell storm sounding, with both unseeded and seeded cases being simulated. The general storm structure and its evolution are essentially the same as those derived using the highly parameterized model. A precipitation cascade, pedestal and shelf clouds, and echo weak region are all evident in the model results. This model is unable to form the vast amounts of large hail observed for this case mainly due to the depletion of liquid water caused by too-efficient embryo generation mechanisms, particularly frozen drop embryos. The one simulated seeding run conducted on this case indicated a hail suppression effect of about 25% with a 10% decrease in rain and a net decrease of about 15% in total precipitation. The weakness of this model in its simulation of the rain process contributes to these seeding effects, making them more applicable to hailstorms with hailstones originating from frozen drops.

Chapter 10: Three-Dimensional Modeling

This chapter presents results from the numerical simulation of a severe storm using a three-dimensional time-dependent cloud model. The particular environment chosen was that of the 22 June 1976 NHRE case study.

A discussion of the sensitivity of the solutions to the type of lateral boundary conditions imposed is presented. Of main concern here is the question of specification of field variables at an inflow boundary. It was found that using a relaxation to specification at the inflow boundaries allowed for solutions which were stable with respect to changes in domain size and horizontal resolution.

Another topic which is discussed is the unusual behavior of present cloud models to exhibit cell splitting very early in the storm evolution. It is suggested that this behavoir may be due to initialization effects. Initializing with warm bubbles, for example, produces tilted vortex pairs which appear to be unstable due to a strong positive correlation between vertical vorticity, ζ, and vertical velocity, w, and due to the existence of stably stratified air. One experiment is presented where the w and ζ correlation is purposely reduced in an ad hoc manner during initial storm development. This results in a stabilizing effect for the vortex pairs, which was the expected result from intuitive arguments presented. The possible relationship of this model type of storm splitting with naturally observed storm splitting is also discussed.

There is often a question with severe storms on the relationship between the storm dynamics and the gust front. One sensitivity experiment is presented where the gust front is "turned off" by not allowing precipitation to form. The storm dynamics for this particular case showed no significant effect, suggesting that the two entities are dynamically uncoupled. The general features of the modeled gust front and storm propagation speed are also discussed and compared with the observations.

Chapter 11: Statistical Testing of Hail Suppression Hypotheses

This chapter presents a concise overview of the design, execution, and analysis of the NHRE randomized seeding experiment. The historical antecedents to the chosen seeding hypothesis, based on claims of success in hail prevention by Soviet scientists, are described and the cautious wording of the NHRE hypothesis is emphasized. The steps involved in translating the hypothesis into a field experiment are reviewed in order:

1. The randomization procedure
2. The seeding method
3. The evaluation
   a. primary statistical evaluation
   b. evaluation based on the hailstone size distribution
   c. evaluation based on radar variables
   d. evaluation based on hailstone embryo types.

None of these evaluations indicated a statistically significant effect of seeding.

A study carried out to examine the representativeness of the way in which the available experimental units (haildays) were partitioned into treated and control sets is reviewed. The observed, but not statistically significant, partition of hail intensity showed more hail, by several measures such as total mass of hail over the target area, in the treated set. The representativeness study, which considered several widely accepted estimators of hail potential, such as stability indices and one-dimensional cloud model parameters, indicated that the selection process produced a partition of the sample such that the seeded set had greater hail potential than the control set.

Another study evaluated the degree to which the seeding, as projected in the experimental design, was actually carried out. This showed a "seeding coverage" of only 46%, averaged over the three years of operations.

After the critical review of the NHRE seeding experiment, the remainder of the chapter is devoted to the formulation of recommendations for future experiments, covering:

1. Seeding techniques
2. The employment of meteorological predictors
3. A new statistical design, with consideration of
   a. size of area over which to perform an experiment
   b. number of years of testing required for statistical significance
   c. accuracy required in surface measurement of hailfall
4. Dealing with the largest storms, which are few in number.

Chapter 12: Societal Aspects

This chapter summarizes activities and studies led in NHRE by the Environmental and Societal Impacts Group (ESIG) of the NCAR Advanced Study Program. The topics covered include the attitudes of the residents of the NHRE study area toward weather modification; the legal aspects of weather modification; the economic, social, and environmental effects of hail suppression. The experiment was generally accepted and supported by the people of northeastern Colorado and researchers did not encounter any significant opposition during more than five years of field work. The seeding agents used during NHRE caused no detectable changes in ecosystem functioning and had no detectable effects on precipitation in the downwind region.

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SCIENTIFIC COMPUTING DIVISION

INTRODUCTION AND OVERVIEW

The Scientific Computing Division (SCD) provides 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.

Atmospheric research is dependent on large-scale computing to pursue the studies needed to advance the science. Simulation modeling of a wide range of phenomena is required, as is the analysis of very large data sets. These activities demand computing resources not normally available at universities. The principal mission of the SCD is to provide the large computing power that will support computations for extensive modeling and data analysis as well as the storage and archive capacity for major data collections. The emphasis is on high-performance equipment and support services tuned to this research. For this reason, the SCD facility includes a CRAY-1, which can carry out 80 million instructions per second for high-speed computational power, a Control Data 7600 for fast data analysis and file handling, an Ampex Terabit mass storage system for extensive archives and large on-line storage, and a remote job entry system that communicates with 75 universities across the country. The facility also includes a Dicomed graphics system and a Network Systems Corporation (NSC) high-speed network to connect the various systems.

In 1980, the SCD supported 600 principal investigators at 80 universities and NCAR as well as about 400 support scientists or graduate students associated with them. Two-thirds of the computer usage was research in climate, weather prediction, and upper atmospheric studies. Mesoscale and severe storm studies have become very active research topics in the last few years with more computing resources being allocated to modeling and data analysis. Research in oceanography and astrophysics has also grown as resources became available.

The research being supported by SCD has expanded in two predictable ways. First, as modeling has developed, more complex and refined models of a wide variety and scales have been introduced, leading not only to a greater demand for computational power but also to very large history files to be archived, analyzed, and manipulated in complex ways. The second expansion has been the development of data collection systems that offer extensive coverage of a field program and deliver enormous quantities of data that must be processed, analyzed, and aggregated into a coherent picture of the experiment. Both these development trends seem to be touching only the early phases of the scientific opportunities that are realizable; the further development of hardware and software promises real qualitative, as well as quantitative, advances in the science.

Overall Strategy and Accomplishments for 1980

With the expanding need for computational power, large archives, communication links to universities, graphics tools, and software libraries, the SCD is experiencing major growth in user demand of these facilities. The university use has expanded rapidly this year and has now reached the allocation percentage (45%) prescribed by the UCAR Board of Trustees. The CRAY-1 system has been very popular with our users as a computational engine and reached saturation in August 1980, only 32 months after its introduction. The Terabit Memory System (TBM) has also received wide acceptance as an archive and contains two trillion bits of users data. The number of data sets in the archive grew 80% this year, and we see no reduction in this rate of increase in demand. The remote job entry (RJE) system for communication with universities and other remote sites met a 20% increase in demand and will be at saturation when the new system, an IBM 4341, is installed in the summer of 1981. This new system will not only perform the RJE task but also provide a modest level of interactive service to the NCAR community. This new system will have a significant impact on the kinds and the extent of services that can be provided.

SCD has been developing a high speed network to tie its major systems together and provide independence from the 7600 or any other component on the network. During 1980 many systems were integrated onto the network and the network software was tested for speed and reliability. With the integration of the 4341, the network will become the principal communication link between systems and offer the high speeds demanded to accomplish the large file transfers of the workload.

Organization

The SCD is organized into four sections and several staff functions that report to the Director. 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 data archives, data exchanges, and field experiments.

The User Services Section offers consulting services to users, provides information on all services and operational procedures of the division, and provides software libraries of numerical and utility tools. The Systems Section develops network, communication, and mass storage systems, as well as maintaining operating systems and language compilers supplied by the vendors. The Operations Section operates and maintains the systems of the facility and provides digital data library services, use statistics, microfilm/microfiche production, and movie capabilities.

In addition to these four sections, the SCD has an Advanced Methods Group to conduct research into numerical algorithms widely used in atmospheric research and to provide consultation on the best methods and software for numerical problems. The SCD administrator is responsible for managing the division budget and the management reporting system. The Clerical Support Group provides clerical services to about 93 members of the SCD.

DATA SUPPORT SECTION

Introduction

The Data Support Section (DSS) is responsible for maintaining a digital data base appropriate for the research needs of NCAR and for the broader needs of the research community, especially the universities that use the NCAR facilities. Just as a major science center such as NCAR needs a library, it also needs quick and easy access to digital data for use on computers. In a library it makes sense to maintain shelf copies of the books and journals most central to the research needs. Less frequently used publications can be borrowed (with a time delay) when a user has a requirement. For digital data at NCAR, a similar split is made between data that are routinely maintained and those obtained when a research project needs it. A continuing effort is made to obtain necessary data and to know the location and status of various data sets and data projects.

The DSS maintains many large sets of analyzed grid data and observed data from the National Meteorological Center (NMC), the National Climatic Center, the U.S. Navy, and the U.S. Air Force. Other countries and laboratories have also provided data.

When the DSS receives requests for data to be used on NCAR computers, it supplies users with catalog information, access programs for reading the data, and general information about data content and quality. The access programs read in the data, unpack it when desired, and present the user with data arrays ready for calculations. A selection of subroutines is also available to help the user with such tasks as grid interpolation and transformation and geostrophic wind calculation. Users do not have to be at NCAR to use data on the NCAR computer. A program to use the NCAR data can be sent to the NCAR computer by telephone from a university. Use of NCAR data by remote access is increasing. We will describe data support to users in more detail below.

Additions to Scientific Data Archives

Significant efforts are required to update and maintain the data archive. In addition, new sets are added to the archive as sets become available and new needs are identified. Some data are obtained for the archive to meet a specific request. More often, data are acquired in anticipation of research needs by assessing the general needs of the research community in combination with specific current and past requests.

Several new data sets were added in 1980. A selection of NMC's Limited Fine Mesh analyses and forecasts were obtained for October 1971 to June 1980, and this set will be updated regularly. A partial monthly precipitation set for African stations is now available, and Dennis Joseph is working with Sharon Nicholson of Clark University in preparing the remainder of this set. Southern Hemisphere analyses from South Africa have been received and will soon be available for use. A set of long-term summary-of-day data for U.S. stations (including cooperative stations) is currently being processed to reduce overall volume and make the set more easily accessible. Other new sets include Nimbus ozone observations, Navy 10' elevation data, and time series of permanent ship observations. In cooperation with NSF and T.N. Krishnamurti of Florida State University, the DSS is acquiring upper air and rainfall observations for India from the India Meteorological Department.

Data from the National Meteorological Center contribute over 200 tapes each year to the growth of the archive. When back-up tapes and subsets developed for easy accessibility are included, the actual archive growth rate is greater. The NMC data include gridded analyses and forecasts and observed surface and upper air data for the globe.

Other major grid data set updates over the past year included Southern Hemisphere analyses from Australia and surface parameter tapes from the Navy. Observed surface and upper air files were also updated from Navy archives. Other updates included monthly mean surface and upper air data, hourly U.S. precipitation data, and various updates to the time-series raob set.

National and International Planning

The DSS participates in various data planning efforts and data exchanges to help make necessary data more readily available. Some of the major involvements will be described.

Roy Jenne spent seven weeks in Geneva in early 1980 to develop the report "Planning Guidance for the World Climate Data System." About 150 preliminary copies have been used in World Meteorological Organization (WMO) meetings relating to the World Climate Program. Jenne built the report on work done while he was at the U.S. National Climate Program Office during 1978-79.

The DSS recently has been especially active in planning for collection of data on clouds. The reason is that one of the main factors of uncertainty in models that predict climate changes due to increasing carbon dioxide is the question of the feedback of energy by clouds. Jenne attended a meeting sponsored by WMO in Hungary in June to prepare plans for a "real-time satellite-observed cloud climatology." Follow-up meetings were held at Fort Collins and at a NASA workshop in October. Jenne gave a paper and chaired a panel discussion. He later met with key people in Japan's satellite and climatological services to try to achieve an accessible archive of the Japanese synchronous satellite data. A major cloud calculation problem is the high volume of data from most satellite sensors; thus useful data subsets must be defined.

The DSS also worked with the Air Force to help define new formats for the three-dimensional cloud data that would sharply reduce the volume from the present 1,440 tapes per year.

Dennis Joseph attended a meeting in the United Kingdom in June to plan for ALPEX, an observational GARP mountain experiment. It will study the influence of European mountains on local climate and on the global circulation.

UCAR has been exploring the possibility of developing an enhanced capability to help meet national scientific needs for ocean data, especially satellite data (ODUS - Ocean Data Utilization System). The DSS has been involved in the preparation of planning documents to define the options.

The DSS has also been involved in several activities to promote the data exchange among countries. Jenne attended a Miami meeting in October for planning on the exchange of data between the U.S. and the USSR. If politics do not interfere, actual copying of tapes for exchange could begin soon. Jenne visited China from 2-22 December under a bilateral agreement to consider data problems. The trip included talks at the Central Meteorological Bureau (CMB) and the Academy of Sciences in Beijing (Peking), lectures at the Meteorological Institute and University in Nanjing, and a visit to the meteorological offices in Shanghai. The CMB was interested in learning more about methods for data handling and quality control. While in China Jenne attended the WMO technical conference on climate in Canton. Trip notes include information on the history of the Chinese observing network, status of conventional data, information on data inferred from historical records and tree rings, and some information on sunspot records. The notes include several charts that describe climatic variations in China during the past 500 years.

The section also continued working on defining strategies to deal with large sets of data. Further information about archival costs was prepared, and Jenne presented a paper entitled "Strategies to Develop and Access Large Sets of Scientific Data" at the marine geology and geophysics data workshop in November (sponsored by the National Geophysical and Solar Terrestrial Data Center).

MONEX Data Processing

The international experiment on monsoons (MONEX) was held during the winter of 1978-79 in Malaysia and during the summer of 1979 in India. The DSS cooperated with the U.S. MONEX Project Office at NCAR by processing the research aircraft data. The aircraft involved were the NCAR Electra, a NOAA P3, and the NASA CV990.

The processing, done by Dean Frey, consisted of data collected on 27 flights (available on 30 tapes) during Winter MONEX and 57 flights (available on 60 tapes) during Summer MONEX. The processing and documentation are complete for Winter MONEX, and the Summer MONEX will be completed by February 1981.

NCAR archives have a variety of data to support MONEX research in addition to the aircraft data, including observed data and analyses for many years, thus permitting a comparison of the intensively observed MONEX data with data from other years.

Data Support Provided

Many of the data needs of users can be met by helping them find the specific data they need, and (if NCAR has the data) by providing tape numbers, access programs, and other computing aids to use the data. Such support is used by the NCAR staff, visitors, and people submitting programs via telephone communications.

Beyond support for the data archive, DSS also supports the general data users through consulting assistance and utility programs for general data handling. For example, a user brought a tape with ASCII characters, built on a machine that set the left bit to one (standard is zero). This required a short special program. Another user had a tape with 16-bit integers built on an IBM machine but copied by a different laboratory. Data dumps showed the data had been repacked into 12-bit integers. With this information, Wilbur Spangler showed how the data could be quickly unpacked and used.

Requests for data to be used elsewhere are generally filled by generating magnetic tapes to be mailed to the users at cost. These shipments include information on tape content, format descriptions, and other information on the characteristics of the data and how best to read the tapes. During 1980, the DSS responded to about 240 requests for data to be used on non-NCAR computers and sent out about 600 magnetic tapes (the information was taken from 1,350 tapes). There were also a few requests for data printouts and data on microfilm.

A few examples of requests during 1980 are:

1. German stratospheric analyses by the University of Washington

2. NMC surface and upper air observed data and gridded analyses by Lance Bosart, State University of New York, Albany

3. Various sets of geophysical, climatological, and daily gridded data by R. Mittner, Director of Meteorology, Paris, France

4. Year-month ice grids by Steve Ghan, Pacific Marine Laboratories, Seattle, Washington

5. Air Force elevation data by NASA, Greenbelt, Maryland; SRI International, Menlo Park, California; and NMC, Washington, D.C.

6. Time series of 700 mb height gridded analyses by T.Y. Wu, Central Weather Bureau, Taipei, Taiwan

7. Limited Fine Mesh Analyses for a three year period sent to George Halliwell, Oregon State University

8. Year-month mean grids, daily sea-level pressure from 1899, and sea-surface temperature grids by Prof. Nakajima, Kyoto University, Japan

9. NMC 700 mb grids by the University of Wisconsin

10. Monthly mean sea-level pressure grids by Robert Lofgren, Laboratory of Tree Ring Research, Tucson, Arizona

To support user access to data sets, and for archive maintenance, it is helpful to have information about tapes and mass-store volumes on-line. Through the efforts of Gregg Walters and Spangler, most basic documentation (including volume serial numbers (vsn) lists, content summary information and cross references to programs and further documentation) is now on-line, and the files are being used for updating of data sets and version maintenance, vsn and subject content searches, and statistics on vsn content and distribution.

Direct Research Project Involvement

The DSS also becomes directly involved in selected research activities, usually on a cooperative basis. In past years it participated in projects to prepare climatological analyses of the Southern Hemisphere (from the surface to 100 mb) and prepare a climatology of the Northern Stratosphere. Several movie films have been generated on computers to show climate information and atmospheric flow patterns at 500 mb. One recent project involved comparisons of ground-based and satellite ozone data in cooperation with Greek scientists C. Zerefos and C. Repapis (Research Center for Atmospheric Physics and Climatology, Academy of Athens).

Other direct project support included Spangler's calculation of zonal means of wind and temperature for Philip Thompson and a wide variety of statistical calculations for winter seasons for Harry van Loon (Atmospheric Analysis and Prediction Division).

USER SERVICES SECTION

Functions

There are two principal functions that the User Services Section performs. One is to provide effective user interfaces to the hardware and operating system software for all scientists who use the SCD facilities. Some of the specific services that are provided include consulting, documentation, and limited training. In addition, consulting and advice are provided for the mathematics, utility, and graphics software that is ordered or developed and maintained by the section.

The other primary function is to provide an effective liaison with scientific users of the SCD, ensuring that state-of-the-art computing tools are available to facilitate their research. The activities that serve these functions are quite diverse. These include the determination of access methods for the variety of NCAR computer systems, the provision for multi-user data processing system, and consultation and collaboration on a number of projects including a community climate model used by the atmospheric research community.

In addition to these functions, User Services staff participated in the planning and procurement of the input/output satellite computer that is to be installed in March of 1981.

User Interfaces

First Annual Computer Users' Conference. "Planning for the 1980s" was the title of the NCAR SCD First Annual Computer Users' Conference held 5-6 January 1981. Plans and arrangements for this conference were made by a User Services Committee chaired by Buck Frye. The conference consisted mainly of workshops on research goals and computing needs.

Consulting Office. The consulting office, as part of the Consulting Project managed by Ann Cowley, is one of the primary services for users. It is staffed eight hours each weekday with at least one consultant. During peak hours and in the summer months when many scientists visit NCAR, additional staff members are assigned or on call. Many referrals are made to a specialist within the SCD for special assistance on the best routines to use from among mathematical and utility software, graphics, or potential operating system problems. During 1980 there were 6,784 in-person requests for help from the consulting office. In addition, the staff answered 2,979 telephone queries. Many of these contacts (367) involved extensive documented follow-up. From these, 63 reports on verified problems were published.

In addition to the general consulting, a consulting service is provided for remote sites. These contacts serve scientific users who wish to establish a new site for terminal access to the SCD systems and to assist them in maintaining and troubleshooting for an established site.

Documentation. There are two periodicals published; one is monthly (The Record), the other is circulated daily (The Daily Bulletin). The Record contains feature articles of interest to the general user community, as well as regular columns on computer usage, computer resources granted, trouble reports, and suggestions and comments. The circulation is 850.

The Daily Bulletin is available on-line to remote users through the RJE newsfile program. An additional 25 hard copies are distributed throughout the NCAR building. The bulletins update operational, systems, and general user information on a daily basis.

Two types of documents, user guides and reference manuals, are produced. During 1980, the Documentation Project under Benedict Domenico released the following documents: Overview of the NCAR Scientific Computing Division; Running Jobs at NCAR; Storing, Retrieving and Editing Programs; and 7600 Monitor Control Language.

Vendor manuals are also distributed to scientific users.

Training. Training programs for the SCD during the past year have been limited by staffing constraints. It is planned that courses will be offered again in the next year. Some of these courses will introduce the user to the new interactive facilities that will be provided on the IBM 4341. Others will include fundamentals of programming languages and special techniques for the use of graphics software and other multi-user software facilities. During 1980, there was an introduction to graph theory taught by an outside consultant and an introduction to computing at NCAR taught by NCAR SCD staff. Lecturers were invited to present topics on standards, mathematical techniques, and vendor software.

Computing Resource Applications. Cicely Ridley and John Adams processed requests for computing resources and prepared support materials for the SCD Advisory Panel. In 1980, 180 requests for resources were received and 1,381 CRAY Resource Units (CRUs) were granted by the panel.

Software and Libraries. The Software and Libraries Group, headed by Russell Rew, provides support for graphics, utilities, and mathematical software required by scientific users. The trend in recent years has been to acquire software that various vendors, users, and software houses supply. These packages are occasionally supplied with no charge; however, most of them have, at the minimum, an initial purchase price. It has been concluded that development of these general packages by NCAR staff is not cost-effective. In addition, portability of programs from NCAR to a "home institution" is promoted by the availability of broadly used quality software. Packages are provided in standard FORTRAN when possible whether the routine is developed at NCAR, acquired or provided by a vendor.

After the Software and Libraries Group evaluates candidate packages, it makes appropriate selections, followed by acquisitions and development. In support of any given acquisition, the staff installs the library or package, prepares articles and announcements of the new software, provides maintenance services, revises routines as needed, and consults with users on the best routine to use for a given problem. A library catalog containing 70 subject areas is maintained on-line. When new software is added, entries are made in this catalog; a hard copy is kept in the Library and Consulting Office for the convenience of users. Some of the newer software that is available is PORT, a portable library from Bell Laboratories; LINPACK, ITPACK, routines for the solution of linear systems; some ordinary differential equation (ODE) solvers; and a number of graphics utilities. The Numerical Algorithms Group (NAG) library is the most recent acquisition, but it is not yet installed for general use.

After evaluating software available in the area of boundary value problems for ODEs, we acquired several new packages that represent the current state of the art in this field. These acquisitions will improve the quality of software significantly in an area that has been fairly weak in the past.

In addition to the routine development and maintenance of the software libraries, a Software Distribution Service is available. Over 340 tapes containing requested software from the NCAR library were distributed last year.

The development and testing of the Dicomed On-line Operating System by the Graphics Project, managed by Lofton Henderson, continues. When the system is released, users will be able to gain access to the Dicomed for quality graphics facilities directly from their programs. Plans are to include network transmission tools when the interface to the local internal network among computer systems is completed.

Preprocessors

A preprocessor is a computer program that translates a program written in a higher level language to, say, FORTRAN. The preprocessor language includes extensions and features that are not available in languages such as FORTRAN.

IFTRAN is the most widely used preprocessor at NCAR. It provides structured programming syntax, indented listings, conditional compilation, internal subroutines, character string replacements, and a facility for in-line comments. This is the only preprocessor that the Software and Libraries Group is committed to support at the highest level. PP1 is another preprocessor that receives only minimum support; however, it does provide a macro facility that has been in demand by some users. Rew completed an evaluation of a number of preprocessors for the 1981 Annual Users' Conference held in January at NCAR.

Liaison with Scientific Users of the SCD

Liaison with users involves facilitating access to the computer systems (Data Communications Group), facilitating program development (Multi-User Software Group), collaborating with scientists, and contributing to the planning for computer procurements (Planning and Collaboration Group).

Data Communications. At the end of 1980, there were 127 remote job entry sites that were linked to the NCAR system via the MODCOMP computer. Over 100 of these are non-NCAR sites that represent 75 universities and research organizations around the country. The number of sites has increased by about 130% over the last three years and 20% during 1980. About 57% of all the jobs submitted were entered from remote sites. These jobs used 36% of the available CRAY central processing unit (CPU) hours. David Fulker heads the Data Communications Policy Committee (staffed from the User Services, Systems, and

Operations Sections), which was recently formed to provide management with guidelines for establishing policies for remote use of the network. There is a limited consulting service provided by this section.

Planning for the Input/Output Satellite Computer

UCAR has contracted to purchase an Input/Output Satellite (IOS) computer from IBM Corp. Planning was begun in 1979 when the procurement committee headed by Jeanne Adams gathered information and prepared a study report on requirements. A formal request for proposal was sent to 13 computer system manufacturers in April 1980. Numerous meetings were held with users, current usage statistics were studied, and a questionnaire was sent to users to obtain information about their needs. The hardware was delivered on 13 March 1981; the system is expected to be available for general use this fall.

The IOS is intended to serve several input/output-related functions. Some of these functions are to provide a program development environment that includes capabilities for editing and storing files; to provide mechanisms for submitting programs to, distributing output from, and exchanging data with other computers, such as the CRAY and the 7600, that are attached to NCAR's high-speed network (the Network Systems Corporation Hyperchannel); to provide access to magnetic tapes in a variety of formats and densities; and to provide data communications facilities for remote access to the system. The latter will provide modest interactive capabilities to users of the NCAR facility for the first time.

At the core of the IOS is an IBM 4341, running the Virtual Machine/System Product (VM/SP) as its operating system. Within VM/SP are four major components. Of these components, three that are largely invisible to the user are the Control Program (CP) that manages the hardware resources, the Interactive Problem Control System (IPCS) that helps identify and report system problems, and the Remote Spooling Communication Subsystem (RSCS) that handles remote access to the system. Most user activity takes place within a fourth component, the Conversational Monitor System (CMS), that provides an interactive (time-sharing) environment for program development and file management.

In conjunction with CP enhancements permitting 4341 attachment to the high-speed network, the SCD will devise commands within the CMS environment that facilitate the submission of batch jobs to the CRAY-1 or other computers on the network. The central processor is a 4341, Model L1, with 4 megabytes (one million 32-bit words) of main memory. The disk subsystem includes four 3370 drives with a total capacity of more than 2,400 megabytes of direct access storage. The magnetic tape subsystem includes one seven-track 556/800-bpi drive, one nine-track 800/1,600-bpi drive, and four nine-track 1,600/6,250-bpi drives; all operate at tape speeds of 200 ips. Unit record equipment comprises an 800-cpm card reader and a 1,200-lpm line printer. Attached to a channel of the 4341 is a 3705 Communications Controller.

The 4341, the 3705, and the available software provide a wide variety of related options. Asynchronous communications protocols will be available to users at 300 and 1,200 bps. 2780/3780 protocols at 2,400 and 4,800 bps will also be available.

The IOS offers substantial possibilities for expansion. Among these are field upgrades to a faster central processor with up to eight megabytes of memory, additional disks with up to 16,000 megabytes of direct-access storage, additional communications controllers to support more ports (well over 250) and/or higher transmission speeds (including ports at 50 kbps), and a variety of additional peripheral equipment such as printers. Support is also available for configuring the system with multiple central processors.

The IOS will be interfaced to the local high-speed network. In this way, there will be facilities implemented that give users easy and logical access to the entire computing environment.

Research and Development

Research and study of state-of-the-art techniques in computer hardware and software are continuing goals of all groups in the User Services Section. During 1980 the Special Projects staff under Herbert Poppe have been engaged in studying uniformity questions as they relate to the use of the local network. Feasibility studies are underway to implement uniform accessibility to the network, to implement a uniform file system to all host machines on the network, and to provide a uniform or common job control language for all network computers. These may be idealized goals that can only be partially realized. A result of this research might be a single set of instructions usable with a variety of host machines, which would be of great importance to users.

Multi-User Software

A number of comprehensive tools are needed in order to provide effective liaison with scientific users in an environment like that of NCAR. Data processing has become an increasingly important part of the research designs created by NCAR scientists. In response to these needs, the Multi-User Software Group under Robert Lackman, in collaboration with the Research Aviation Facility (RAF), has undertaken the work of generating a general-purpose data management software system for the handling of numerous kinds of scientific and engineering data called GENPROII. The first use of this software was the data processing of RAF aircraft data. Some of the guidelines used in the design and development of this program were software flexibility, portability, ease of maintenance and error detection, ease of use, and efficiency. This system will provide capabilities for accessing, archiving, creating, editing, calibrating, displaying, and analyzing an arbitrary number of scientific or engineering variables. It also will provide a wide array of statistical, spectral, and signal processing capabilities.

The development phase of the program is complete. Fine tuning of the code continues, and documentation for the user is being written. It is hoped that this package designed for multi-user distribution and maintenance by the SCD will be only the first of such community efforts in software design and development for atmospheric scientists.

Scientific Modeling

Collaboration with scientists engaged in various research projects at NCAR is another liaison activity of the User Services Section. Richard Sato has been working with scientists supporting a community climate model, as has Gerald Browning of the Advanced Methods Group. Gloria Williamson has been monitoring production and development runs of the NCAR General Circulation Model (GCM) and its associated processors as well as providing assistance to scientists in understanding the structure of the GCM data archive. Cicely Ridley has been doing collaborative research with Raymond Roble (ACAD) and Robert Dickinson (AAP) on modeling of thermospheric dynamics. John Adams has been involved with producing software for solving partial differential equations and consultation in its use.

Other projects that involve application-specific computer technology may in the future result in programs that serve a community of users doing research in the atmospheric sciences.

SYSTEMS SECTION

Mission and Goals

The Systems Section provides maintenance of the operating systems and subsystems in the division. It also develops and maintains network and communication software to link the various elements of the NCAR system. It develops and enhances system software to provide better service.

The Systems Section also provides services in support of activities in other sections of the SCD.

Major Overall Accomplishments

During 1980, the Systems Section provided consultation to users in several areas. They consulted with users on problems with systems' features and advised them on the use of system software. They assisted users having input/output problems with large data processing codes.

The Systems Section maintained operational software, i.e., repairing problems in production systems code and making minor modifications as needed to provide user satisfaction.

They consulted with Operations personnel on problems with systems such as determining whether machine failures are caused by hardware or software.

They consulted with customer engineers from Control Data Corp. (CDC), Network Systems Corp. (NSC), AMPEX Corp., CRAY Research, Inc. (CRI), MODCOMP, Digital Equipment Corp. (DEC), and Systems Engineering Laboratories (SEL) on interrelated hardware/software problems.

The Systems staff developed software to support the interconnecting of the local network with the NSC network adaptor boxes and the Hyperchannel. Software was also developed to support major user-requested features, performance and operational improvements, statistics gathering, and general system enhancement.

They participated in the drafting of technical specifications for hardware/software procurement of the IBM 4341 IOS computer. They assisted in the proposal review process, benchmarking, and selection of the system.

The Systems Section talked with vendors' representatives during contract negotiations and equipment installation, for example, on the IOS, as well as on hardware upgrades, such as those on the MODCOMP II remote job entry device.

CRAY

Introduction. The CRAY Group provides systems software support for the CRAY computer. In 1980, the members of the group were Eugene Schumacher, Bang-Yaw Chin, David Kitts, and Barbara Bateman. This activity ranges over the areas of installation of software releases, program problem analysis, special studies, and advice to the user community on how to best utilize the various features of the CRAY. The group provided these services in 1980 at an average staffing level of three persons.

Software Installations. Two software releases from CRI were installed on the CRAY in 1980. Installation of a software release follows a very structured procedure. First, we examine the local modifications to the system and the released modifications from CRI and then tailor the local modifications to the new release. The components of the release are made available to users for a pretesting period. Various large-scale models, representative of the computer load, are tested using the new release software. This procedure will inevitably bring to light some errors in the new software. CRI provides fixes for the discovered errors and the tests continue until the new release software is considered safe to be installed as the default system. Finally, we test run the system to detect instability in the local version.

Release number 1.07 (seventh in the series of CRAY system software updates) was installed in mid-February 1980. This release provided some new features and some fixes for previously reported problems. A disk error correction task and a system performance monitor for gathering system performance statistics were among the new features. Problems remedied included two situations that led to system crashes, recovery calling sequence errors, and several FORTRAN compiler problems. The most significant 1.07 performance improvement was the greatly reduced input/output (I/O) times clocked during the program load process.

Release number 1.08 was installed in mid-October 1980. Included in this release were a job classification capability that assigns classes to jobs in the input queue and thereby determines the order of job initiation, a multiple disposal capability for local and permanent datasets, and a selective loading capability for the loader. Several other problems in the FORTRAN compiler and in library routines were fixed with this release.

Hardware Installation. CRI installed a new multiplication unit in the CRAY mainframe over the 1980 Labor Day weekend. The new unit was designed to provide a capability for symmetric multiplication. Various calculations had shown that the commutative property of multiplication could not be met for some operands in the machine. With the change, the rounding operation was also modified. An unfortunate secondary result of the change was that divisions with certain operands can now cause some problems for FORTRAN users due to the method used for rounding off. Division of numbers by the hardware is accomplished by performing a reciprocal approximation followed by multiplications, and so the division operation is linked to the multiplication hardware.

CRI has investigated the problem and will be issuing FORTRAN changes in 1981 to correct the problem.

Studies and Reports. The CRAY Group engaged in various studies during 1980 to gather pertinent information from the complexities of the internal software and present it in a concise form to the users so that they can use various features more effectively.

Presentations covering some of the topics under study were given at local user group meetings. The values of software installation parameters was the subject of one meeting. Knowledge of the values of the more important parameters can help users plan for various problems in the operation of large programs. Other topics presented covered the new user charge program and features of various system maintenance software. The workings of the automatic disk scrubber, which maintains the level of data on the disk, is an example of system maintenance software.

One of the most important studies done in 1980 investigated the CRAY disk I/O performance. Schumacher reported on a series of controlled test runs that he made on the CRAY to measure effective disk data rates for a variety of conditions. The parameters that were allowed to vary included access type (sequential vs. random access), record length, buffer block size, the number of records in a dataset, and the method for reading in of the data (binary unformatted read vs. BUFFER IN).

While some anomalous cases occur within the results, generalizations can be made about optimizing data flow under various conditions. Performance was measured for read operations using sequential and random access. For both cases, it can be concluded that the rate of data transmission improved with increased record length and that nonbuffered operations produced a better data rate than asynchronous or buffered operations. The data rate improvement provided by nonbuffered operations must be weighed against the ability to overlap buffered operations with computing. As the number of records in a data set increases, performance improves if sequential access is used, but it declines with random access. Small block sizes degraded sequential access more than random access.

NCAR-generated System Software Packages for the CRAY. The current disk configuration can hold enough data for approximately three to four hours of work. Users must save any data they need by transmitting it to the 7600 and saving it on 1/2" tape or by transmitting it to the AMPEX mass storage system, the TMS-4 Terabit Memory System. Because the users frequently do not erase the CRAY disks after they have saved the data, the CRAY disks are not always emptied of unwanted data by users. A software tool has been developed to erase these data and prevent CRAY disks from overflowing and causing the CRAY operating system to lock up.

A disk scrubbing routine was developed by the Systems staff to be automatically submitted and run for the purpose of scanning for and disposing of datasets that are no longer connected to a running job and are over three hours old (during a weekday, prime time). This has been a most useful utility program since without it the disks can overflow causing the CRAY operating system to lock up.

Another utility jointly developed by the Systems Section and the local CRI engineering staff is a user-level hardware diagnostic program that is also submitted automatically on a regular basis. The diagnostic program conducts various sequences of operations that test the set of registers and functional units of the CRAY. The purpose of the diagnostic is to sense at an early stage the indications that a component in the machine is failing. When failures are indicated, diagnostics are provided by the program and the machine is turned over to the customer engineers for more testing and repairs.

This diagnostic has detected errors early enough that they could be fixed before they were propagated into the results of users' programs.

It became necessary to develop a generalized I/O channel driver on the CRAY. Since the CRAY was designed to be strictly a back-end processor, the only channel driver in the system was for its own disk channels. This fact left to individual sites using the CRAY operating system no mechanism to directly operate any peripheral devices other than disks on the CRAY.

The generalized I/O driver was needed to help solve the problem of data movement between the CRAY and the TMS-4. Originally, data disposed from the CRAY was sent to the 7600 and from there to the TMS-4. By utilizing a 7600 channel emulator attachment furnished by CRI, and a second Channel Interface Unit (CIU) purchased from AMPEX, the generalized I/O driver was the low-level system software tool needed to allow data movement from the CRAY to the TMS-4. The generalized I/O driver was subsequently used to connect the CRAY to the local network. Completion of this project is planned for 1981.

The user-level system code was developed which completed the interface for user programs transferring data to the TMS-4. This code has been called the direct CRAY/TMS-4 connection. This is a system code that drives the generalized I/O driver for disk data being transferred to the TMS-4. The advantages of this combined package of system codes were quite evident by the end of 1980. A small group of users volunteered their programs to be used for check-out of the direct CRAY/TMS-4 connection. It soon became clear that delays in data transmission were reduced since data were not transferring through a congested 7600. A decrease in data transmission failures should be seen with the reduction in data path length.

A special user utility program was developed along with the above effort to translate data volumes previously written to the TMS-4 in 7600 format to CRAY format when they are read over the CRAY/TMS-4 link. This utility is used on the CRAY and has provided for the immediate use of old formatted data without forcing the user to put this data through more complex data paths to achieve the required translations.

Immediate plans for the next year are quite well defined. The CRAY operating system, version 1.09 (COS 1.09) will be installed. There are several needed features in this version of which some of the most important are speedup of integer multiplication and division, addition of FORTRAN 77 standard CLOSE, OPEN, INQUIRE, and PAUSE statements, and use of the recursive capabilities of the vector hardware to optimize dot-product calculations.

Accounting capabilities for the CRAY will be installed that will be used to check a user's permission to run jobs on the CRAY and to verify that the user has sufficient funds allocated for the run. Accounting capabilities have become a key requirement since the network has begun operation. Previously, all verification checks occurred on the 7600, which was the sole front end to the CRAY. Now, several machines have access to the CRAY via the network, and the verification must be accomplished on the CRAY.

A set of programs will be written to process accounting charges for jobs submitted to the CRAY from machines other than the 7600. Results from these programs will subsequently be processed into the overall data base accounting system used by the SCD.

The latter part of 1981 should witness the installation of COS 1.10. Some of the important features of this version will be the complete implementation of the FORTRAN 77 standard, optional dynamic memory management, and DO-loop speedup.

All COS releases will undergo initial test periods and will contain all local modifications. A list has been developed of 35 work items to be accomplished on the CRAY for 1981.

TMS-4

A Mass Storage System (MSS) attempts to provide the greatest possible on-line data storage capacity at the lowest cost per bit that the current technology will allow. It provides access times and data transfer rates commensurate with host requirements. An MSS minimizes the amount of mounting and demounting of the recording media, such as tapes. Through off-line storage, an overflow capability exists so that there is no upper limit to the amount of available storage. MSS is usually considered to be the tertiary level of storage within a storage hierarchy, where secondary storage is a magnetic disk subsystem and primary storage is the main computer memory.

The NCAR MSS, an AMPEX TMS-4, was acquired and then expanded in three phases to reach the current configuration. Phase one began with a basic configuration that provided enough hardware for testing, software development, and system use. This phase saw no system component redundancy. In phase two, two additional dual transport modules and a second data channel were obtained. At this point, the system had some component redundancy. In phase three, a second Channel Interface Unit (CIU) was obtained. The second CIU provided a redundant data path between the 7600 and the TMS-4. This CIU was to become the data path between the CRAY and the TMS-4 in 1980. Each phase has been accompanied by significant software improvements that have greatly increased the usefulness of the system.

In early 1979, a study of file distribution and accesses on the TMS-4 was undertaken by Willard Crittenden of the TMS-4 Group to identify methods for reducing mounts of mass storage volumes. The space occupied by files on the TMS-4 grew well beyond the on-line capacity of the system. The number of TMS-4 tape mounts necessary to be performed each day increased to the point of becoming an operational problem. As a result of the findings of this study, operational and system changes were instituted to control the content of on-line volumes based on file size and access criteria.

System and operational changes were made to implement a biased retention scheme beginning in early 1980. A daily count was made of actual tape mounts across all TMS-4 tapes. This count showed a drastic reduction of mounts. Since that time, TMS-4 tape mounts have gradually increased as a result of increased TMS-4 usage, but they still remain at an acceptable level.

A fourth software phase has recently been completed by John Merrill of the TMS-4 Group. The objective of this phase was to provide software for the connection of the CRAY to the TMS-4. The TMS-4 now serves both the 7600 and the CRAY.

The software development effort on the TMS-4 required changes allowing all of the transactions and data trafficking from two host computers to be handled by the TMS-4 software. This software effort was manpower-intensive because of the careful changes that had to be installed while production was allowed to continue in a normal fashion.

Another AMPEX-produced MSS, the TMS-3 system, became available in 1980 as surplus from the Department of Defense. This system was obtained and installed in the SCD. A version of the TMS-4 software has been installed on the TMS-3 by Merrill and Joseph Choy (TMS-4 Group). A master tape head has been obtained from AMPEX, and the system is being used to perform mass storage tape initialization. The system is also a temporary source of parts for the TMS-4 in emergency situations.

The TMS-4 library contains a high percentage of active data. Catalog handling techniques are now available that prevent data loss and allow catalogs to be dumped to the normally used areas of the storage media without requiring specially reserved blocks.

The TMS-4 has provided valuable lessons about requirements for any new data archival system. A clearer picture has emerged about the functions required at both the host and archival systems. We now have greater appreciation for the memory and computational requirements of a future data archival system. Only small amounts of the necessary resources were available on the minicomputer purchased with the TMS-4. Reasonable amounts of memory, I/O bandwidth, and computational power are required to control and manage a mass storage device. A very important fact that has become evident after using the TMS-4 for several years is that once data are written, most activity against the data is for reference ("read only"), with a few re-writes of the data performed.

In summary, the TMS-4 now provides an MSS that is tightly coupled to two major host systems. The system provides a good off-line data management feature, and controlled storage growth has been built into the day-to-day operation since the system was installed. There is the possibility of enhancing the software capability to provide more host interfaces into the TMS-4. An example of such an interface effort may be considered for the IBM 4341 IOS system, depending upon various factors such as availability of funds and manpower to meet defined requirements.

Future Options. Some are of the opinion that NCAR should never again attempt to install an MSS that is not adequately configured and installed as a turnkey system. Using this criterion, all of the development problems are assumed to be avoided. In the future, every effort will be made to avoid extensive development cycles. At issue, however, is whether some development and natural system evolution can be avoided if real gains in performance and data-storage capacity within the local network are to be made in the 1980s.

A replacement for the TMS-4 has been budgeted for fiscal year 1983. Overlapping funds will allow use of both systems through fiscal year 1985. During this period, the data on the TMS-4 must be off-loaded onto the replacement MSS.

Initial planning for a replacement MSS has been very conservative. The TMS-4 technology of the mid-1960s would be replaced with MSS technology of the mid-1970s. Gains are anticipated in reduced maintenance costs and possibly reduced access times for data residing on a closely coupled system.

Some immediate solutions to NCAR's mass storage needs can be constructed from a group of currently available components that may be viewed as building blocks. These components are the NSC network adapters along with a small-scale computer to serve as the MSS control processor and catalog manager. In addition, there are various magnetic cartridge storage devices available. Other components being considered are an automatic tape library device and a pool of staging disks.

Utilizing appropriate groupings of these items, NCAR can construct a mid-1970s MSS technology to replace the TMS-4. A set of MSS characteristics can be selected to match planned configurations through the mid-1980s.

The TMS-4 can hold 504 gigabits on-line and can select data from about 2,500 gigabits overall. The accumulation of these data has been carefully controlled by quarterly purges, but conservative estimates signify that it will reach 67,500 volumes or 4.7 terabits by the mid-1980s and 107,500 volumes or 7.5 terabits by the end of the decade. The replacement of the 7600 with a class VI computer and the CRAY with a class VII computer, along with the addition of raster graphics capability and an increase in the amount of satellite data, could make these figures seem extremely conservative. This data growth rate is one of the factors pointing to the urgency of obtaining replacement equipment. The amount of TMS-4 data cannot rise beyond the point which disallows off-loading to a replacement MSS in some reasonable period of time. Since the installation of the TMS-4 has been successful, its increased use will make it difficult to discard it in favor of a less expensive more capable successor. New technology must become available in conjunction with the production of the new MSSs that can service the data requirements of the class VI machines in the 1980s. The current CRAY channels can operate at up to 0.27 gigabits/s. The computers to be installed as 7600 and CRAY replacements can be expected to perform at this speed. The data rates possible on today's MSSs vary from 0.005 to 0.012 gigabits/s. These rates are at least an order of magnitude slower than those of the host channel. Such rates place too great a burden on any migration scheme. Further, the growth of NCAR's storage requirements cannot be gracefully accommodated on present devices.

NCAR Local Network

The NCAR local computer network has been under development by the Network Group consisting of Gilbert Green, B-Lynn Irwin, Marc Nelson, and Darrell Holley. A preliminary version of the network software was in service beginning in February 1979 and was used to test design concepts for more advanced versions involving all the SCD computers. The network will allow replacement of the 7600-centered configuration with a distributed network of interactive, batch, and special-purpose processors. This network, with redundant data paths and elements from the original hardware/software links, should provide excellent access to each processor available to the SCD user community.

General Description. The network is composed of an assortment of processors and operating systems attached to two high-speed data trunks through the mechanism of NSC adapter boxes. Each NSC adapter box connects a data channel on a processor to one or more data trunks. The boxes differ only at the processor channel interface board(s) and are otherwise identical. This provides the SCD with a common method of creating an interface between any processor and the network. All connections cost the same, and a standard device is available to connect any processor. One of the few restrictions for connecting a candidate processor to the network is its ability to devote memory resources to the network software.

The network software consists of a group of user-level programs that manage most of the network activity and some system-level routines to manage the network channel. This software provides a file- and job-transport mechanism that can be extended to allow intertask communication between processors. These programs were designed to be independent of the operating systems of the host processors and to require minimal operating system connections.

The largest of these programs, Network Control Program (NCP), has been written in IFTRAN, a fairly portable FORTRAN dialect. NCP has been constructed so that the processor-dependent parts are in separate subroutines. This feature enhances portability of NCP onto machines currently available to the network or facilitates the installation of NCP on new processors. Most of the machine-dependent parts are short and well defined although large in number. NCP causes files, datasets, or volumes to move from one processor to another. It manages the communication with the network and multiplexes the single physical data channel among multiple users on multiple machines.

NCP uses a table of control information called a "control segment" to initiate the transmission of information that is in a network standard format. To aid in the generation of the control segment and cause file conversion to a standard format, two additional programs are provided: Pre- and Post-Processor. These are not as readily portable from processor to processor because they must deal with each processor's file format and job control language. Additionally, FORTRAN-callable conversion routines and control-segment generators will be made available.

Installation Experiences. Prior to 1980, all these routines were developed on a stand-alone SEL 32/55 processor that isolated the network activity from the systems supporting our user community. In the first quarter of 1980, we began installing the software on the DEC PDP 11/70s that provide interactive computing to SCD staff. By the summer of 1980, the network was operational between the PDP 11/70s and the SEL 32/55. This service was provided within the SCD only. Development of NCP routines proceeded, several difficult problems were solved, and the community of users outside of the SCD were not affected by this phase of check-out.

By late September we were in a position to begin installation on the large batch machines. Much of the direct modifications to the CRAY software system were in place and tested as part of the TMS-4-to-CRAY link effort. It was planned to use these modifications for both endeavors and thereby minimize the impact of system testing on the users as well as reduce the overall amount of code to be generated and tested. By the end of 1980 the network included the following computers: an SEL 32/35, the SEL 32/55, the 7600, the CRAY, and both of the PDP 11/70s. This version of the network is now in restricted use by SCD personnel and by the Atmospheric Chemistry and Aeronomy Division to link their 32/35 to both the CRAY and the 7600. The MODCOMP II software has been extensively reworked to accept the network modules, but we are undecided about completing the effort because of the amount of user disruption so close to the end of the MODCOMP's life. Another consideration is the necessity of installing the software on the IBM 4341, which will eventually replace the MODCOMP. The DICOMED software has been tested, and file transmission functions as originally planned. However, special file conversion is needed and is not complete at this time.

Results. The network is now at a stage of advanced testing by a small user community and further development and cleanup will occupy our time in 1981. Also, problems with host software have appeared, especially with the CRAY, which must be corrected before we can generally use the network. In particular, issues tangential to the network, but necessary for its success, must be addressed. These issues are the variety of job control mechanisms particular to each network host and their file characteristics. Some common job control and file identifiers are needed to simplify use of the network.

OPERATIONS SECTION

The SCD Operations staff is a multifaceted group whose primary purpose is to provide fast, reliable computing services to the scientific community at NCAR and its associated organizations.

The staff, consisting of 26-3/4 full-time equivalent positions, is divided into five operating groups under two assistant managers, one for Computer Operations, the other for Computer Maintenance.

The Computer Operations staff provides computer service 24 hours a day throughout the year. Personnel are scheduled so that reasonable turnaround is available relative to the computer workload. There is an Operations supervisor in charge at all times who is responsible for the overall operation of the computer room. The staff assists users in solving minor problems that arise in the day-to-day program submission over the counter as well as in remote job entry, helping prepare program and data decks on a limited basis. Assistance to users is also given in operational run procedures, tape assignment, and film processing, as well as in the operation of the on-site remote access terminal.

The work characteristics of the shifts are as follows:

8:00 a.m. - 6:00 p.m.: The emphasis is on check-out and debugging runs.

6:00 p.m. - 12:00 midnight: The larger (production) jobs are run. Check-out and debugging jobs are run periodically.

12:00 midnight - 6:00 a.m.: The larger (production) jobs are run. Special scheduled runs for short-term users are processed. Check-out and debugging jobs are run periodically.

6:00 a.m. - 8:00 a.m.: Monday through Friday this period is reserved for preventive maintenance and systems software check-out. On Saturday and Sunday this time is set aside for systems software check-out.

All shifts engage in the following activities, which are not necessarily visible to users: monitor all systems for efficient and reliable performance; schedule job flow; diagnose equipment malfunctions, notify appropriate SCD personnel and customer engineers when problems arise and take corrective action; read in program decks; remove, sort, and shelve program paper listings and punched output; mount both half-inch and mass storage (TBM) tapes on drives; perform TMS-4 volume maintenance; clean tape drives; change printer ribbons and paper; clean and certify tapes; process and distribute microfilm and microfiche, on other than prime shifts; maintain liaison with and assist users, keeping them updated on the status of the system; assist remote terminal users by phone; keep system and hardware performance logs and update manuals.

Computer operators are each assigned prime responsibility for a particular system, for example, the CRAY, 7600, TMS-4, DICOMED, PDP 11/70s, SEL, and

MODCOMP. This includes assisting in training other operators, system documentation, and changes to on-line instruction manuals.

Operator instruction manuals have been designed for all systems for which the Operations Section is responsible. Manuals have been compiled by the staff and entered on-line to the interactive system by the Data Entry section. This allows quick changes to be made to the manuals when new operational procedures are implemented. Printed copies have also been generated and are kept at each work station for instant reference.

Shift supervisors provide on-the-job training for operators on a year-round basis. In addition, operators attend courses in supervisory skills, as well as vendor-conducted computer hardware classes. Video self-taught classes in computing principles were also offered to all operators.

Operations management personnel have been involved in various computer equipment procurement activities, including those for the IBM I/O satellite, a Port Contention Device, modems for new terminal lines, and a 300 MB disk, for added storage for the DICOMED computer output microfilm (COM) device.

Planning for computer and associated equipment installation and arrangement related to the various remodeling projects completed in 1980 were also the responsibility of Operations management.

During 1980 the activities of the Operations staff can best be summarized by the following monthly production statistics:

700,000 computer output pages printed

800,000 frames of microfilm processed

300,000 computer cards punched

4,350 half-inch tapes mounted

1,350 mass storage (TBM) tapes mounted

400 packages of computer output (film, paper and tape) mailed

24 sets of available software processed and mailed

Data Entry

The Data Entry section of Computer Operations is a small, versatile group, using both word processing equipment and the more traditional keypunch and verifying machines for many purposes in support of scientific, programming, and operations personnel. The work of the group is divided about equally between these two forms of data entry.

Keypunch and verifying machine work includes formatted and unformatted source data representing books, technical reports, computer programs, field experiments, and statistical data. Source data for the word processors is even more varied, consisting in addition to the above of memos, letters, manuals, forms, tables, questionnaires, and schedules.

Additional user support is provided by the Data Entry group through advice on efficient formatting, instruction in machine usage and program card preparation, and the maintenance of a well stocked and pleasant working environment for keypunch and minicomputer terminal users in the data entry area.

The group is also responsible for the operational status of all data entry equipment, performing minor maintenance and repairs and notifying the concerned contractors of more major repair needs.

Computer Graphics

Another component of the Operations group is the Computer Graphics section, composed of one supervisor and two technicians. The responsibilities of this section include the processing of microfilm and microfiche generated by a DICOMED COM device and an on-line DD80 35 mm microfilm camera. Capabilities of the system include production of 35 mm raster and vector microfilm, 105 mm microfiche, as well as 16 mm roll film.

Output from these devices is developed, processed, and distributed to users on an hourly basis during prime shift hours and in two-hour intervals on night and weekend shifts. On other than prime shifts, operations supervisors accommodate urgent film processing needs of users, depending on work load.

A quality control program has been initiated to assure stabilization of the chemistry in the Allen film processor and to allow quick diagnosis of problems with film or chemicals.

Seventy-five microfilm reader/printers, located throughout the NCAR establishment in various sites in and near Boulder, are serviced and maintained by the Computer Graphics staff. Several microfiche reader/printers were added this year, to accommodate increasing microfiche use.

Operations Support - Computer Data Base Management and Accounting

Tracking and recording computer use, and generating statistical reports for the use of SCD management, NCAR management, and the NSF, are the main responsibilities of this part of the Operations Support group. Accounting and data-base statistical records enhance the ability to plan kind and amount of computer augmentation, both over the short and long ranges. The integrity of the data and security against destruction are two of the prime considerations in the maintenance and enhancement of these records.

Detailed computer accounting records are updated and posted daily for the information of users. Among the information listed is computer use by project number, showing computer resource units authorized, used to date, and remaining in each account.

Similar information is sent monthly to the remote job entry (RJE) sites. Other information generated includes visitor (non-NCAR) computer use, as well as project categorization by scientific area of interest.

Operations Support - Tape Libraries

Magnetic tape, made of Mylar plastic and coated on one side with iron oxide, is a device admirably suited to the collection and storage of computer-produced scientific data.

Two types of magnetic tapes are used for computer data storage in the Scientific Computing Division. Both types serve multiple purposes for SCD users, and both types may be erased and reused many times. The first type is a half-inch wide computer reel tape. When fully recorded, a tape of normal size, 2,400 ft long, can contain over 4 million 60-bit "words" of information. Each tape contains data belonging to only one user.

Features of half-inch tapes that make them useful to the modes of computer operation at NCAR are their portability, durability, and reliability. Scientists at remote sites can process data on NCAR's large computers, then ship the data tapes to their own sites for further processing and evaluation. Users find half-inch tapes convenient and easy to use, and tapes provide a means to store programs and data permanently if necessary.

SCD maintains a half-inch tape library limited to 40,000 tapes; it recycles tapes and tape numbers to prevent proliferation of tapes. There is also an off-site tape library to accommodate less used tapes. The library will shrink with the introduction of 6,250-bpi tape drives and the conversion of some current tapes to this density.

The second type of magnetic media used by SCD Operations is video tape two inches wide and 3,800 feet long. About 200 of these tapes are currently in use on the AMPEX TMS-4. The data-holding capacity of each reel is almost 44 billion bits, or the equivalent of about 200 fully packed 1,600-bpi half-inch tapes. Each tape may contain data belonging to many users. In the SCD computer environment, some of these tapes are reserved for archival storage, and some are available to large users to consolidate data being processed. About 32,000 data "volumes" are either archived or in current use. Most data stored on TMS-4 tapes are subject to quarterly purging if not used. This policy helps maintain a manageable tape library in terms of speed of access and convenience for the user.

Computer Maintenance Group

The Computer Maintenance Group (CMG) has responsibility for the maintenance of all network hardware, as well as numerous computer mainframes and terminals. Included in these activities are the following functions:

1. Total responsibility for TMS-3
2. Maintenance of the DEC equipment installed in TMS-4
3. Maintenance of all terminals installed within the SCD (about 70)
4. Any terminal wiring installation within NCAR
5. All RJE hardware and communications equipment
6. Coordination of all contracted computer maintenance.

The members of this group also advise and contribute to contract actions, procurement activities, users' groups, and other related functions.

The SCD Maintenance Group

The following is an overview of the data communications hardware in SCD; the installation and upkeep of this equipment; and the services the SCD Maintenance Group (SCDMG) provides to the NCAR RJE user.

At present all RJE tasks are handled by a MODCOMP II computer. The jobs are passed on to the 7600. This may be augmented with the implementation of the network in the near future. The MODCOMP presently handles calls from 32 ports or lines. Eight of these are asynchronous at speeds of 300 and 1,200 baud. The remaining 24 lines are either CDC UT200, or IBM 2780/3780 synchronous protocol, at speeds of 2,000, 2,400, and 4,800 baud. We support dialup, leased, and hardwired data communications. The MODCOMP hardware has been recently updated to support baud rates of 9,600 bps and line expansion above the present 32. The software is presently under development to utilize this upgrade.

We have digital "mips" (modem interface patch panels) between the 32 ports of the MODCOMP and the modems that interface to the telephone lines. These mips allow the SCD Maintenance Group to monitor data communications between the RJE user and NCAR, as well as to switch a modem or MODCOMP port in the case of hardware failure.

The SCDMG is using a Spectron 901 Data Scope to monitor these lines. We assist the NCAR user on hardware as well as protocol problems. When a user notifies us of a suspected problem; we will set up a session with the user and monitor line connection as well as hardware and software protocol.

We support the user with recommendations on modems and line speeds and provide protocol support for new equipment. On the Bell modems we can run in a stand-alone mode as well as perform modem-to-modem tests with the user. This is done when either the modem or phone line is suspected to be faulty. The SCDMG also works with the telephone company to isolate bad lines or modems.

The SCDMG evaluates new modems and communication advances as they are offered by the vendors. We then work with the SCD Data Communications Policy Committee on the purchase of modems that we feel will best support the user community. This year we have added a Vadic 3467 modem to increase our support of 1,200-baud asynchronous communications. This modem will support Bell 212A, as well as Vadic 3400 series modems. We have also added two of the UDS RM201C modems. This increased our 2,400-baud service to the user in both UT200 and bisynchronous protocol. The Spectron Data Scope was updated to a 901D to enable us to do protocol emulation and monitor and record the higher transfer rates now available to us.

The SCDMG is presently involved in the planning and installation of hardwired data communications between the I/O Satellite (IBM 4341) computer and the various facilities throughout the Mesa building. We are also involved in the future purchase of a port selection device (PSD). The PSD will interface between the user and the IBM 4341, or the MODCOMP computer and possibly one or two other computers in the facility. The PSD will offer the user even greater flexibility and service than is now available.

ADVANCED METHODS GROUP

The Advanced Methods Group plays a dual role at NCAR. It performs research in areas of mathematics that are directly applicable to the atmospheric sciences. It also provides consultation to both internal and external users of the NCAR computers. The members of the group include Paul Swarztrauber and Gerald Browning as full time employees. Swarztrauber is on a one-year leave of absence as of 1 September 1980. The group also includes John Gary (University of Colorado) as a part-time consultant. Gary is a full professor of computer science at the University of Colorado at Boulder and consults at NCAR approximately one day a week. Roland Sweet was also a consultant to the Advanced Methods Group prior to 1 September 1980, when he accepted a position with the Scientific Computing Division at the National Bureau of Standards (NBS) in Washington, D.C.

A manuscript by Paul Swarztrauber entitled "On the spectral approximation of discrete scalar and vector functions on the sphere" appeared in the December 1979 issue of the Society of Industrial and Applied Mathematics (SIAM) Journal on Numerical Analysis. The methods that were developed in that paper have been implemented in a software package for representing functions in terms of spherical harmonics.

Another manuscript by Swarztrauber entitled "The solution of tridiagonal systems on the CRAY-1" appeared in the recent two-volume issue on supercomputers by Infotech International, Ltd. By using an efficient variant on the Cramer's rule, it was shown that an arbitrary tridiagonal system of equations with order n could be solved in $O(\log n)$ operations on a parallel computer with n processors. Research in this area has helped to provide state-of-the-art consulting to NCAR on numerical algorithms that are particularly adapted to parallel or vector computers like the CRAY-1.

Swarztrauber and Akira Kasahara (Atmospheric Analysis and Prediction Division [AAP]) have recently completed a software package for computing the normal modes of the linearized shallow-water equations on a sphere. It consists of about 1,500 lines of code and took about two months to complete. A description of the theory and software will be submitted to the new SIAM Journal on Scientific and Statistical Computing. Last year Swarztrauber was selected as associate editor for this journal. This work on the shallow-water equations will aid atmospheric scientists in two ways: First, it will provide a facility to modelers for empirical stability analysis, i.e., the modelers can code their method (spectral or finite difference) for the linearized shallow-water equations. They can then initialize with a mode corresponding to any wave number and compare model results with the exact results available from the software. The second use of the software is to develop spectral models of complex dynamical systems on the sphere using the Hough functions as a basis.

This past year, Swarztrauber also completed a package of fast Fourier transforms called FFTPACK. The package is vectorized on the CRAY and includes 18 programs for various Fourier transforms including the real, complex, and standard symmetric transforms such as sine and cosine, etc. The package consists of approximately 2,000 lines of code. FFTPACK is currently in use at NCAR and several other laboratories including NBS Washington, Los Alamos, Sandia Corp., and in the SLATEC mathematical library developed by the Department of Energy laboratories.

Swarztrauber's manuscript entitled "The approximation of vector functions and their derivatives on the sphere" will appear in the April 1981 issue of the SIAM Journal on Numerical Analysis. This is a special issue that is dedicated to Robert Richtmyer on his 70th birthday. In this paper it is shown that many terms in a partial differential equation on the sphere are unbounded at the poles, which creates serious computational difficulties. However, the unbounded terms are identified and grouped into bounded expressions that can be computed in a stable way using the spectral method.

Browning, Kasahara, and Heinz Kreiss (California Institute of Technology) have applied the bounded derivative method to initialize shallow-water flow in a channel both in the midlatitudes and in the equatorial region. In the former case, they showed that the initialization scheme obtained by quasi-geostrophy theory is just a special case of the bounded-derivative method. In the latter case, quasi-geostrophy theory does not apply and so the initialization problem has not been well understood. However, the bounded derivative method was also applied to this case and shed light on some of the initialization problems for that region, i.e., the need for the inclusion of extra terms in the nonlinear balance equation and for increased numerical accuracy to handle the extra cancellation in the computation of the divergence.

Browning and Kreiss have been working on the application of the bounded-derivative method to shallow-water flow in the case of open boundaries. They have proven that well-posed open-boundary conditions can be chosen so that the solution on the interior of the region is correctly computed. They also show that care must be taken with respect to the boundary data. These results do not apply to the primitive equations, as they are not a symmetric hyperbolic system. However, they can be applied to the Eulerian equations. In that case Browning and Kreiss have shown how to derive a new system of equations that describes the large scale atmospheric motions very accurately and is well posed for the open-boundary problem (a trait not possessed by the primitive equations).

Gary has consulted mainly in the area of computational fluid dynamics; however, he has been consulted on both software and hardware in areas of computer science as well as applied mathematics.

Currently, most of his effort at NCAR is devoted to writing two codes for atmospheric chemistry problems which also involve advection and diffusion. The first code (about 1,200 lines) is for parabolic systems in one-space dimension and time. It is based on a conventional difference scheme in space and the method of lines for the time approximation. He is helping Raymond Roble, Barbara Emery (both of the Atmospheric Chemistry and Aeronomy Division), and Dave Anderson (National Oceanographic and Atmospheric Administration) use this code. He has also written a second code (about 2,000 lines) for the same type of problem in two spatial dimensions. He developed a new numerical method for this problem. The problem is difficult because the equations are very stiff and in two dimensions. The method and code are still under development. This code is being used by Roble, David Rusch (Laboratory for Atmospheric and Space Physics), and James Kasting (Advanced Study Program).

In addition, over the last few years Gary has been involved in building up the NCAR library of mathematical routines, especially the differential equation routines. He has obtained and tested some of these routines and assisted people with their use.

More recently, he has been developing a multigrid package for large elliptic problems on the CRAY. Such problems commonly occur in both meteorology and oceanography. Gary is investigating the multigrid method for solving elliptic problems on irregular regions. He has also made extensive modifications of the stiff two-dimensional solver for an atmospheric electricity model under development by Israel Tzur (ACAD).

During the year Sweet and Swarztrauber continued work on their package of subroutines for solving elliptic partial differential equations called FISHPACK. An earlier version of this package was documented in the NCAR technical report, Efficient FORTRAN Subprograms for the Solution of Elliptic Partial Differential Equations published in 1975. About 1,200 copies of this report have been provided on request, and over 300 copies of the package itself have been distributed around the world. FISHPACK has been expanded considerably over the years. The current version contains 20,000 lines of code that provides solutions in cartesian, cylindrical, and spherical coordinates to problems subject to all of the standard boundary conditions. The code is specifically written for geophysicists and includes some three-dimensional programs as well as programs for staggered grid problems that are frequently encountered in atmospheric research. A description of FISHPACK appeared in the September 1979 issue of the ACM journal, Transactions on Mathematical Software. Sweet has recently co-authored another article in the December 1980 issue of this journal with M. Machura (Institute of Nuclear Research, Otwack-Swierk, Poland) entitled "A survey of software for partial differential equations."

Before leaving NCAR, Sweet spent a large part of his time consulting with William Holland in AAP. Sweet adapted the fast elliptic solvers to a problem that is defined on an irregular region (an ocean basin). As a result, he has increased the speed of the model by a factor of 50, thus saving a substantial amount of computing time on the CRAY. However, the resolution of the model was later increased, and a different approach was needed. Sweet worked on a method to reduce the storage requirements and is continuing this research at NBS.

The entire group spends a portion of their time consulting. Although it is not reasonable to describe all of these encounters, we illustrate the importance of this function by several examples. The first example involves a visiting programmer who had spent a number of days trying to get a relaxation scheme to converge for what his scientist-employer called a second-order "elliptic" boundary value problem. When the program failed to achieve convergence toward solutions, he came to the AMG for help. We were able to show that the equation was hyperbolic and, in fact, could be derived from a first-order equation. Thus the boundary conditions were overspecified, and it was not surprising that any iteration scheme would diverge.

In the second example, a scientist approached us with a mixed elliptic/hyperbolic problem. He was having difficulty solving the problem by relaxation methods and asked for our help. We first discovered that a boundary condition he was using on the line separating the elliptic and hyperbolic domains was incorrectly derived and that there should be no boundary condition on that line. We then suggested that he use the Yale Sparse Matrix Package to solve the problem directly. Although we addressed the question of uniqueness for this problem, the irregularity of the region prevented a detailed analysis. Thus we suggested that he test the stability of his solution by varying both his domain and right-hand side.

Visitors and Users of the Scientific Computing Division in 1980

User_Name	Affiliation	Start Date	End Date	Project	Days
ACKERMAN, BERNICE	ILLINOIS WATER SURVEY	0	0	35481005	0
ACKERMAN, BERNICE	ILLINOIS WATER SURVEY	0	0	35481007	0
AHLQUIST, JON	UNIVERSITY OF WISCONSIN	0	0	35381011	0
ALPERT, JORDAN	UNIVERSITY OF MIAMI-MIAMI	0	0	35191007	0
ANTHES, RICHARD A.	PENNSYLVANIA STATE UNIVERSITY	0	0	35281008	0
ASTLING, ELFORD	UNIVERSITY OF UTAH	0	0	35351005	0
ATWATER, MARSHALL	CTR FOR ENVIRONMENT AND MAN	0	0	36121004	0
AYRES, THOMAS	UNIVERSITY OF COLORADO	0	0	35071058	0
BAER, F.	UNIVERSITY OF MICHIGAN	0	0	35201006	0
BARBER, P.	UNIVERSITY OF UTAH	800402	800404	35351008	3
BAUER, ROGER	COMPASS SYSTEMS, INC	800609	800621	36651000	13
BENTON, NED	UNIVERSITY OF COLORADO	0	0	35071054	0
BERNHARDT, PAUL A.	STANFORD	0	0	35661009	0
BESSEY, ROBERT J.	UNIVERSITY OF WYOMING	0	0	35711010	0
BIRCHFIELD, G. EDWARD	NORTHWESTERN UNIVERSITY	800618	800817	36101002	61
BLECK, R.	UNIVERSITY OF MIAMI-MIAMI	0	0	35191008	0
BOSART, LANCE	STATE UNIVERSITY OF NEW YORK	801122	801130	35251003	9
BOVILLE, BYRON	UNIVERSITY OF WASHINGTON	0	0	35371007	0
BRAHAM, JR., ROSCOE R.	UNIVERSITY OF CHICAGO	0	0	35061024	0
BRETHERTON, FRANCIS P.	WOODS HOLE OCEANOGRAPHIC INST.	0	0	7013016	0
BUSINGER	UNIVERSITY OF WASHINGTON	0	0	44093025	0
CANFIELD, R.	UNIV. OF CALIFORNIA-SAN DIEGO	0	0	36011003	0
CASTLEMAN, A.W.	UNIVERSITY OF COLORADO	0	0	35071064	0
CHEN, ROBERT	STANFORD	0	0	35661017	0
CHEN, TSING-CHANG	IOWA STATE UNIVERSITY	0	0	35461004	0
CHEN, TSING-CHANG	IOWA STATE UNIVERSITY	800901	810901	35461003	366
CHEN, TSING-CHANG	IOWA STATE UNIVERSITY	801211	801231	35461006	21
CHERVIN, ROBERT	UNIVERSITY OF WISCONSIN	0	0	3013705	0
CHIPMAN, ERIC	UNIVERSITY OF COLORADO	0	0	35071061	0
CHOLLET, JEAN PIERRE	UNIVERSITE DE GRENOBLE	800624	800817	36711000	55
CHYLEK, PETR	STATE UNIVERSITY OF NEW YORK	0	0	35251007	0
COTTON, WILLIAM R.	COLORADO STATE UNIVERSITY	0	0	35081067	0
COTTON, WILLIAM R.	COLORADO STATE UNIVERSITY	0	0	35089012	0
COX, STEPHEN	COLORADO STATE UNIVERSITY	0	0	35081030	0
COX, STEPHEN	COLORADO STATE UNIVERSITY	0	0	35081040	0
COX, STEPHEN	COLORADO STATE UNIVERSITY	0	0	35081041	0
CRAVENS, THOMAS E.	UNIVERSITY OF MICHIGAN	0	0	35201021	0
CUPERMAN, SAMI	TEL AVIV UNIVERSITY	0	0	35881000	0
CURRY, JAMES	MASSACHUSETTS INST. OF TECH.	0	0	35171018	0
DALY, STEVE	UNIVERSITY OF CHICAGO	0	0	35061026	0
DANIELSEN, EDWIN	OREGON STATE UNIVERSITY	0	0	35271005	0
DANIELSEN, EDWIN	OREGON STATE UNIVERSITY	0	0	35271006	0
DAS, PHANINDRAMOHAN	TEXAS A+M UNIVERSITY	0	0	35311024	0
DAVEY, MICHAEL	UNIVERSITY OF WASHINGTON	0	0	35371014	0
DELUISI, JOHN	NOAA	0	0	35561000	0
DOLE, RANDALL	MASSACHUSETTS INST. OF TECH.	0	0	35171020	0
DOMM, JEFF	MASSACHUSETTS INST. OF TECH.	0	0	35171019	0
EBERLY, J.H.	UNIVERSITY OF ROCHESTER	800116	800220	36521000	36
EDMON, HAROLD, JR.	UNIVERSITY OF WASHINGTON	0	0	35371012	0
EMANUEL, KERRY	UCLA	0	0	35681006	0
ESPOSITO, LARRY	UNIVERSITY OF COLORADO	0	0	35071059	0
ESTOQUE, M.	UNIVERSITY OF MIAMI-C. GABLES	0	0	35501008	0

EVERHART, EDGAR	DENVER UNIVERSITY	0	0	35101010	0
FERNALD, FRED	DENVER UNIVERSITY	0	0	35101019	0
FESEN, CASSANDRA	UNIVERSITY OF MICHIGAN	801023	801107	35201033	16
FINGERHUT, WILLIAM	COLORADO STATE UNIVERSITY	0	0	35081057	0
FOURNIER, JEAN-LOUIS	JOHNS HOPKINS UNIVERSITY	0	0	35151006	0
FRISCH, URIEL	HARVARD UNIVERSITY	0	0	35121018	0
FUA, DANIELE	UNIVERSITY OF COLORADO	0	0	35071092	0
GAL-CHEN, TZVI	UNIVERSITY OF TORONTO	0	0	35341002	0
GARDNER, ROBERT	UNIVERSITY OF COLORADO	0	0	35071099	0
GARY, JOHN	UNIVERSITY OF COLORADO	0	0	35071042	0
GATES, LAWRENCE	OREGON STATE UNIVERSITY	0	0	35271008	0
GEISLER, JOHN	UNIVERSITY OF MIAMI-C. GABLES	0	0	35501013	0
GEISLER, JOHN	UNIVERSITY OF MIAMI-MIAMI	800616	800621	35191012	6
GELLER, MARVIN A.	UNIVERSITY OF MIAMI-MIAMI	0	0	35191002	0
GIAMPAPA, MARK	UNIVERSITY OF COLORADO	0	0	35071094	0
GOLDMAN, AHARON	DENVER UNIVERSITY	0	0	35101018	0
GOLDMAN, AHARON	DENVER UNIVERSITY	0	0	35101025	0
GRAMS, GERALD	GEORGIA TECH	0	0	36511000	0
GRANT, L. O.	COLORADO STATE UNIVERSITY	0	0	35081042	0
GRAY, WILLIAM M.	COLORADO STATE UNIVERSITY	0	0	35081052	0
GRIFFITH, CECILIA	COLORADO STATE UNIVERSITY	0	0	35081066	0
GUSTAFSON, CARL	UNIVERSITY OF COLORADO	800813	810530	35071080	291
HAGSTROM, STANLEY	UNIVERSITY OF CALIF.-BERKLEY	0	0	35811002	0
HAIDVOGEL, DALE	HARVARD UNIVERSITY	801227	810108	35121011	13
HAIDVOGEL, DALE	WOODS HOLE OCEANOGRAPHIC INST.	800322	800408	35781010	18
HAN, YOUNG-JUNE	OREGON STATE UNIVERSITY	0	0	35271010	0
HARTMANN, DENNIS	UNIVERSITY OF WASHINGTON	0	0	35371010	0
HAUSTEIN, JAMES	TEXAS A+M UNIVERSITY	800512	800523	35311031	12
HENDERSHOTT, M. C.	SCRIPPS INST. OF OCEANOGRAPHY	0	0	35631003	0
HEYMSFIELD, GERALD	UNIVERSITY OF CHICAGO	0	0	35061022	0
HJELMFELT, MARK	UNIVERSITY OF CHICAGO	800107	800331	35061025	85
HOBBS, PETER V.	UNIVERSITY OF WASHINGTON	0	0	35371017	0
HOLLOWAY, GREG	SCRIPPS INST. OF OCEANOGRAPHY	0	0	35631006	0
HSU, CHIH-PING FLOSSIE	UNIVERSITY OF WASHINGTON	0	0	35371004	0
HSU, HSIAO-MING	UNIVERSITY OF MICHIGAN	800721	800821	35201032	32
HUDSON, MARY	UNIVERSITY OF CALIF.-BERKLEY	0	0	35811001	0
HUMMER, D. G.	UNIVERSITY OF COLORADO	0	0	35071006	0
HUMMER, D. G.	UNIVERSITY OF COLORADO	0	0	35071077	0
ICKE, VINCENT	UNIVERSITY OF MINNESOTA	800409	800415	35211002	7
ILLING, RAINER	UNIVERSITY OF COLORADO	0	0	35071098	0
INAN, UMRAN S.	STANFORD	0	0	35661007	0
INAN, UMRAN S.	STANFORD	0	0	35661015	0
INAN, UMRAN S.	STANFORD	800524	800627	35661013	35
JACOBS,CLIFFORD	CTR FOR ENVIRONMENT AND MAN	0	0	36121002	0
JAIN, BABU	FLORIDA A+M UNIVERSITY	800820	800907	36061001	19
JOYCE, GLENN R.	UNIVERSITY OF IOWA	0	0	35471001	0
KAO, S.K.	UNIVERSITY OF UTAH	0	0	35351009	0
KASAHARA, AKIRA	NEW YORK UNIVERSITY	0	0	9013001	0
KEEN, CECIL S.	UNIVERSITY OF CAPE TOWN	0	0	36611000	0
KEEN, RICHARD	UNIVERSITY OF COLORADO	0	0	35071050	0
KELCH,WALTER	UNIVERSITY OF COLORADO	0	0	35071048	0
KELLY, ROBERT	UNIVERSITY OF CHICAGO	800630	800706	35061032	7

KLEIN, RICHARD I.	BRANDEIS UNIVERSITY	0	0	35761002	0
KLEIN, RICHARD I.	UNIVERSITY OF COLORADO	0	0	35071039	0
KNUTI, JOHN	USSR ACAD OF SCIENCES	0	0	36581001	0
KRAICHMAN, ROBERT	NO AFFILIATION	0	0	35791001	0
KRISHNAMURTI, T. N.	FLORIDA STATE UNIVERSITY	0	0	35111040	0
KRISHNAMURTI, T. N.	FLORIDA STATE UNIVERSITY	800118	800203	35111038	17
KRISHNAMURTI, T. N.	FLORIDA STATE UNIVERSITY	800724	800727	35111034	4
KUO, H. L.	UNIVERSITY OF CHICAGO	0	0	35061031	0
KURUCZ, R.	SMITHSONIAN	800912	800919	35651000	8
LANGER, STEVEN	STANFORD	0	0	35661005	0
LAU, WILLIAM	NAVAL POSTGRADUATE SCHOOL	800610	800617	35981001	8
LEDREW, ELLSWORTH	U OF WATERLOO	800617	800630	36671000	14
LEE, DONG KYOU	UNIVERSITY OF WISCONSIN	0	0	35381010	0
LEVINE, RANDOLPH	HARVARD UNIVERSITY	0	0	35121015	0
LEVINE, RANDOLPH	HARVARD UNIVERSITY	800801	800819	35121010	19
LEWIS, FRED	UNIVERSITY OF UTAH	0	0	35351010	0
LOESCH, ARTHUR Z.	STATE UNIVERSITY OF NEW YORK	800722	800801	35251004	11
LONDON, RICHARD	SMITHSONIAN	0	0	35651001	0
LONDON, RICHARD	UNIVERSITY OF MIAMI-MIAMI	0	0	35191009	0
LOVELL, CLIFTON	SCIENCE APPLICATIONS, INC.	800922	800930	36481000	9
MAHRT, LARRY	OREGON STATE UNIVERSITY	0	0	35271011	0
MCCOMAS, II, CHARLES H.	WOODS HOLE OCEANOGRAPHIC INST.	0	0	35781008	0
MCCORMICK, STEPHEN	COLORADO STATE UNIVERSITY	0	0	35081053	0
MCCRAY, RICHARD	UNIVERSITY OF COLORADO	800218	800310	35071081	22
MCGUIRK, JAMES	TEXAS A+M UNIVERSITY	800424	800502	35311029	9
MCKEE, THOMAS B.	COLORADO STATE UNIVERSITY	0	0	35081029	0
MEGILL,LAWRENCE	UTAH STATE UNIVERSITY	0	0	35361007	0
MENEGUZZI, MAURICE	OBSERVATOIRE DE NICE	800827	801031	36701000	66
MIHALAS, BARBARA	COLORADO STATE UNIVERSITY	0	0	35081037	0
MOHNEN, VOLKER A.	STATE UNIVERSITY OF NEW YORK	0	0	35251006	0
MOLINARI, JOHN	STATE UNIVERSITY OF NEW YORK	800401	800406	35251008	6
MOORE, DENNIS	NOVA UNIVERSITY	800701	800704	35571001	4
MUELLER, EUGENE	UNIVERSITY OF ILLINOIS	0	0	35141015	0
MULLAN, DERMONT J.	BARTOL RESEARCH FOUNDATION	0	0	36141000	0
MURAKAMI, MASATO	CORNELL UNIVERSITY	0	0	35091005	0
MUTAKAMI, TAKIO	UNIVERSITY OF HAWAII-HONOLULU	0	0	35131004	0
NAGY, ANDREW	UNIVERSITY OF MICHIGAN	0	0	35201028	0
NAVATO, ALFREDO	MASSACHUSETTS INST. OF TECH.	800929	801003	35171024	5
NEITZEL, G. PAUL	ARIZONA STATE UNIVERSITY	800922	800924	36751000	3
NELSON, S. CRAIG	UNIV. OF CALIFORNIA-SAN DIEGO	800317	800406	36011002	21
NGHIEM-PHU, LAN	UNIVERSITY OF MIAMI-MIAMI	0	0	35191006	0
NICHOLSON,SHARON	CLARK UNIVERSITY	0	0	36681000	0
NORCROSS, DAVID	TEXAS A+M UNIVERSITY	0	0	35311013	0
O"BRIEN, J.	FLORIDA STATE UNIVERSITY	800321	800331	35111044	11
O"BRIEN, J.	FLORIDA STATE UNIVERSITY	800815	800825	35111043	11
OOYAMA, K.	UNKNOWN	0	0	33013035	0
ORSZAG, S. A.	MASSACHUSETTS INST. OF TECH.	0	0	35171017	0
ORVILLE, HAROLD	SOUTH DAKOTA SCHOOL OF MINES	0	0	35641012	0
OTTO-BLIESNER, BETTE	UNIVERSITY OF WISCONSIN	800210	800213	35381006	4
OTTO-BLIESNER, BETTE	UNIVERSITY OF WISCONSIN	800927	801001	35381005	5
OWENS, W. BRECHNER	WOODS HOLE OCEANOGRAPHIC INST.	0	0	35781007	0
PAEGLE, JAN	UNIVERSITY OF UTAH	0	0	35351006	0

PAEGLE, JAN	UNIVERSITY OF UTAH	800802	800807	35351007	6
PASKEN, ROBERT	ST. LOUIS UNIVERSITY	0	0	35301004	0
PATEL, VITHALBHAI L.	DENVER UNIVERSITY	800930	810930	35101024	366
PEARSON, CARL	UNIVERSITY OF WASHINGTON	0	0	35371006	0
PELTIER, W. R.	UNIVERSITY OF TORONTO	800521	800627	35341000	38
PESKIN, RICHARD	RUTGERS UNIVERSITY	0	0	36151000	0
PESKIN, RICHARD	RUTGERS UNIVERSITY	0	0	36151001	0
PETERS, L. K.	UNIVERSITY OF KENTUCKY	0	0	35971001	0
PIELKE, ROGER A.	UNIVERSITY OF VIRGINIA	0	0	35691005	0
PLOOSTER	DENVER UNIVERSITY	0	0	35101012	0
PRATHER, MICHAEL J.	HARVARD UNIVERSITY	0	0	35121019	0
PROCTOR, FRED H.	TEXAS A+M UNIVERSITY	800827	800903	35311030	8
RAO, G. V.	ST. LOUIS UNIVERSITY	0	0	35301003	0
REES, M. H.	UNIVERSITY OF ALASKA	0	0	35011000	0
REITER, ELMAR R.	COLORADO STATE UNIVERSITY	0	0	35081034	0
REITER, ELMAR R.	COLORADO STATE UNIVERSITY	0	0	35081056	0
RICHARDS, PHILIP	UNIVERSITY OF MICHIGAN	0	0	35201030	0
RISER, STEPHEN C.	U OF RHODE ISLAND	800322	800406	36621000	16
ROBERTS, WALTER ORR	UNIVERSITY OF COLORADO	0	0	51193001	0
ROBINSON, G.D.	CTR FOR ENVIRONMENT AND MAN	0	0	36121012	0
ROGERS, JEFFREY	UNIVERSITY OF COLORADO	0	0	35071076	0
RONNHOLM, KEITH	UNIVERSITY OF WASHINGTON	0	0	35371011	0
ROTUNNO, RICHARD	UNIVERSITY OF COLORADO	0	0	35071086	0
ROTUNNO, RICHARD	UNIVERSITY OF COLORADO	0	0	35071089	0
RUMBLE, JOHN	UNIVERSITY OF COLORADO	0	0	35071063	0
SAENZ, RICHARD	COLORADO COLLEGE	0	0	36351000	0
SALPETER, E.E.	CORNELL UNIVERSITY	0	0	35091007	0
SANI, ROBERT	UNIVERSITY OF COLORADO	0	0	35071057	0
SASOKI, YOSHIKAZU	UNIVERSITY OF OKLAHOMA	0	0	35261002	0
SASOKI, YOSHIKAZU	UNIVERSITY OF OKLAHOMA	800505	800509	35261005	5
SCHERRER,PHILIP	STANFORD	800130	800201	35661010	3
SCHLESINGER, ROBERT E.	UNIVERSITY OF WISCONSIN	0	0	35381004	0
SCHLESINGER, ROBERT E.	UNIVERSITY OF WISCONSIN	0	0	35389002	0
SCHLESINGER, ROBERT E.	UNIVERSITY OF WISCONSIN	800128	800131	35381008	4
SCHUBERT, WAYNE H.	COLORADO STATE UNIVERSITY	800815	800817	35081026	3
SEATON, M.J.	UNIVERSITY COLLEGE, LONDON	0	0	36221000	0
SEKORSKI, JOSEPH	CTR FOR ENVIRONMENT AND MAN	800422	800428	36121013	7
SEKORSKI, JOSEPH	CTR FOR ENVIRONMENT AND MAN	801011	801013	36121000	3
SHEMANSKY, D.	UNIV OF SOUTHERN CALIF.	0	0	36381002	0
SHOUB, EDWARD C.	UNIVERSITY OF COLORADO	0	0	35071055	0
SIEVERING, HERMAN	GOVERNORS STATE COLLEGE	0	0	36401000	0
SINCLAIR, PETER	COLORADO STATE UNIVERSITY	0	0	35081068	0
SMITH, DAVID R.	TEXAS A+M UNIVERSITY	0	0	35311028	0
SMITH, ERIC	COLORADO STATE UNIVERSITY	800827	801127	35081060	93
SMITH, JR., PAUL L.	SOUTH DAKOTA SCHOOL OF MINES	0	0	35641013	0
SMITH, PHIL	PURDUE UNIVERSITY	0	0	35291004	0
SNOW, TIMOTHY	UNIVERSITY OF VIRGINIA	800714	800718	35691003	5
SRIVASTAVA, R. C.	UNIVERSITY OF CHICAGO	0	0	35061012	0
STEDMAN, DONALD H.	UNIVERSITY OF MICHIGAN	0	0	35201025	0
STEINOLFSON, RICHARD	UNIVERSITY OF ALABAMA	800518	800615	36471001	29
STENCEL, ROBERT	UNIVERSITY OF MICHIGAN	0	0	35201016	0
STEPHENS, GRAEME	COLORADO STATE UNIVERSITY	0	0	35081063	0

STEPHENS, JESSE	FLORIDA STATE UNIVERSITY	0	0	35111042	0
STEPHENS, JESSE	FLORIDA STATE UNIVERSITY	0	0	35111046	0
STREET, ROBERT	STANFORD	0	0	35661012	0
STULL, ROLAND B.	UNIVERSITY OF WISCONSIN	800728	800830	35381014	34
SUTERA, ALFONSO	CTR FOR ENVIRONMENT AND MAN	0	0	36121007	0
SWARZTRAUBER, PAUL	UNIVERSITY OF COLORADO	0	0	43513022	0
TAKAHASHI, TSUTOMU	UNIVERSITY OF HAWAII-HILO	800415	800506	35451007	22
TAKAHASHI, TSUTOMU	UNIVERSITY OF HAWAII-HILO	800804	800811	35451005	8
TAKAHASHI, TSUTOMU	UNIVERSITY OF HAWAII-HONOLULU	801118	801217	35131001	30
TAKLE, EUGENE S.	IOWA STATE UNIVERSITY	800813	800821	35461005	9
TAKLE, EUGENE S.	UNIVERSITY OF COLORADO	791231	800108	35071084	9
TENCH, ALAN H.	COLORADO SCHOOL OF MINES	0	0	35801001	0
TENCH, ALAN H.	INDEPENDENT - BOULDER	0	0	36341002	0
TOOMRE, JURI	UNIVERSITY OF COLORADO	800107	801231	35071088	360
TRENBERTH, KEVIN	UNIVERSITY OF ILLINOIS	800618	800817	35141014	61
TRIPP, DAVE	WEBER STATE COLLEGE	0	0	36451001	0
TRIPP, DAVE	WEBER STATE COLLEGE	800907	800913	36451000	7
VAN HELVOIRT	UNIVERSITY OF VIRGINIA	0	0	35691006	0
VASTANO, ANDREW C.	TEXAS A+M UNIVERSITY	0	0	35311018	0
VASTANO, ANDREW C.	TEXAS A+M UNIVERSITY	800308	800316	35311006	9
VASTANO, ANDREW C.	TEXAS A+M UNIVERSITY	801011	801020	35311010	10
VAZIRI, ARSALAN	UNIVERSITY OF DELAWARE	0	0	35751001	0
VIGDORCHIK, MICHAEL	UNIVERSITY OF COLORADO	800711	801231	35071067	174
VONDER HAAR, ET AL	COLORADO STATE UNIVERSITY	0	0	35081048	0
WAITE, J. HUNTER	UNIVERSITY OF MICHIGAN	0	0	35201024	0
WALKER, JAMES C.G.	NATIONAL ASTRONOMY & IONOSPHER	0	0	36551000	0
WALSH, JOHN E.	UNIVERSITY OF ILLINOIS	0	0	35141011	0
WALSH, JOHN E.	UNIVERSITY OF ILLINOIS	801025	801102	35141016	9
WASHINGTON, W. M.	FLORIDA STATE UNIVERSITY	0	0	9033704	0
WATSON, ANDREW J.	UNIVERSITY OF MICHIGAN	0	0	35201026	0
WELCH, RONALD	COLORADO STATE UNIVERSITY	0	0	35081044	0
WELCH, RONALD	U OF MAINZ	800626	800823	36631000	59
WHITE, DICK	UNIVERSITY OF COLORADO	0	0	28403017	0
WHITEHEAD, JOHN	WOODS HOLE OCEANOGRAPHIC INST.	0	0	35781009	0
WROBLEWSKI, JOSEPH S.	FLORIDA STATE UNIVERSITY	800910	800918	35111024	9
YEH, T.	METRO STATE COLLEGE	0	0	36601000	0
YOUNG, KENNETH	UNIVERSITY OF ARIZONA	0	0	35021005	0
YOUNG, KENNETH	UNIVERSITY OF ARIZONA	800714	800815	35021008	33
ZABUSKY, NORMAN	UNIVERSITY OF PITTSBURGH	0	0	35601000	0
ZDUNKOWSKI, WILFORD	UNIVERSITY OF UTAH	0	0	35351003	0

NOTE: Zeroes shown in Days column indicate use of computers from remote sites.

STAFF AND VISITORS

Administration Section

Darlene Atwood
Mary Bartels
Melinda Burton
Beverley Chavez
Jay Cook
Margaret Drake (Deputy Director)
Walter Macintyre (Division Director)
Percy Peterson
Colleen Velie

Data Support Section

Dean Frey
Roy Jenne (Manager)
Dennis Joseph
Paul Mulder
Wilbur Spangler
Gregg Walters

User Services Section

Jeanne Adams (Manager)
John Adams
Daniel Anderson
Linda Ballard
Jean Bell
Linda Besen
Frederick Clare
Ann Cowley
Astrik Deirmendjian
Benedict Domenico
John Donnelly
Salvador Farfan
William Frye
David Fulker
Bonnie Gacnik
Kenneth Hansen
Lofton Henderson
Stuart Henderson
Barbara Horner
John Humbrecht
David Kennison
Robert Lackman
Jack Martindale
Gregory McArthur
Donald Morris
Harsh Passi
Herbert Poppe
Russell Rew
Cicely Ridley
Richard Sato
Richard Valent
Eric Wainwright
Gloria Williamson

Systems Section

Barbara Bateman
Phylecia Brandley
Betsey Chen
Joseph Choy
Willard Crittenden
Karen Friedman
Sandra Fuller
Gilbert Green
Darrell Holley
B-Lynn Irwin
Louis Jones
David Kitts
John Merrill
Marc Nelson
Bernard O'Lear
William Ragin
Paul Rotar (Manager)
Eugene Schumacher
Marie Working

Operations Section

Donna Barday
Julia Bartram
Mary Buck
Steven Chapel
Sylvia Darmour
Cynthia Del Pizzo
George Fuentes
Marlene Furmanek
Nancy Goldstein
Sue Hartter
Rita Hemsher
Jesse James III
Gary Jensen (Manager)
Sue Jensen
Wanda Keeney
Richard Lindenmoyer
Stephen Long
Stan McLaughlin
Pamela Moore
Robert Niffenegger
Vickie Pinedo
Andrew Robertson
Susan Schemel
Larry Scott
Valerie Shanahan
Steven Storm
David Strayer
Mary Trembour
Alfonso Trujillo

Advanced Methods Section

Gerald Browning
John Gary
Paul Swarztrauber (Manager)

ATMOSPHERIC TECHNOLOGY DIVISION

INTRODUCTION

The Atmospheric Technology Division addresses one of the two prime foci of NCAR by providing unique, centrally administered facilities for use in atmospheric science research. Traditionally ATD's capabilities have consisted of high-quality aviation, ballooning, field observing, and computing facilities augmented by strong internal research and development activities. The scope of ATD's activities was narrowed in FY 1981 when the Computing Facility received divisional status as the Scientific Computing Division. This organizational change has resulted in a substantially smaller and more sharply focused ATD that has, as its mission, to provide support to experimental science.

A second important organizational change took place when Clifford Murino resigned from his position as director of ATD in July 1980. For the remainder of the year Robert Serafin, manager of the Field Observing Facility, served as acting division director and Harold Baynton, staff scientist in the Field Observing Facility, served as deputy director. (These individuals have since been appointed to these positions on a regular basis.) A third significant change affecting ATD is the introduction of cost recovery policies, which have been communicated to our user community. These policies may well lead to significant changes in operating procedures. There are numerous mechanisms through which this may take place; among them are UCAR Cooperative University Programs, independent non-NSF funded programs, or jointly funded NCAR programs. Clearly there will be significant changes in the NCAR and ATD modes of operation. ATD will adapt readily to these new conditions. Indeed, along with change there are likely to be exciting new opportunities for research and new challenges for instrument development.

ATD is now composed of five facilities, the Research Aviation Facility (RAF), the Field Observing Facility (FOF), the Research Systems Facility (RSF), the Global Atmospheric Measurements Program (GAMP), and the National Scientific Balloon Facility (NSBF). These five facilities provide the community with measurement capabilities that extend from the earth's surface through the troposphere and into the stratosphere. A wide variety of instrument systems are available; among them are instrumented aircraft, Doppler radars, surface networks, sounding systems, and balloon platforms. RSF provides outstanding research and development capabilities, particularly in sensor development, tracking systems, data processing, interactive computing, and displays. GAMP has a well-deserved international reputation as an innovative and highly competent developer of ballooning techniques. The breadth of these facilities is extraordinary both in types of instrument systems employed and in the science served. All of the traditional meteorological disciplines make use of ATD facilities. Major users of NSBF include astronomers and researchers studying the middle atmosphere.

ATD contends that service to each scientific community must be complete and must consist of several or all of the following components:

- Competent technical staff
- High-quality instruments
- Data processing
- Data archiving
- Strong scientific staff
- Active development programs

With these components ATD ensures that it will remain at the forefront of technology for atmospheric research.

In 1980, facility support to science remained at a high level; in addition, a number of important development programs were under way. The thrust of these development programs is aimed at the instrument needs of experimental atmospheric science in the coming decade. In the 1980s ATD sees a number of major field programs developing in the national atmospheric science community. Among these are various initiatives in mesoscale meteorology, including successors to the Severe Environmental Storms and Mesoscale Experiment (SESAME), the Cooperative Convection Precipitation Experiment (CCOPE), and the Global Atmospheric Measurements Experiment on Tropospheric Aerosols and Gases (GAMETAG), as well as new programs related to extratropical cyclones, orographic precipitation, and weather modification. There will be a greater emphasis on scale interactions (from the microscale through the mesoscale) and we expect to see major advancements in basic studies of cloud electrification. Programs in the 1980s will need coordinated observations from a multiplicity of instrument systems. Included are fleets of aircraft, arrays of Doppler radars, automated surface observations, upper air soundings, and satellite images. Indeed, virtually the total resources of the atmospheric science community are often required for the conduct of a single program and, because of the high level of commitments, the operational periods of such programs tend to be of greater duration than has been typical in the past. These considerations suggest that demand will continue at a very high level and that higher quality programs, deserving of ATD support, will stretch ATD's capabilities.

In preparing for the next decade, ATD is currently engaged in several developmental efforts. RAF will replace one of its Queen Air aircraft with a new twin turboprop. Development of new on-board and ground-based data systems is taking place simultaneously. RAF and FOF are cooperating in the airborne Doppler radar development and RSF is developing a new liquid water measurement device with RAF and CSD. FOF has the lead role and is supported by RSF in development of the next generation PAM. PAM II will utilize satellites for communications, and will accommodate small or large users and several independent programs simultaneously. FOF is also engaged in renovation of the 10 cm CP-2 radar which will provide major new capabilities in time for CCOPE and will be available in later years for use by the community.

In RSF there are several major developments underway. Perhaps most exciting is the Safesonde, which promises quantum improvements in tropospheric sounding capabilities as compared to the GMD. RSF and GAMP are the major collaborators here, with FOF providing consultation. RSF and FOF have continued to advance the capabilities of the Research Data Support System (RDSS), and ATD has committed funds to upgrade substantially the system's computing capacity. The most significant recent development has been an interactive editing software package for radar data. This software has resulted in an order-of-magnitude savings in time as compared to batch processing on the 7600.

In GAMP there are exciting development programs underway. The Radiation Controlled Balloon (RACOON) will provide low-cost, middle-atmospheric, long-duration profiling capabilities and will complement NSBF's long-duration ballooning program. Long-Lived Atmospheric Monitoring Airship (LLAMA) is a very long-duration (several years), constant-latitude, middle-atmospheric platform, while MicroGHOST is a low-cost global monitoring system for winds.

The recent real-time shipboard sounding system, developed for Storm Transfer and Response Experiment (STREX) will serve as a prototype for several operational systems in the future. Each of GAMP's development efforts addresses specific measurement needs for studies in meteorology and atmospheric chemistry. NSBF's principal development effort focuses on long-duration, constant-altitude ballooning, a capability needed by gamma-ray, heavy-particle, and solar physicists interested in observing rare events. In response to an increased demand for medium-duration flights, NSBF plans an East Coast launch facility to meet peak demands. And, to meet increased atmospheric sciences needs for remote flights, NSBF is developing a special mobile operations team, capable of making balloon launches at appropriate locations around the globe.

The above is a very brief synopsis of the many development programs currently underway within ATD. Upon their completion ATD will launch new development programs beginning in the middle 1980s.

These long-range plans include complete replacement of the RAF fleet, a transportable sounding network for research, rapid-scanning radars, new communications capability, and new field-based data acquisition and display capability for real-time field program direction. ATD proposes also to interact with the university community, through an expanded visitors' program, to a greater degree than has been possible in the past. This comprehensive program will lead to new advances in our understanding of convective storms, precipitation, atmospheric electricity, and chemical processes in the atmosphere. ATD is well prepared to undertake this program and looks forward to its realization.

RESEARCH AVIATION FACILITY

Missions and Goals of RAF

The primary objectives of the Research Aviation Facility (RAF) are two-fold:

- To support the atmospheric science community by operating a fleet of state-of-the-art instrumented research aircraft with the necessary operational and data processing ground support capabilities

- To undertake the technical development necessary to maintain and to update this capability.

The RAF provides technical assistance in all phases of research equipment, testing, and data evaluation. The four RAF aircraft, which have different operational flight characteristics, are equipped with in situ and remote sensors and with on-board data systems for use in scientific field programs. These research platforms are also capable of incorporating and interfacing with specialized instruments acquired or provided by the user for specific programs.

Highlights of 1980

During CY 1980 RAF had heavy commitments in both program support and development. A total of 15 scientific user programs and two in-house development-test programs were flown. The development effort within RAF was greatly increased and more sharply focused compared to previous years--especially in the areas of data system hardware and data processing software. During 1980 RAF began to increase the level of scientific interaction with the community. RAF has been very active in scientific planning for the 1981 CCOPE program.

A large effort has gone into the planning and acquisition of the twin-turboprop aircraft scheduled to be purchased in 1981. A workshop was held in February to define the aircraft's scientific requirements. Specifications were completed following the workshop and a study of all available aircraft was made. This resulted in a sole-source justification for a Beech King Air Super 200 series aircraft. NSF approval for this acquisition was awarded in October 1980. The formal issuance of the Request for Proposal will occur early in 1981.

During CY 1980, a total of 781 hours were flown in support of scientific programs (not including proficiency flight hours): 540 by the Queen Airs, 113 by the Sabreliner, and 128 by the Electra.

RAF Aircraft

Electra. RAF's four-engine turboprop Lockheed Electra can cruise at speeds of around 275 kt and climb to above 25,000 ft msl, with a range of 2,600 n mi under a normal load. Its range is well suited to long-range research flights including long over-ocean research missions. The large cabin volume (5,000 ft^3), ample electrical power, and the large payload (14,000 lb) available on the Electra are such that the aircraft can accommodate several experiments at once. The aircraft is especially advantageous for large chemistry experiments and for operation in large-scale meteorological research programs.

Sabreliner. The North American Rockwell Sabreliner is a twin-jet aircraft with a maximum flight altitude of 44,000 ft msl and a range of 1,300 n mi and a payload of 1,800 lb (including crew). This aircraft has been used extensively for upper troposphere/lower stratosphere air chemistry and atmospheric dynamics measurements.

Queen Airs. RAF's two Beechcraft Queen Air twin-turbocharged piston engine aircraft have been the workhorses of the fleet. They have a range of 800-1,000 n mi and an altitude capability of 25,000 ft msl, and can carry a 1,000 lb payload (including crew). When purchased these aircraft were completely satisfactory for the research missions. In the years since, research requirements have made it necessary to add data systems, gust probes with inertial navigational systems (INS), wing-tip probes, etc. Today, the Queen Airs are severely limited in performance--range, altitude, endurance, payload, electrical power, etc.--to the point where it is mandatory that these workhorses of the RAF support mission be replaced in the earliest possible time frame. The RAF presently (FY 1981) will acquire a twin-turboprop Beech Super King Air which should reach instrumented flight-research status by early 1983 (CY). Aquisition of a second twin-turboprop is scheduled in the 1982-83 period.

All RAF aircraft are in excellent mechanical condition and are comparatively low-time aircraft.

Programs Supported in CY 1980

Programs supported by RAF are generally in three principal areas: atmospheric chemistry, cloud and precipitation physics, and turbulence and air motion. Some programs involve measurements in all three areas; commonly programs are flown involving two of the areas. The RAF support for programs includes research and operational planning, aircraft instrumentation, pre- and post-flight calibrations, program field execution, and final data processing. For most Queen Air programs at least three experienced RAF crew members are assigned, including a pilot, a technician, and a project engineer-scientist who is responsible to the user for achieving the defined program goals, as well as for monitoring equipment performance, data quality, and final data processing. Electra programs normally require support crews of seven to ten RAF staff.

Scientifically, RAF supports the atmospheric sciences at four levels:

1) at the project engineer level described in the paragraph above,

2) at the co-investigator level--usually when the assigned RAF project scientist's interest and expertise are closely associated with the science of the program,

3) at the principal-investigator level--usually in multi-organizational programs where the aircraft measurements comprise one of several data sets and where an RAF scientist is clearly expert,

4) at the consultant level--often in areas of instrumentation, aircraft modification, etc.

While responsibility within these various support levels is principally centered on the project engineer-scientist, all assigned RAF staff share the responsibility for successful program execution. RAF pilots are truly professionals, motivated to achieve all possible research goals within the limits of flight safety.

Table 1 lists the programs and the principal investigators who were supported by RAF during 1980. The program field period, hours flown, and data delivery date are given. Program-related ferry time and tower fly-by calibration flights are included within the program research hours. Proficiency flight time is not included.

Brief descriptions of several programs, typical of those supported by RAF, are given below. One future program--CCOPE-1981--is outlined from present plans which have been developed during CY 1980.

Acid Precipitation Experiment (APEX) 1980

Principal Investigator: Al Lazrus (NCAR) et al.

The RAF has supported four nationally important field programs during FY 1979 and FY 1980 to investigate the phenomenon of acid precipitation. The APEX program was conducted by a group of 14 scientists from eight universities. APEX I measured the concentration ranges of various acids and their precursors (especially sulfur dioxide and nitrogen dioxide) throughout the midwestern and northeastern United States. The APEX II and APEX III field phases studied cases of warm, cold, and orographic precipitation. During APEX IV, in-depth studies were made of the in-cloud and subcloud chemical processes occurring under various meteorological conditions. Several important discoveries were made from these studies concerning the major role of hydrogen peroxide (H_2O_2) in producing acidity within warm-front clouds and the increased concentration of nitric acid in lower cloud volumes due to the hydrometeor absorption of nitric acid vapor (HNO_3). From these studies atmospheric acidity and atmospheric acidity potential parameters were established. Researchers hope that these parameters will make it possible to predict changes in precipitation acidity from changes in air quality under specific meteorological conditions. Follow-on experiments are being planned.

Mountain-Induced Convection--1978-1980

Principal Investigators: David Raymond and Marvin Wilkening, New Mexico Institute of Mining and Technology

During the summers of 1978 and 1980 David Raymond and Marvin Wilkening used an instrumented Queen Air to study the interrelationship between cloud formation and air circulation patterns near mountains. Both mass flow and turbulent fluctuations were measured by the Queen Air's INS gustprobe. A continuous radon sampler aboard the aircraft also provided data on the mixing, vertical transport, and entrainment properties of thunderstorms. Radon was sampled at desired distances ranging from a few hundred meters to 1.5 km across a number of convective elements within cumulus clouds in the early stages of thunderstorm development. From these studies the investigators have constructed a two-dimensional model of convection. The model does not simulate the mountain orographic effects; however, heating of the model's lower boundary layers creates a convective-circulation response similar to that induced by a heated mountain. The principal investigators are cooperating with Terry Clark of NCAR's Convective Storms Division in running Clark's three-dimensional numerical model, initialized with their data. Preliminary results indicate excellent agreement between the model and measurements. The mountain can apparently induce an aerial extension of roll vortices oriented along-the-wind under convective conditions.

Storm Transfer and Response Experiment (STREX) 1980

Principal Investigator: Joost Businger, University of Washington

During November and December of 1980 the NCAR Electra participated in the Storm Transfer and Response Experiment (STREX), a multi-institutional study of interactions between cyclonic storms, the planetary boundary layer, and the oceans. The major goals of STREX were to measure the vertical transfer of heat, momentum and moisture in the storm environment boundary layer; to examine the relationship of these boundary layer processes to cloud structure and development; and to investigate changes in the structure of the oceanic mixed layer, including changes in upper oceanic currents and sea-surface temperature associated with the passage of storms. These obviously represent very large-scale goals. Simultaneous measurements were made from three aircraft, ships, drilling buoy platforms, and a satellite, with the area of interest being centered upon ocean station PAPA (50°N, 145°W). Richard Pearson of the University of Michigan participated on the Electra as a piggy-back investigator. Pearson's measurements will relate oceanic ozone concentrations and ozone flux to specific meteorological conditions. Four research missions were flown in the November-December period.

Lake-Effect Snow Storms

Principal Investigator: Roscoe Braham, University of Chicago

RAF supported the Braham Lake Effect Snow Storm study during December 1980 and January 1981. This study is a continuation of research begun in 1977, with NCAR aviation support, into the dynamical and cloud physical aspects of lake-induced storms over Lake Michigan. The program was supported by the RAF Queen Air N306D, the University of Wyoming's King Air, and the NCAR Field Observing Facility CP-4 and CHILL Doppler radars. This program produced apparently excellent sets of a variety of lake-effect storms. The Braham program represented a particularly good example of good field program management which resulted in close cooperation among the working group within the program.

Cooperative Convection Precipitation Experiment (CCOPE)

Principal Investigator: Pat Squires (NCAR), numerous Co-Principal Investigators

During the summer of 1981, RAF will participate in the Cooperative Convective Precipitation Experiment (CCOPE). CCOPE is a multi-institutional program involving a large number of universities and government research groups. NCAR and the Water and Power Resources Service of the U.S. Department of the Interior are leading and managing the experiment. Centered in Miles City, Montana, CCOPE will investigate the initiation, cloud physics, structure, and kinematics of moist convection. Specific research goals include the investigation of hydrometeor evolution, the origin of ice, precipitation efficiency, entrainment mechanisms, storm dynamics and storm initiation mechanisms including possible topographic mesoscale convergence, and larger scale triggers. RAF is participating strongly in the design and planning of CCOPE and will support the experiment in the field with two Queen Air aircraft and the Sabreliner. This is an example in which the scientific strengths of RAF are important to both the design and execution of the field program.

Recent and Current Developments

The following is a list of recent and current developments. A brief description of each is given in the paragraphs which follow.

Remote CO_2 IR Radiometric Cloud-Air Thermometer
De-iced Air Motion Vanes
Lyman-alpha Specific Humidity Hygrometer
ADS Aircraft and Ground Quick-Look Data Systems
Liquid Water Content Instrumentation
PMS Probes--Acquisition and Interfaces
Dropwindsonde
GENPRO II Software
Twin-Turboprop Research Aircraft
Aircraft Doppler Radar--Design Study and Cooperative NOAA Test

Remote CO_2 IR Radiometric Cloud-Air Thermometer

Accurate measurements of in-cloud temperatures and cloud temperature variations have proven difficult using immersion-sensing probes which invariably are affected by water deposition and evaporation on the probe itself. During 1980, RAF has specified and contracted for a 15μ CO_2-band infrared radiometer which is stabilized to operate in the aircraft flight environment in and out of clouds. In clouds, the radiometer "looks at" the cloud-droplet (temperature) radiation; in the free air, at the CO_2 molecular radiation in temperature equilibrium with the air. Response time is on the order of 0.1 s or less. The radiometric temperature is "calibrated" by comparison to the standard immersion probe temperature in the free air before and after cloud penetrations. Cloud drop temperature corrections for evaporation or condensation are estimated to be less than 0.5° for normal conditions in clouds.

De-iced Air Motion Vanes

The need for turbulence measurements in clouds dictated the development of de-iced gust probe vanes. This was done in conjunction with the Research Systems Facility (RSF). The design criterion was that the vanes remain free of ice in a flight environment of 6 g/m^3 cloud water content at -15°C. There is a continuing effort to improve the reliability of the vanes under environmental conditions. We believe that present vane failures are associated with the wetting of the strain gage and strain gage bonding during flights through clouds and rain. Improved waterproofing and additional flight tests are planned.

Lyman-alpha Specific Humidity Hygrometer

RSF's development of RAF's four fast-response Lyman-alpha humidity instruments was completed during 1980. The requirement was for a Lyman-alpha instrument that could be mounted forward on the gust probe boom adjacent to the air motion and temperature sensors. The new units are heated to prevent heavy ice accumulation on the frontal surface. The present units function well. Lamp reliability is a remaining problem, in part because of the replacement cost (≈\$500).

ADS - Aircraft and Ground Quick-look Data Systems

In a review (during early 1980) of RAF's existing capability for collection, display, and processing of aircraft data, it was clearly apparent that improved data systems were needed to meet even the current requirements for aircraft and ground data processing at RAF. Some considerations that initiated this review were limitations on the reliability, accuracy, expandability, and display capability of the existing ARIS IV airborne data system. Also it was increasingly important to consider quick turnaround data processing and data quality control as part of the RAF system concept. Soon after this review, RAF undertook the design and fabrication of the Aircraft Data System (ADS). This system is designed to provide for airborne data collection and display as well as for ground-based, quick-look data processing and display. Three fundamental design areas were addressed. First, the data system should take advantage of recent improvements in state-of-the-art components and design philosophies to produce a system with improved reliability and capabilities over existing systems. Second, the system should be designed to encompass the collection, display, and processing of data in real time, post-flight, and long-term time frames. Third, the system after development should be labor non-intensive with hardware and software flexibility.

The new system design uses a distributed intelligence concept, consumes moderately less power than ARIS IV, and has higher frequency response and excellent accuracy. It has built-in flexibility and, because it was designed for current use of only 50%, it can be expanded to meet RAF's foreseen requirements through the late 1980s. The overall design is centered on fulfilling the on-board data system requirements of the planned twin-turboprop aircraft. Additionally, RAF is building a quick-look ground system, an expanded Electra data system, and a mini-data system (for programs requiring minimum data display). All systems are designed for maximum commonality of hardware and software. RAF will have its first ADS on the Sabreliner during CCOPE 1981, and plans to support the three RAF aircraft in CCOPE with a mobile trailer-mounted, quick-look, ground-based ADS system at Miles City. The mobile system will be composed largely of components of the Electra ADS (which is not scheduled for use during summer 1981) and will use quick-look ground station software from RAF's Jeffco Airport facility.

Liquid Water Content Instrumentation

RAF has recently completed a wet wind tunnel calibration of its four Johnson-Williams cloud water content instruments using the Canadian National Research Center facility at Ottawa, Ontario. With RSF, we are beginning to look at the broader requirements for the measurement of liquid and total water content. A King LWC device will be evaluated for possible use and improvement by RAF/RSF.

PMS Probes

RAF has recently (FY 1981) ordered new 32-diode element two-dimensional cloud and precipitation probes and one 60-channel one-dimensional probe from Particle Measuring Systems. These are RAF's first two-dimensional probes. Electronic interface boards are being built to record and display data through the ADS.

Dropwindsonde and Dropwindsonde Data Processor

RAF has acquired a dropwindsonde receiver-processor unit suitable for use on the Electra under a previous agreement with the NOAA-Global Weather Experiment office. Check-out of the unit has been completed. RAF has approximately 100 sondes on hand for use in support of future programs. RSF is developing a ground data unit for dropwindsonde processing. RAF has funded this development, which closely duplicates the system constructed under NOAA contract for the Global Weather Experiment.

GENPRO II

A joint RAF-SCD (Scientific Computing Division) software development of GENPRO II is now nearly completed. Begun in 1977, GENPRO II is a second-generation computer program designed for batch-mode RAF data processing. The program is currently being checked for portability on the NCAR Control Data 7600, CRAY-1, and DEC VAX 11/780 computers. Operational use of the program by RAF will begin in the summer of 1981, with full documentation planned for completion during 1981. GENPRO II is a general-purpose program which is documented at several levels to provide for ease of use and which is designed to reduce RAF's staff requirements for data processing. GENPRO II also is designed to be readily transported to other institutions where scientists may wish to process data on their own. Some of the more important features of GENPRO II are:

- Faster data turnaround.

- Modularity--modules are easily added, deleted, or reconfigured as required for digital filtering, interpolation, graphics, inputs, etc.

- Portability--ensured by the use of Fortran IV and byte-oriented controls and data structures.

- Program can run in or out of core.

- Reuseable code for efficiency and minimum size.

- Digital processing modules allow for options from simple averaging to complex digital filtering and interpolation as required to insure data integrity.

- Extensive defaulting provides for minimal user setup time for standard output.

- Tape merging on input and byte-oriented output tape formats can accommodate user needs for different types of computers.

Twin-Turboprop Research Aircraft

RAF has progressed over the past twelve months toward the purchase (in FY 1981) of a twin-turboprop aircraft to replace the oldest of the limited-capability Queen Airs. A Twin-Turboprop Specification Committee was formed in late 1979 to identify RAF's aircraft requirements. A workshop was held in February 1980. These efforts identified RAF's requirement as a twin-turboprop aircraft in the 12-14,000 lb gross-weight class. An evaluation of all aircraft available worldwide resulted in a conclusion that only the Beech Super King Air 200 Maritime Series aircraft could satisfactorily meet the RAF requirements. A sole-source procurement justification has been written and was approved in late October by NSF. A draft request for proposal (RFP) is prepared for issuance to Beech for the aircraft, engineering, and modifications to RAF specifications. This has been discussed with Beech engineers who are preparing cost estimates. Funding arrangements are currently being determined by NCAR Administration. RAF expects to contract for the aircraft and modifications by 1 June 1981. The aircraft should be on line as an instrumented aircraft in the first half of 1983.

Aircraft Doppler Radar - Design Study and Cooperative NOAA/ATD Test

RAF and the Field Observing Facility (FOF) have begun studies related to aircraft radar and aircraft Doppler radar. Peter Hildebrand and Richard Oye have used the RDSS (Research Data Support System) to analyze the effects of beam width and attenuation for 12 in., 18 in. and 30 in. antennas and for X-band and C-band frequencies. These studies use real data (recorded from NCAR ground-based radars) from two severe-storm situations (as the "true" reflectivity). A study result is that for an 18 in. antenna diameter, the reduced attenuation at C-band frequency is much more important than the narrower beam with increased attenuation of X-band for research aircraft radar. We believe these results are also important to general and commercial aviation (which at present predominantly use X-band radars). A summary paper, "X-band vs C-band aircraft radar: the relative effects of beam width and attenuation in severe storm situations," has been submitted to the Journal of Applied Meteorology. Research is planned to extend the simulation study to a larger meteorological sample and to include effects of beam width and attenuation on Doppler radar performance.

Experimentally, RAF and FOF tested a meteorological aircraft Doppler radar cooperatively with NOAA during December 1980. This NOAA Doppler radar has been under development since 1977 and was flown on the P-3 aircraft. Results of the test are important to RAF's planned aircraft Doppler radar developments.

Summary

The programs supported in 1980 were of high scientific quality and, along with RAF's increased development effort, required a maximum commitment of the resources of RAF. RAF personnel responded well to the challenges of each supported program. Data quality and data turnaround time continued to improve due to the efforts and high standards of the RAF technical and scientific personnel. RAF's scientific involvement in programs is increasing. Development has been accelerated. A new airborne data system under development is designed to work with a quick-look ground data system now on line at the Jeffco Airport base. The twin-turboprop Queen Air replacement aircraft workshop was held in February of this year. This was followed by aircraft and modification design specifications and the selection of the Beech Super 200 King Air series aircraft for sole-source purchase in FY 1981. This latter effort has required a large commitment of RAF time apart from the program support and other development efforts.

The tremendous scope of scientific research supported by the Reseach Aviation Facility is undeniable. The atmospheric sciences must rely in major part on the facilities and services which can be supplied by this group. The Research Aviation Facility is able to support only a fraction of the scientific program needs because of limits on the number of flight hours and on instrumentation capabilities. The needs of the next decade for research observations are large. The pace of scientific progress in large measure will be determined by RAF's ability to provide the experimental data inputs and observations needed to provide definitive answers for step-by-step scientific advancement. In recognition of this, RAF will press forward to achieve significant and dramatic changes in aircraft types, in instrumentation, and in staff ability to support university and NCAR investigations. These are needs which must be met despite limiting factors of budget and personnel.

RAF FLIGHT SUPPORT - FY 1980

Principal Investigator	Project Title	Date of Program	Hours Flown	Date Data Sent to Investigator
Queen Air N304D				
Cadle (448)	Volcanic Plumes	Feb 1 - 28, 1980	62.1	March 1980
Cadle (449)	Mt. St. Helens Volcano	April 2 - 14, 1980	22.5	N/A
Lenschow (437)	Ozone Destruction Flux	May 28 - June 21, 1980	49.9	Sept 1980
Raymond (489)	Mountain-Induced Convection	July 23 - Aug 12, 1980	45.3	Sept 1980
Queen Air N306D				
Grant (680)	COSE	Nov 15 - Dec 31, 1979	49.4	March 1980
Riehl (681)	UPSLOPE	Nov 15 - Dec 31, 1979	16.0	March 1980
Garstang (669)	Coastal Winds	Jan 24 - Feb 11, 1980	94.4	April 1980
Spyers-Duran(650)	Dew Point Test	Feb 10 - 20, 1980	2.7	N/A
Scoggins (682)	HIPLEX	May 15 - June 15, 1980	52.8	Sept 1980
Lazrus (641)	APEX IV	July 17 - Aug 14, 1980	78.5	Aug 1980
Braham (668)	Lake Effects Snow Storms	Dec 1, 80 - Jan 23, 1981	65.8	Pre-Production
Queen Air Sub-Total Hours*			539.4	
Sabreliner N307D				
Friehe (751)	Humidity Sensor Test	Nov 1 - 30, 1979	4.8	N/A
Mankin (734)	Stratospheric NO_X	Dec 19,'79-Feb 15,'80	41.5	March 1980
Voltz (739)	Vertical Profile 14CO	Mar 15 - June 15, 1980	11.5	Oct 1980
Crutzen (718)	Queimadas	Aug 11 - Sept 10, 1980	54.9	Nov 1980
Sabreliner Sub-Total Hours*			112.7	
Electra N308D				
Herman (886)	Arctic Stratus Experiment	June 10 - July 2, 1980	85.7	Complete
Businger/Miyake (866)	STREX	Nov 13 - Dec 15, 1980	42.4	Complete
Electra Sub-Total Hours*			128.1	
TOTAL HOURS			780.2	

*Proficiency hours are not included

Table 1

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

The overriding strategy described in last year's Annual Scientific Report remains essentially unchanged. Large cooperative programs will be carefully planned at the national level, in part as a consequence of NSF's leadership. These programs will take place at three-to-four-year intervals and thereby provide ample time for analyses. There will be continued demand and justification for smaller field programs led by individual investigators. Since large programs will require virtually all of the nation's field observing resources, some of the smaller field experiments are likely to be preempted. Nearly all field programs will require more advanced observing systems than now exist. If FOF is to meet these requirements, a new generation of quality observing systems must be developed to replace existing systems. However, in view of likely budgetary constraints, only modest increases in the quantity of support are indicated. Consistent with this strategy, a large fraction of FOF's resources was directed toward new development in 1980. This follows a period of several years when emphasis was placed on field support.

Looking into the immediate future it appears that mesoscale research interests will continue to be focused on convective storm dynamics, microphysics, and electrical structure. Winter storms and planetary boundary layer research are likely to receive increased attention during the 1980s. Specific applications of these basic research efforts may become more visible in terms of weather modification, air quality, and air traffic safety problems. The Cooperative Convective Precipitation Experiment (CCOPE) in 1981 and the Joint Airport Weather Studies (JAWS) program in 1982 are two immediate examples of research programs related to such objectives. Similarly, winter programs such as the University of Chicago's Lake Effect Snow Storm effort at Muskegon and the University of Washington's CYCLES project both rely heavily on dual-Doppler observations of winter storms.

The tendency for an increasing number of programs to require multiple-Doppler support combined with automated surface observations and upper air soundings ensures a shortfall of support capabilities from FOF. Recognizing this fact, FOF plans to focus its developments on essential hardware and software systems, with limited expansion to meet the most pressing demands. These demands consist of a new upper air sounding system, rapid-scan Doppler radars, an improved portable automated mesonet (PAM), a greatly expanded RDSS system, and an experiment control center. These developments require a strong parallel commitment to data processing and interactive analysis techniques.

A final observation is that cooperative university programs and interagency programs may be desirable and/or necessary to realize some of the development objectives. This is particularly true in the case of a new upper air sounding system. FOF expects to pursue such opportunities when they appear to be of clear benefit to the community's needs.

Accomplishments of the Past Year (1980)

Field Program Support. Seven field programs were supported during 1980 in spite of the fact that emphasis was placed on system development. Project AEOLUS was supported by the PAM system during January and February in Boulder. This program, headed by Al Bedard of NOAA/WPL, emphasized the study of downslope winds and other topographically induced phenomena. Several major events were captured and reliable performance was achieved from a remote station located atop Niwot Ridge near the Continental Divide.

The Sierra Cooperative Pilot Project (SCPP) was supported with the CP-3 5 cm Doppler radar during the first three months of 1980. John Marwitz of the University of Wyoming, together with other SCPP investigators, observed winter cyclonic storms. The emphasis in this study is precipitation mechanisms, orographic effects of the Sierra Nevada Range, and potential for snowpack augmentation. Seven high-priority cases were captured by the CP-3 radar and the University of Wyoming's King Air instrumented aircraft.

During the spring and summer the CP-4 radar supported Ron Alberty for the NOAA Prototype Regional Observing and Forecasting Service (PROFS) data collection effort. These observations emphasized low-level radar data for inclusion in flash flood modeling. The data also represent a trial case for development of display techniques associated with short-term forecast requirements.

The Boulder Intercomparison Experiment was conducted by Fred Brock of FOF during the spring and summer in cooperation with NOAA/ERL/NSSL, WPRS, and NCAR/CSD. This experiment was for the sole purpose of examining the relative performance characteristics of three mesonetwork systems. Remote stations from the NCAR PAM system, the WPRS PROBE system, and the NSSL SAM system were located near Boulder and the measurements compared. All systems achieved their original design specifications and the various strengths and weaknesses of individual sensors were evaluated. The experiment was motivated by the NCAR Convective Storms Division and WPRS in connection with the CCOPE design effort. The results indicate that these systems can be used together in large mesoscale experiments.

The Atmospheric Studies in Complex Terrain (ASCOT) field project was supported in California during August and September. ASCOT's basic objective was to investigate transport and diffusion processes in highly complex terrain. The PAM system served as a key real-time evaluation and experiment control system for the experiment under the direction of Paul Gudiksen of Lawrence Livermore Laboratory.

Roscoe Braham of the University of Chicago received CP-4 radar support during December for lake-effect snow studies. This program was conducted in the vicinity of Muskegon, Michigan, in conjunction with the CHILL radar and the NCAR Queen Air and University of Wyoming King Air aircraft. The weather was particularly cooperative and a number of highly coordinated cases were obtained among the various measurement systems. It should be noted that a joint NOAA/NCAR test of an airborne Doppler meteorological radar was conducted within the context of this experiment. The NOAA P-3 platform coordinated observations with the CHILL and CP-4 radars.

An informal observational program was conducted with the CP-3 radar for Doug Lilly of NCAR during December. These observations serve as a basis for evaluating the usefulness of Doppler radar in the study of upslope precipitation systems.

<u>PAM II Development</u>. Design and development of a second-generation mesonet system was initiated during 1980 by FOF and RSF. The PAM II design is likely to utilize a satellite for data transmission, thus removing the current requirement of a line-of-sight base station radio link from the remote stations. This will allow for a much more mobile system, and will also permit various clusters of remote stations to be placed in different geographical regions simultaneously. Goals were established for short-term developments and prospective sensors were evaluated by Fred Brock. A new mast assembly was designed and a

laboratory microcomputer system was developed for testing remote station hardware. The front-end computer was selected and ordered and arrangements for use of the GOES satellite were established for tests of four prototype stations. Specifications for the base station downlink were formulated by Brock and George Saum of RSF.

Doppler Radar.

1. RP-5. This data acquisition system was completed in the spring and deployed in the PROFS program. It is the first NCAR radar processor designed to eliminate arithmetic truncation errors over the achievable dynamic range.

2. Low-noise Receiver Chain. The CP-4 radar sensitivity was increased by roughly 5 db. Observations during the PROFS program demonstrated that boundary layer clear air detection is now routine in summer--frequently in excess of 150 km range.

3. CP-2. Nearly the entire CP-2 (10 cm) system was redesigned and reconstructed. By the end of 1980 all subsystems were near completion in preparation for the CCOPE program in 1981. Specifically, the pedestal was upgraded, interlocks were redesigned, transmitter and receiver chains were rebuilt, the entire radar was rewired, and a new antenna control servo cabinet was built. Major innovations include a preselected ultra-wide dynamic range front end, and a solid-state IPA modulator with improved reliability and pulse shape control. System noise temperature is less than 400°K.

4. CP-2 3 cm Wavelength. A new 3 cm incoherent radar was designed and fabrication was well under way by late 1980. The 3 cm antenna will be mounted on the 10 cm pedestal and the entire system will be deployed in CCOPE. This radar will provide improved sensitivity and reliability over that which was previously available.

5. Real-time Software. A new framework for radar control software was developed by Charles Frush and Robert Barron based upon the separation of tasks in a multi-processor hardware environment. Display and control capabilities will be enhanced as a result of this design, and man-machine interaction will be greatly improved. Initial implementation will be on the CP-2 system.

6. 6250 Tape Drives. High-density, high-performance tape drives and controllers were ordered for the CP-2 and one 5 cm radar. These acquisitions increase the effective bandwidth of FOF radars, which have previously been limited in their data acquisition rates by the tape transport. Four-variable data in 1024 range gates at short dwell times will be easily accommodated.

7. Antenna Controller. A new microprocessor-based controller was designed by Arthur Klittnick and nearly completed by year's end. The controller will be installed and tested on the CP-2 radar. It

represents precision control capability and programability heretofore not available with FOF radars for certain scan types.

8. Remote Display/Control. Design and construction of hardware for a master display/control console was accomplished. Software development has begun. The system is based on an Apple computer-driven color display and will permit sophisticated interactive radar control remote from the CP-2 radar van. Operational features will include light pen interactions and various graphics overlays such as aircraft tracks.

9. RP-6 Development. Similar to the completed RP-5 system but expanded to include two-frequency power channels and more versatility in selection of spectral variance output quantities. Completion and installation for CP-2/CCOPE is expected.

Other Accomplishments

Software Development. The Interactive Doppler Editing System (IDES) was made available to users during 1980. By year's end the code was in mature form and providing sophisticated editing capabilities required for multiple Doppler analysis. This interactive system, implemented on the RDSS by Richard Oye, has reduced editing time by roughly a factor of five from that which was possible in batch mode on the Control Data 7600. Other code developments include implementation of the universal exchange format, harmonic (VAD) analysis, and rainfall analysis programs.

Airborne Doppler Radar. Peter Hildebrand (RAF) and Richard Carbone joined with NOAA/ERL investigators in the first meteorologically definitive test of an airborne Doppler radar. The observations were made near Muskegon, Michigan, in December. The data will be analyzed in 1981. Numerical simulations, which employ ground-based radar data, are also being manipulated through IDES to quantify airborne radar performance as a function of several parameters, including radar and storm characteristics.

Research and Technique Development. Fred Brock performed a thorough evaluation of mesonet data acquired during the Boulder Intercomparison Experiment and identified some systematic differences between the PAM, SAM, and PROBE systems. Richard Carbone completed data processing and analysis on a severe winter squall line study. The results add new dimensions to the understanding of certain cold fronts and potential for meso-synoptic forcing of severe storms. John McCarthy initiated a joint experimental program with Theodore Fujita of the University of Chicago. The Joint Airport Weather Studies (JAWS) project promises to be the first definitive study of fine-scale shear kinematics as driven by convective storms. Technology transfers married to basic research understanding of the low-level wind shear problem are the motivating factors. James Wilson has participated in the development of JAWS and has contributed to the analysis of SESAME data with NSSL scientists. He was also the principal scientist responsible for debugging IDES and training various users on this interactive editing system.

Field Observing Facility - Users

Ron L. Alberty	NOAA/ERL/PROFS Program
Al Bedard	NOAA
Roscoe Braham	University of Chicago
Dale Durran	NCAR
Gordon Ellis	Boulder Valley Schools (RE-2)
Sonia Gitlin	NCAR
Paul Gudiksen	Lawrence Livermore Labs
M. E. Harward	Oregon State University
Raymond Jordon	Colorado School of Mines
Patrick Kennedy	NCAR
J. E. Kuettner	MONEX
John Marwitz	University of Wyoming
Maynard Miller	Foundation for Glacier and Environmental Research
Patrick Squires	NCAR
Larry Vardiman	Water and Power Resources Service
Elizabeth Wright-Ingraham	Wright-Ingraham Institute

RESEARCH SYSTEMS FACILITY

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, measurement, and data analysis. 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. 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, the Instrument Shop, and an Electronics Stockroom.

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 its value to the scientific world.

In planning future projects, RSF is in tune with the needs of the ATD facilities. Together with the facilities and their advisory panels, 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 research needs.

Accomplishments of the Past Year

Machine Shop and Mechanical Design Group. Major developments completed by the Mechanical Design group included a new consolidated instrument package, a tuneable laser system, and a mobile antenna mount.

The consolidated instrument package was an updating and miniaturizing effort for the National Scientific Balloon Facility (NSBF). This package contains the communication and control instruments, and batteries. It is the standard package flown on almost all flights. The new package is substantially smaller and lighter and features improved maintenance and repair access.

The tuneable laser system is an air quality monitoring instrument designed for use on the Saberliner aircraft. The laser light beam is used with a multi-pass cell to continuously monitor a sampled airstream. The system will be used extensively by Bill Mankin of the Atmospheric Chemistry and Aeronomy Division (ACAD).

The mobile antenna mount was another effort for NSBF wherein a parabolic tracking antenna and pedestal were mounted on a hydraulic-powered frame on the rear of the electronic equipment van. This equipment permits rapid and efficient deployment and stowage of the tracking equipment on the mobile van under field conditions.

Other major projects requiring both design and shop effort were:
PAM Swing Tower for FOF (Brock)
CP2 Radar Modifications for FOF (Lewis)
Field Equipment for CSD (Grover)
Cryogenic Sampler for ACAD (Lueb)
Launch Spool for NSBF (Gore)
Ballast Hoppers for NSBF (Gore)
Balloon Launcher for GAMP (Stenlund)

Helium Valves for NSBF (Kubara)
Air Motion Vanes for RAF (Friehe)
Tensiometer for ACAD (Delany)

The Machine Shop provides additional services to a wide variety of customers throughout NCAR, and typically handles more than 200 projects per year.

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 repair service 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 complete cost by comparison with known costs at vendor repair facilities. Added advantages are quick emergency repairs, expertise in the use of sophisticated instruments, and confidence that all instruments are working well and accurately.

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 of 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. 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.

Electronic Stockroom. The RSF maintains a storeroom of electronics parts. This function is unique within NCAR in that it operates entirely without direct funding. All parts "purchased" have a surcharge added. It amounts to 25% of the cost--not to exceed $25.00 per order. This fund goes to pay the stockroom manager, Ed Aden. He also performs the very valuable service of locating the source of speciality components and expediting their delivery.

The Research Data Support System (RDSS) is a color image/graphic display system used in the interactive analysis of large data sets. These data sets typically are produced by FOF's Doppler radars, the High Altitude Observatory Solar Maximum Mission satellite, the Global Atmospheric Measurements Program Equatorial Wind Experiment, and the CHILL and NSSL radars. The RDSS was designed to fit between and complement existing facilities at NCAR. These include field data acquisition systems with real-time display capabilities and the batch-oriented CRAY/7600 computer. The general purpose of the RDSS is to allow the user to interact with the data to produce and analyze high-resolution color images.

Heavy scientific use of RDSS ranks as the number one feature during the last year. System use was so high during the summer that evenings and weekends were constantly scheduled and still users "stood in line." We look on activity of this sort as exactly what should happen to a successful project.

Two application programs matured and created much of the increase in use. One of these programs allowed users to rapidly peruse large volumes of data in an interactive fashion. Users could, during a session, display the images of a data set and document them as 35 mm slides and/or 11"x11" color printer output. This quick-look capability was used to determine those days and times during storms when significant events occurred.

Selection of an event started a second process of intensive use and interaction with RDSS. This time, detailed editing and unfolding of scan volumes would occur. For example, a scientist could typically unfold and edit out bad data for an entire volume in about 10 h. This compares to a clock time of 10 days for the same type of data processing, using the CRAY/7600.

This result is dramatic and impressive until one considers the availability of the RDSS for multi-Doppler analysis. The present RDSS computer restricts this editing capability to two or three non-simultaneous users on a 24 h/day schedule. Time-share competition from other types of users during the regular 40 h work-week slows the rate of editing. Therefore, while the present RDSS has been an unqualified success, expansion to a larger computer and additional peripherals to accommodate the long-term demand is required.

In preparation for the next three years, UCAR user needs for RDSS support are being thoroughly studied. CCOPE and JAWS, because of the interaction across administrations and facilities, will increase both the quantity and complexity of the data to be processed. As a result of this anticipated use, much time from all the RDSS staff has been concentrated on future preparations to support these needs.

Safesonde. The Safesonde is one of the major design and development efforts in RSF at this time. It involves the following team of engineers and technicians: Harold Cole (Team Leader), P.K. Govind, George Saum, Ken Norris, Dean Lauritsen, and Jim Ziese. RSF has the overall responsibility for the project and is collaborating with NCAR's Global Atmospheric Measurement Program, which is designing the balloon system and the launching mechanism. The team has also worked very closely with Dr. Barnes in the NOAA SESAME Project Office for definition of the meteorological specifications and with NCAR's Field Observing Facility for logistical and operational requirements.

The Safesonde system is being designed to meet three major objectives. The first objective is an atmospheric sounding system with improved accuracy over the existing GMD system. The need for improved accuracy is dictated by the requirements of mesoscale and regional scale research. The SESAME program is an example of such research. As the scale of the system decreases (i.e., synoptic to mesoscale), the requirement to make more measurements increases and the horizontal spacing (station spacing) between those measurements decreases. With this decrease in horizontal spacing the amplitude or gradient of the meteorological variables (e.g., wind speed, temperature, humidity) becomes smaller, thus requiring an increased accuracy in the measurement of those variables. A key requirement for the system is to significantly improve the accuracy of the wind speed measurement compared with the existing GMD 1. The goal for wind speed is 0.5 m/s for a 30 s averaging period when the sonde is at a range of 100 km and an altitude of 15 km. The design goal for temperature is $\pm$ 0.25°C and for humidity is $\pm$ 3%. In the altitude range of 0-15 km, height accuracy will vary from 10 to 100 m.

A second major objective of the program is to reduce the hazard to aircraft in the event of a collision with the sonde. The design approach taken to meet this objective is to reduce the sonde mass and mass density. The goal for the program is to produce a sonde that has a weight of 200 g or less and a lineal mass density not to exceed 0.5-1.0 kg/m.

The third objective of the Safesonde system design is simple logistics and operation. The system will be portable, will use simple omni-directional antennas, and will be suitable for one-man operation. The data output will be in scientific units and in real time with the additional capability of automatically producing coded messages for transmission to a data center as needed.

As a result of last year's effort in analyzing the various types of tracking techniques, the range-angle method was selected for the Safesonde system. The proposed system will consist of four tracking stations in a "Y" configuration. The primary station will be located at the center and will contain the ranging transmitter and the computer, control, and data processing equipment. The central station also will be the site for launching sondes. The other three stations will be radio repeaters located at the tips of the Y . They will receive sonde transmissions and retransmit those transmissions to the central station. The ranging measurements then will consist of one direct range measurement at the central station and three-range difference measurements. To meet our third objective (simple logistics), the spacing between the central station and the three remote stations will be on the order of 1-2 km.

This year's effort has been concentrated on laboratory and field tests of the ranging technique. A breadboard sonde simulator and central station simulator have been built and tested in the laboratory and in a series of field tests. The results have been quite encouraging but have uncovered several engineering problems that require solutions. A redesign of the sonde and base station receivers has already eliminated several of these problems. Additional laboratory and field tests are being made to verify the new designs.

Current plans call for the development of a prototype Safesonde tracking system and its test in FY 1981, first in the Boulder area, and finally at a test range such as Wallops Island or Cape Canaveral. Following the completion of tests, RSF will develop a complete portable operational system which NCAR's Field Observing Facility can take into the field in support of university and other research programs.

Lyman-alpha Hygrometer. This long-term effort, involving Arden Buck, Bryan Lee, and Michl Howard of RSF and James Tillman of the University of Washington, has produced innovative solutions to a long-standing problem in the meteorological community, and won Buck the 1980 NCAR Technology Advancement Award. The Lyman-alpha hygrometer now has become the preferred way to measure fast-fluctuating humidity.

The technique uses a source of UV radiation at the Lyman-alpha line (hydrogen lamp), and a detector (ion chamber) 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. This simple technique had been rejected by most meteorologists due to severe drift and linearity problems. The linearity problem was solved by sealing hydrated uranium into 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. Current work is aimed at improving the window seals and improving the free airflow characteristics of the sensor.

Three of the latest model Lyman-alpha hygrometers are now flying on NCAR aircraft. Two more were built for NOAA for use on the BAO tower. The University of Wyoming has also used Buck's design for airborne measurements, and the University of Nebraska is using it for agricultural studies. Buck's design is being used by other researchers in the U.S. as well as in Europe, Japan, and the People's Republic of China.

Calibration Laboratory. This facility has equipment to generate reference values of pressure, temperature, and humidity for both development work and for the calibration of working references and field sensors. Julian Pike and Bryan Lee made our first fully automated calibrations of pressure sensors at differing environmental temperatures during 1980. Humidity will soon have the same capability. These features will make possible quality sensor calibration to users of modest skill with very little staff time investment. Likewise, data for sensor development and characterization will be enhanced in quantity and quality at significant time savings through the automation of the previously labor-intensive calibration procedures. Our future work will be largely concerned with determination of the error limits of the reference values, improvements in operations, and eventual automation of temperature calibration as well.

Liquid Water Content. This project stemmed from a request by James Dye of the Convective Storms Division for development of a King-type liquid water instrument for the Explorer sailplane, and interest by the Research Aviation Facility for a similar instrument for powered aircraft. The Machine Shop developed the capability to build the sensors, and a laboratory version of the instrument was dry-tested in the NCAR wind tunnel by Julian Pike and Bryan Lee. Now, owing to the expected commercial availability of the King design, the project has been put on a lower priority and the goals have been narrowed.

Digital Barometer. Investigation of capacitance pressure capsules continued throughout 1980. Automotive ceramic types, after much testing, have proved to be insufficiently stable. Results with soldering sensor halves on a ceramic substrate are very encouraging. We initiated discussions with AIR, Inc. for commercial manufacture of the NCAR barometer, and have been working with them, by evaluating capsules they have produced. Julian Pike and Bryan Lee have provided routine calibrations for the PAM barometers, and are studying barometers designed for PAM II.

Boulder Intercomparison Project. Electronic weather stations from the Water and Power Resources Service, the National Severe Storms Laboratory, and NCAR were tested by FOF under Fred Brock's leadership in an intercomparison experiment at the Marshall field site during July 1980. Julian Pike of RSF was responsible for obtaining reference data with manual field instruments. Overall mean differences between the four NCAR PAM stations and the temperature reference data were very close to those obtained previously; we conclude that the system calibration is excellent. However, the variance in the individual means was sufficiently high to raise serious questions about using manual reference instruments for field calibration measurements. Alternate methods of on-site calibration checks are being considered.

PAM II Communications. During the past year George Saum has collaborated with Fred Brock in the design of the second-generation communications system for the portable automated mesonet (PAM II). PAM II data communications will use one or more channels of the Geostationary Operational Environmental Satellite. The principal effort this year has been directed toward procurement and installation of the earth terminal receiving equipment, including a 4.5 m antenna. In addition, several data collection platforms have been procured and are being fitted with sensors in preparation for evaluation in the Cooperative Convective Precipitation Experiment which will take place during the summer 1981 thunderstorm season.

Word Processing. RSF has played a key role in the establishment of word processing at NCAR. An RSF staff member, Lynn Post, headed the Word Processing Committee one year ago and won the 1980 Research Support Award for that effort. She continues to be instrumental in the implementation phases of the project during this year. Lynn coordinated the four-week in-house training program for 42 NCAR operators following installation of fifteen systems in October. Small training sessions were designed with emphasis on specialized applications and individualized instruction. The systems are now operating in five NCAR divisions. Each division maintains control and direction of their system and procedures; continued support is provided for all divisions for solution of common problems and special application seminars. Study of communication options is in progress.

WEFAX and APT. WEFAX photos from the GOES satellites of nearly a hemisphere of the earth are transmitted every half hour. APT photos from the NOAA-6 polar orbiter are available whenever the satellite is within radio range--nominally one or two passes every twelve hours. RSF took over a receiving and display unit obtained from MONEX and it was returned to operating condition by Dale McKay. He has also automated the antenna tracking for polar orbiters. The data, Laser-fax photos, are supplied to David Baumhefner of the Atmospheric Analysis and Prediction Division and will eventually be directly accessible to users of the RDSS.

GLOBAL ATMOSPHERIC MEASUREMENTS PROGRAM

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

The completion of the Global Weather Experiment in December 1979 drew a close to over ten years of activity in development of vehicles and sensing systems to provide global measurements for the GARP programs. The data from 313 superpressure balloon flights in 1979 were made a part of the GARP archives. These balloon data, however, provide additional information when considered as Lagrangian probes rather than as a means for obtaining discrete wind vectors at synoptic times. The Global Weather Experiment data are being reanalyzed and a movie is being prepared on the trajectory data for all 313 flights.

New development programs were started on a microGHOST system to provide wind data at low cost in the midlatitudes as an integral part of the World Weather System; a radiation-controlled balloon, RACOON, to provide a vehicle for measurement of winds, gases, and aerosols in the stratosphere; and a technique for obtaining real-time upper air wind data from ships.

Accomplishments of the Past Year

STREX

Early in CY 1980, GAMP was asked to investigate the feasibility of obtaining real-time wind data from the NOAA research vessel, Oceanographer, and from the Canadian weather ship, Vancouver. These data were needed as part of the Storm Transfer and Response Experiment (STREX) scheduled for November and December 1980. The plan was to use Omega shipboard sounding systems which had been deployed during the Global Weather Experiment. These systems had been designed for post-processing of data recorded on shipboard cassettes and mailed to Finland. A ship-to-NCAR satellite link had to be designed and developed. Despite grave difficulties in interfacing, incompatible equipment, and operation under the severest storm requirements, the system worked. A total of 381 soundings were made from the Oceanographer and Vancouver. The Oceanographer had no means for launching balloons under high wind conditions. A launcher was built which is now the prototype for an automatic balloon launcher for remote sites as well as for ships. The technique developed for launching balloons and transmitting sonde data via satellite link is now being considered by NOAA and the Canadian Weather Service for operational use on container vessels in the Pacific to replace the ocean-weather station, Papa--a ten million dollar per year operation.

RACOON

The RACOON is a low-cost polyethylene balloon flying at 35 to 40 km during the day and at 20 to 25 km at night for 30 days or longer without ballast. Soundings of wind and temperature can be made during the dawn ascent and the sunset descent. The technique is also usable for vertical sampling of gases and aerosols in the stratosphere.

Flights were made from French Guiana in September 1980 with durations of 27 and 38 days. The balloons performed exactly as predicted. Future flight series are planned to explore all of the exciting potential of this newest sounding technique.

Middle Atmosphere Program (MAP)

GAMP and Robert Holzworth of the Aerospace Corporation prepared a joint proposal to study the electrodynamics of the middle atmosphere. The proposal calls for a total of eight superpressure balloon flights from the GHOST Flight Station in New Zealand. The research team includes Aerospace Corporation, Cornell University, and Utah State University. The proposal has been received favorably, and if awarded, will provide a strong backgound flight program for GAMP through 1983. Microprocessor control and telemetry systems as well as transmitter designs will be applicable to RACOON and other programs.

The Long-Lived Atmospheric Monitoring Airship (LLAMA)

The objective of this program is to develop and fly a balloon system capable of flight at 20 km for several years. Since the average meridional velocity at 20 km approaches zero, modest power capabilities will permit the vehicle to move to an appropriate latitude belt for a particular experiment. Two 3 m spheres were fabricated and tested in 1980 to determine the operation of the ballonet system and the characteristics of the metallized laminate planned for LLAMA. After completion of tests on the 3 m spheres, the design for the LLAMA flight balloon of 14 m diameter was modified to correct problems uncovered in model tests. The flight balloon was fabricated and shipped to Christchurch for a flight in January 1981.

MicroGHOST

A joint program was instituted with Goddard Space Flight Center during 1980, leading to the development of an improved location and telemetry system for balloons and other low-cost mobile platforms. Prototypes of the low-cost frangible designs will be flown in 1981 to demonstrate the feasibility of an operational system with balloon and electronic costs per flight of $500 or less. The basic balloon design, the "tetrasphere," was tested in 1980 and performs as well as the spherical superpressure balloon at a cost of 20 percent of the sphere.

NATIONAL SCIENTIFIC BALLOON FACILITY

Mission

The mission of the National Scientific Balloon Facility (NSBF) is to provide reliable and efficient operational balloon support to the scientific community and to conduct the research and development programs necessary to meet the changing requirements of our users.

Accomplishments of 1980

NSBF flew a total of 54 flights in 1980. Forty-nine of these were in support of scientific experiments, four were test flights and one was a training flight. Eight flights were flown from remote locations, four from Pierre, South Dakota, and one each from Malden, Missouri, Stuttgart, Arkansas, Canada, and Sicily.

The number of flights in support of atmospheric sciences remains significant, amounting to 27% of the total scientific flights. Other disciplines supported were cosmic ray physics and infrared astronomy, as well as X-ray, gamma-ray and ultraviolet studies. A total of 31 U.S. and foreign institutions were supported during the year.

A new system of preventive maintenance has been adopted by the operations electronics department to ensure the reliability of ground-based equipment.

The balloon control tower and scientific data retrieval areas of the new staging building were put into operation. New equipment was installed to make it possible for simultaneous flights.

Voice relay, through the balloon platform, has become standard on all flights and has proven to be an aid to communications between the aircraft and ground bases.

Microcomputers, for the processing and display of flight parameters, have been placed in operation in the control tower. The processed information is also logged for future use in flight analysis and to aid in balloon development.

A microcomputer has been placed into service in the meteorological section and a program to determine parachute descent times has been completed. This new capability has resulted in more accurate predictions for descent trajectories and impact times.

Two shop vans have been modified and equipped for mobile operations. These vans are maintained on ready status for quick reaction to remote flight requests.

A new mobile launch spool trailer has been procured for remote site use. The trailer is designed to be easily transported to remote

U.S. and overseas locations.

Equipment developed at Texas A & M University through NSBF grants was moved into the new engineering laboratory and prepared for use. Much of the equipment will be interfaced to the NSBF engineering computer with data presentation automated through use of a digital plotter.

The refined Smally balloon design program developed by Rand is now on line and is being modified to run on NSBF equipment. Using this code as a starting point, NSBF engineers plan to develop a completely automated design code over the next several months.

Computer programs for "Sky Anchor" long-duration balloon systems, developed by NSBF, have been refined and updated to handle hydrogen inflations. Other associated programs are under development to provide automated load-altitude curves for complete "Sky Anchor" systems and for design estimation of balloons to fit a particular requirement.

In an effort to clearly define the state of the art of scientific balloon design and to provide NSBF operations personnel a consistent product with which to work, an NSBF specification was issued for zero-pressure balloons. It has already proven helpful in simplifying the balloon selection process.

The joint NSBF-NASA heavy lift balloon program has come to a successful close.

The close inspection of a new 41.47 MCF balloon directly from the shipping box proved to be a most notable work this year. The inspection at NASA-Wallops Island included NASA, NSBF, and Winzen International, Inc. (WII) personnel. The result of the inspection was an immediate and positive reaction by WII to improve quality control.

Several improvements to scientific ballooning resulted from the heavy lift program. Beyond the obvious increased awareness by the ballooning community, some of the tangible improvements are:

1. The soft collar has become operational.

2. Balloon designs have been standardized.

3. A 36" diameter launch roller has become operational.

4. Quality control has been improved in production.

A successful test flight of a balloon with an external cap was flown on 26 February 1980. The 169,901 m^3 balloon carried a payload of 1817 kg to 29.9 km. Other than the external cap, construction was identical to standard balloons with internal caps. Advantages of an external cap are:

1. Added gas barrier protection during inflation and launch

2. More structural effect of caps at float

3. UV protection for the gas barrier.

A Sky Anchor XI long-duration balloon system was launched from Malden, Missouri, in May 1980. The system was comprised of a 116,949 m^3 zero-pressure balloon and a 227 kg payload, and a 35,396 m^3 superpressure balloon. The balloon system remained aloft for 104 h at a daytime float altitude of 36.3 km.

In July 1980 a test flight was conducted from Stuttgart, Arkansas, to obtain radiometric data pertinent to a balloon system's thermodynamics response.

Considerable engineering effort was directed at monitoring the NASA Tracking Data Relay Satellite System (TDRSS) transmitter contract, and issuing a request for proposal, for the long-duration (L/D) electronics package. The TDRSS transmitter contract is nearing completion and acceptance testing will begin shortly. Bids have been recieved on the L/D electronics platform, but a contract has not been awarded.

The new Consolidated Instrument Package (CIP), design is very near completion. Final wiring and assembly of the prototype should begin early in 1981.

Members of the NSBF staff presented a total of four (4) papers at two conferences in 1980.

COSPAR XXIII June 1980, Budapest, Hungary

"Developments in Balloon Stress Analysis", James J. Rotter, P.E.

"The Development of Plastic, Zero-Pressure Balloon Design Since 1945", Keith H. Hazlewood

"Advances in Long Duration High Altitude Flights, Alfred Shipley

International Telemetering Conference, October 13-16, 1980, San Diego, California

"Scientific Balloon Telemetry, Command and Data Recording" Oscar L. Cooper, Ph.D.

National Scientific Balloon Facility Users

J. Adams	Naval Research Laboratory
J. Anderson	Harvard University
J. Benbrook	University of Houston
A. Boksenberg	University College, London
A. Buffington	California Institute of Technology
A. Clark	University of Leeds, England
E. Chupp	University of New Hampshire
A. Dean	University of Southampton, England
J. Drummond	NOAA
W. Evans	AES, Canada
G. Fazio	Smithsonian Observatory
G. Fishman	Marshall Space Flight Center
F. Frontera	TE.S.R.E., Italy
P. Fowler	Bristol University, England
L. Haser	Max-Planck Institute, Germany
M. Hauser	Goddard Space Flight Center
W. Heaps	Goddard Space Flight Center
W. Huntress	Jet Propulsion Laboratory
R. Jennings	University College, London
V. Jones	Louisiana State University
D. Kniffen	Goddard Space Flight Center
M. Leventhal	Sandia Laboratories
W. Lewin	Massachusetts Institute of Technology
J. Lord	University of Washington
E. Maier	Goddard Space Flight Center
P. Marsden	University of Leeds, England
K. Mauersberger	University of Minnesota
A. McFall	AGDA, Canada
J. Mentall	Goddard Space Flight Center
D. Mueller	University of Chicago
J. Nishimura	University of Tokyo, Japan
T. Parnell	Marshall Space Flight Center
M. Pelling	University of California, San Diego
M. Pettini	University College, London
B. Price	University of California, Berkeley
D. Rees	Univeristy College, London
G. Ricker	Massachusetts Institute of Technology
C. Seaman	Jet Propulsion Laboratory
R. Staubert	Astronomisches Institute, Germany
B. Teegarden	Goddard Space Flight Center
W. Traub	Smithsonian Observatory
P. Ubertini	Laboratory TE.S.R.E., Italy
J. Vallerga	Massachusetts Institute of Technology
R. van Duinen	University of Groningen, The Netherlands
G. Villa	University of Milan, Italy
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Terry Kelly
A. Alexander Kennel
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Robert McBeth
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Vincent Lally (Manager)
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Ernest Lichfield
Claude Morel
Ranjit Passi
A. Brewster Rickel
Chris Roark
Aubrey Schumann
Sigvard Stenlund
Jack Tefft
Marcel Verstraete

Visitors

David Davidson) Co-op students from Univ. of
Jerry Stooksbury) Tennessee, alternating 3-month
visits during year.

National Scientific Balloon Facility

Danny Ball
John Bennett
Charles Burris
James Carroll
Grady Cole
Robert Collett
Oscar Cooper
Ron Costlow
Alice Cradler
J.R. Crocker
Bruce Cunningham
Harold Dean
Ricky Dean
Danelle Dickens
Lawrence Farley
Bettie Furman
Don Gage
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Earl Smith
Steve Smith
John Sparling
Howard Stone
Joe Taylor
Virgil Vice
Jeanann Walding
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 1980 are listed below. 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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BRETHERTON, F.P., and J.C. McWILLIAMS, 1980: Estimations from irregular arrays. Rev. Geophys. Space Phys. 18, 789-812.

BROWN, J.M., and J.B. KLEMP, 1980: Water budgets of numerically simulated cumulonimbus clouds. In Preprint Vol., Eighth Conference on Weather Forecasting and Analysis, 10-13 June, Denver, Colo., AMS, Boston, Mass., 212-218.

BROWNING, G., A. KASAHARA, and *H.-O. KREISS, 1980: Initialization of the primitive equations by the bounded derivative method. J. Atmos. Sci. 37, 1424-1436.

CARR, M.B., 1980: On Determining the Number of Predictors in a Regression Equation Used for Prediction. Cooperative Thesis NCAR/CT-59, NCAR, Boulder, Colo., 261 pp.

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COAKLEY, J.A. Jr., 1980: Stratospheric aerosols and the tropospheric energy budget: Theory vs. ground-based observations. In Proc. International Radiation Symposium, 11-16 August, Fort Collins, Colo., Colorado State University, Fort Collins, 4-6.

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----- and *-----, 1980: A parameter study of the mixed instability of idealized ocean currents. Dyn. Atmos. Oceans 4, 185-215.

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