National Center for Atmospheric Research
Annual Scientific Report
April 1978-March 1979

Submitted to National Science Foundation
by
University Corporation for Atmospheric Research
July 1979

CONTENTS

INTRODUCTION

The UCAR-NSF contract for the operation of NCAR calls for UCAR to submit to NSF an annual scientific report "containing a scientific description of all programs conducted by NCAR staff and NCAR visitors during the previous year." The contract stipulates that the report should "include a description of the scientific problems placed in a larger context, accomplishments, and a listing of papers published."

This document is designed to respond to that contract provision, and has as its primary audience those NSF staff members responsible for monitoring UCAR's performance in the operation of a national laboratory under NSF sponsorship.

For each division of NCAR, we first present an overall statement of strategies, objectives, and major problems and tasks of the past year, followed by more detailed reports of the activities of the groups within those divisions. The report is intended to show the overall design of NCAR scientific and facilities programs and to give a general description of program activities. The purpose is to allow perceptions to be formed of the ways in which programs and activities described in the Program Plan for the upcoming year are linked to NCAR's programs and activities of the past year.

This document thus stands at a point between our future plans, as described in the Program Plan and in other, longer-range planning documents submitted to NSF, and two more detailed kinds of documents on NCAR's current and past work. These are, first, scientific publications and technical reports, which are listed in this document; second, the documents prepared for the review panels of the Scientific Programs Evaluation Committee (SPEC), which reports simultaneously to UCAR and to NSF. The SPEC process, which covers all NCAR activities on a three-year schedule, constitutes a rigorous, in-depth review of NCAR performance.

This report reflects the many modes of activities at NCAR: collaborative work among NCAR scientists and university colleagues; the work of individuals and small groups clustered around a central theme; major organized research efforts requiring extensive field experiments; direct facility support to university and other outside scientists; participation in and support of national and international atmospheric research efforts; improvement, development, and deployment of advanced computing capabilities and observing and data-handling techniques and resources; and a wide variety of techniques for bringing together atmospheric scientists on national and international scales to assess the state of knowledge in given areas of atmospheric science, to identify promising paths for future research, and to allow scientists to determine how their own research interests fit within the mosaic of scientific work required to attack the major fundamental problems presented us by the atmosphere.

Our challenge is to maintain healthy balances among current collaborative projects and the work of individuals that prepare us for future collaborations; between research and facilities activities; and between development of capabilities and services to meet current needs. We are mindful of the practical need for knowledge of the atmosphere to assist in enabling us to live in harmony with our atmospheric environment, and at the same time, the vast amount of fundamental work that lies between us and the greatest usefulness of atmospheric knowledge.

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

ATMOSPHERIC ANALYSIS AND PREDICTION DIVISION

OVERVIEW OF RESEARCH ACTIVITIES

Introduction

The Atmospheric Analysis and Prediction (AAP) Division is composed of four sections with specific research interests in climate, oceanography, large-scale atmospheric dynamics, and mesoscale phenomena, as shown in the following table of organization:

Atmospheric Analysis and Prediction Division (Leith)

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

A general description of the AAP research directions was provided in the Annual Scientific Report last year. In this first section of the report this year we describe some shifts in emphasis and some highlights of research activities during the year. In the following sections more detailed descriptions of research activities and directions are provided by the staff. Of course, the final measure of research progress is provided by the list of publications, but these lag behind current research activities by a year or so.

Climate Research

Climate research in AAP is directed toward the second objective of NCAR and of the Global Atmospheric Research Program (GARP), i.e., the understanding of the dynamics of the climate system. Climate system research is a major component of the U.S. National and the World Climate programs to be carried out in the 1980s. The AAP climate research effort is intended to complement that in the university community. It concentrates on studies of the physical process to which the climate is sensitive, the proper treatment of these processes in a global general circulation model (GCM) suitable for climate studies, and the analysis of climatological data sets to provide an observational basis against which the model climate may be compared.

Climate Processes

The energy budget of the earth is largely determined by the radiative properties of the atmosphere and the surface. Basic improvements are being made in the calculation of the interaction of radiation with particles, and they are permitting more accurate treatments of the climatological effects of dust, clouds, and snow albedo. Improved treatment of the absorption of radiation by CO_2 is increasing confidence in estimates of the sensitivity of climate to CO_2 changes. The interaction of clouds and radiation is being studied through an analysis of satellite radiance signals.

Zonally symmetric energy balance models have served a useful role in the study of climate sensitivity questions, but attention is now turning to more realistic asymmetric models.

Observational Studies

Further progress has been made during the year on the determination of the unpredictable climate noise in midlatitudes and the identification of potentially predictable signals of climate variability above the noise level. Large-scale patterns are being examined for improved signal-to-noise ratio.

The structure of a westward-propagating planetary Rossby wave with wavenumber one has been determined. The consequences of its interaction with standing wave components are being studied.

Further studies are elucidating the details of a large-scale, slowly changing component of atmospheric circulation and its association with anomalies in sea surface temperature and sea ice.

General Circulation Model (GCM)

The third-generation GCM has been shown in preliminary tests to provide a much more realistic simulation of the temperature and wind structure of the atmosphere than did the second-generation model. The model contains a far more careful treatment of solar and infrared radiation, clouds, and land surface processes. The effects of soil moisture and vegetation on albedo and evapotranspiration are included. A floating sea ice model suitable for coupling to the GCM has been developed and work is progressing on an ocean circulation model.

The inclusion of many new physical processes in the model now permits experiments to determine the sensitivity of model climate to these processes. Emphasis is now shifting toward the carrying out of these experiments in collaboration with colleagues in the university community. Further progress has been made in developing the appropriate methodology so that statistical significance will be clearly known. Attention here is turning to the determination of the statistical significance of perceived changes in climate variances which, depending on their magnitude, may have greater socioeconomic impact than do changes in climate means.

Oceanographic Research

The ocean plays an important role as a regulator of climate. A large part of the heat transport from the equatorial regions towards the poles that is needed to maintain the energy balance of the globe takes place in the oceans, but by which of several mechanisms is not clear. Thus it will not be possible to understand fully the workings of the climate system without an understanding of the general circulation and heat transport properties of the ocean and the interaction of the oceans with the atmosphere. The greatest observational and theoretical hindrance to such understanding is provided by mesoscale eddies.

AAP oceanographic research is focused on determining the roles of these eddies in the ocean general circulation. Progress has been made in simulating with eddy-resolving models the ways in which eddies limit the growth of large-scale current systems. Turbulent channel flow studies simulating the Antarctic Circumpolar Current have shown the role of eddies there.

The equatorial oceans appear to be more clearly coupled to the atmospheric climate than are those in midlatitudes. A simple model is displaying the nature of this coupling. Successful simulations of many features of the equatorial oceans have been carried out with high-resolution models on the CRAY-1 computer. Further observations are needed and these can be provided by surface drifting buoys, which are being planned as an NCAR contribution to a national program in this area.

The geophysical fluid dynamics commonality of oceans and the atmosphere has led to some atmospheric results from ocean research. Modons, initially studied as models of ocean eddies, appear to be relevant to the theory of atmospheric blocking. The turbulent channel model is being used for studies of the impact of frontal-scale potential vorticity structures on the predictability of atmospheric flows. And fundamental studies of semi-geostrophic isentropic dynamical equations are relevant to all geophysical flows.

Large-Scale Dynamics

Research on numerical weather prediction in recent years has shown that models tend to agree with each other in their forecasts more than with the atmosphere. Little progress is likely to be made therefore by minor tuning of numerical procedures. Emphasis has shifted to more fundamental studies of the large-scale dynamics of the atmosphere.

Particularly rapid progress has been made during the last few years in understanding the properties of the material slow motion of the atmosphere on the nonlinear slow manifold in the phase-space of normal modes of the dynamical system. Not only has the problem of initializing primitive equation models finally been solved after two decades, but the nonlinear normal-mode initialization procedure is providing new diagnostic insight into the nature of balancing secondary ageostrophic circulations.

In order to apply these new techniques to regional models of limited computational domain, the normal modes of such models must be identified. Work is progressing on this problem as part of general research with limited-area models.

A comparison of forecasts made with a hemispheric and a global model has shown that in certain synoptic situations midlatitude forecasts are influenced by equatorial data and dynamics within a couple of days. Opposite conclusions arrived at by experiments at NCAR and the Geophysical Fluid Dynamics Laboratory (GFDL) more than five years ago were apparently prematurely based on an inadequate set of situations. The tropical data set being acquired during the Global Weather Experiment (First GARP Global Experiment, FGGE) will be particularly valuable in studying this question.

Work continues on the properties of observing systems and the optimal representation of data. Progress has been made in understanding the errors in temperature derived from Nimbus 6 radiances, which has relevance to Tiros-N observations.

Mesoscale Research

The mesoscale research in AAP focuses on the interaction of convective storms with their environment, the dynamical and eddy transport properties of atmospheric boundary layers, and meteorology on scales smaller than can be resolved by the conventional radiosonde network.

The modeling of convective storm cells has shown remarkable success in simulating storm cell growth, splitting, and right and left motions in agreement with observations. It appears that such storms may have greater predictability than expected. In any case, studies of predictability and sensitivity to large-scale environmental properties are now possible and are being pursued.

Studies of horizontally homogeneous boundary layers have been made for some decades. But in reality boundary layers are seldom even approximately homogeneous and research is focusing on inhomogeneous cases. It has been found that even slight terrain variations can induce inhomogeneities in the stable nighttime boundary layer. This research combines the use of the Boulder Atmospheric Observatory (BAO) tower observations for vertical structure with aircraft observations of horizontal variations.

Aircraft observations of the mixed layer in the GARP Atlantic Tropical Experiment (GATE) region have been analyzed with particular attention given to cloud interactions. A numerical model of the mixed layer with clouds and precipitation is showing good agreement with observations and permits detailed studies of the relationship of cloudiness to vertical turbulent fluxes of heat and moisture.

The limited-area model developed by a group at Drexel University has been successfully converted to the CRAY-1 computer with adequate documentation to make it available as a general tool for meteorological research on the subsynoptic scale. It is ready to be used, in particular, in the analysis and simulation of the Severe Environmental Storms and Mesoscale Experiment (SESAME) April 1979 observations.

Divisional Research

Some research in AAP is carried out by scientists who are assigned to the divisional office rather than to any of the four research sections.

Richard Grotjahn (Florida State University graduate student) has completed his dissertation on the influence of thermal fronts on the stability, structure, and growth rates of midlatitude wave-cyclones. He finds that frontal structures decrease the scale of growing disturbances and that a competition exists between barotropic and baroclinic instability mechanisms.

Meg Carr (Florida State University graduate student) is completing her dissertation on the effect of finite sample size on the accuracy of multiple regression methods. She has completed a comparison of the Model Output Statistics procedures of the National Weather Service with theoretical expectation and found good consistency with estimates not requiring the use of independent data sets for checking purposes.

Cecil Leith has continued some research on statistical mechanical aspects of the predictability of climate with the development of estimates of climate noise obscuring changes in variance. He has also been analyzing the nature of prediction errors and associated empirical correction of dynamical models.

His principal research during the year has been on nonlinear normal-mode initialization. He has completed an analysis showing that the first iteration of the procedure for a simple f-plane model leads to vertical velocities in agreement with those arising from the ω equation of classical quasi-geostrophic theory. He defines a quasi-rotational dynamics agreeing only in this simple case with quasi-geostrophic dynamics but which is easily applied to a β plane or rotating sphere. He has shown in this work how the slow manifold of atmospheric motions is being approximated in various theories and suggests a modification of the initialization procedure for quasi-geostrophic or quasi-rotational models to represent better the dynamics on the slow manifold of the primitive equation system.

Turbulence Research

Jackson Herring's research during this period was devoted to investigations of (1) a statistical formulation of Jule Charney's (MIT) quasi-geostrophic turbulence theory, (2) a study of the theory of turbulent bispectra, and (3) a continuation of the passive scalar study, in collaboration with Gerald Newman (Southeastern Massachusetts University). All of these projects were completed during this period; the publications on the passive scalar study problem are listed at the end of this volume, while reports on the other two topics have been submitted for publication.

The dynamics of quasi-geostrophic turbulence, as formulated by Charney, consist of horizontal advection of the total three-dimensional vorticity field. Charney proposed (mainly on heuristic grounds) that the small scales of such motion would be three-dimensionally isotropic, an assumption seemingly at variance with the absence of vertical advection. In order to understand this issue, the apparatus of the statistical turbulence theory was applied to homogeneous quasi-geostrophic flow. The study indicated that the small scales indeed tended toward three-dimensional isotropy, albeit slowly. The large scales, however, tended toward two-dimensionality, with the separation between two- and three-dimensionality near the energy peak wavenumber.

Bispectra are a type of third-order moment of the turbulent fields, and are sensitive measures of the effectiveness of nonlinearity in the dynamics of a random system. Recently, a group at the University of California at San Diego (Charles Van Atta and Kenneth Helland) have made extensive measurements of turbulent bispectra over a large range of Reynolds numbers. The present study was undertaken to assess the accuracy of a particular theory (the test field model) in predicting bispectra. Theory and experiments were found to be in moderate accord at both large and small Reynolds numbers. The theory was also found useful in exploring the sensitivity of the bispectra to various dynamical issues. It is planned to continue this project and examine bispectra for a scalar field.

The passive scalar study was undertaken some time ago in collaboration with Newman. The theory's accuracy was first assessed by comparing it with experiments over a range of Reynolds numbers and other parameters of the flow. The more recent study utilizes the theory to obtain turbulence rate coefficients needed in engineering studies of the turbulent convection of a scalar-like temperature or humidity, and to understand some recent experiments of Z. Warhaft and John Lumley (Cornell University).

During the first three months of this period (April-June), Herring was the Green Scholar at the Institute for Geophysics and Planetary Physics of Scripps Institution of Oceanography.

CLIMATE SECTION

Introduction

The Climate Section, headed by Robert Dickinson, continues its work on several objectives of NCAR and of GARP--to understand climatic trends and their causes. The section is subdivided into three groups, each of which is studying different aspects of the climate problem. The Climate Sensitivity Group (CSG) is headed by William Kellogg (presently on leave to the World Meteorological Organization). In his absence, Stephen Schneider is acting head. The Empirical Studies Group (ESG) is led by Chester Newton and the Global Climate Modeling Group (GCMG) by Warren Washington.

CSG is concerned primarily with the relative importance and mechanics of the processes which control the sensitivity of the climate to variations in external factors, e.g., solar output, atmospheric gases and particles, or surface characteristics. They use a hierarchy of models to study climatic sensitivity and perform some limited data analyses to support model development and sensitivity studies.

ESG takes the observational approach to improving our understanding of the climate system and its variations. They are evaluating the past climate variation on a time scale of weeks to decades. They hope to estimate by statistical measures how much of the observed climatic variation appears predictable.

GCMG is primarily responsible for the development, testing, and operational aspects of the large three-dimensional climate GCMs.

Although each group is administratively separate, all interact in many ways to work toward the common objectives of the Climate Section.

Physical Process Studies

CSG emphasizes the study of physical processes involved in climate sensitivity. One approach, detailed radiative calculations, has been used by Warren Wiscombe on a number of processes basic to climate sensitivity studies. These include:

Radiation in Sahara Dust. Toby Carlson (Pennsylvania State University) and Wiscombe completed a series of calculations, using Wiscombe's detailed radiation model and Carlson's GATE data, of the radiative heating rates and of the radiative balance at the surface and the top of the atmosphere during typical Sahara dust conditions. (These results may be expected to apply to dusty conditions caused by any of the world's deserts.) Salient results were that, for the total radiation (short-wave and long-wave), the net flux at the top of the atmosphere was almost independent of the dust amount, but that there was a dramatic redistribution of heating within the atmosphere; in particular, there was a net heating instead of the usual cooling in the trade-wind layer below the dust.

Mie Theory and Geometrical Optics. Wiscombe is pursuing these strategies in order to reduce computer time for Mie calculations:

(1) A head-on approach of developing Mie programs using the most efficient possible numerical approaches; these programs and an NCAR Tech Note describing them are now completed and are factors of ten to 30 faster than what has heretofore been available;

(2) Moysés Nussenzweig (University of São Paulo, Brazil) and Wiscombe have developed correction terms to geometrical optics which make this approximation much more useful for moderate- to large-size spheres, the ones responsible for the lengthiness of Mie calculations.

Nonspherical Particle Scattering. A serious criticism which has been leveled at radiative transfer calculations for ice clouds and dust is that they have relied on Mie calculations, which apply only to spherical particles. Therefore Alberto Mugnai (Laboratorio di Ricerca e Technologia Perlo Studio del Plasha Necco Spazio) and Wiscombe inaugurated a study of the exact scattering properties of a special set of moderately nonspherical particles in the hope of finding to what extent these properties could be mimicked by using "equivalent" spheres. They used a method which solves Maxwell's equations exactly for almost arbitrary concave or convex particles, and found to what extent averaging over size and/or orientation brings the results into better agreement with Mie theory. In our initial studies we investigated the absorption and scattering cross-section and found that, averaging over orientation, the results for equal volume spheres were within 10% of those for moderately nonspherical particles.

Snow Albedo. Stephen Warren (visitor to the Climate Section) and Wiscombe put together a simple model of spectral snow albedo, using just the one-layer delta-Eddington approximation, Mie theory, and measured ice refractive indices. For semi-infinite snow (deeper than about 50 cm) the model has but a single parameter--the mean grain size--which can be estimated on a climatological basis. Its predictions agree well with measurements, particularly for the change in the spectral albedo curve as the snow ages, which is the result of increasing the mean grain size with age in a way which is entirely consistent with observations.

Radiative/Convective Models. Another approach to process studies is through the use of radiative/convective models. V. Ramanathan has used such models to develop radiation parameterizations for use in the NCAR GCM (described in the GCM section of this report). He also (with Robert Cess and Thomas Owen of the State University of New York at Stony Brook) has used a radiative/convective model to study the possible effect of an enhanced CO_2 greenhouse effect as a compensation for reduced solar luminosity for the primordial earth. They conclude that such an effect could have maintained an equable climate, even if the solar constant were substantially reduced, but only by including in their radiation calculation the effects of CO_2 "hot bands," neglected in most other such studies.

Albedo Parameterization. Starley Thompson (now at the University of Washington) developed while at NCAR a zonal albedo parameterization for use in energy balance models. It includes the effect of zenith angle dependence of cloud albedo. He finds that more than half of the seasonal cycle of planetary albedo in midlatitudes can be attributed to zenith angle effects, and the remainder can be related to surface albedo effects (snow cover) associated with surface temperature variations.

Cloud/Radiation Studies from Satellite Data. A third approach to cloud/radiation studies has been undertaken by James Coakley, namely, to obtain cloud distribution and optical properties directly from satellite observations. He is using National Meteorological Center (NMC) analyses of temperature and moisture fields to compute clear-sky radiances, and is using the differences between these radiances and the observed radiances to determine cloud properties. The algorithm for retrieval from the High-Resolution Infrared Radiation Sounder instrument has been under development, and results are not yet available.

Climate Sensitivity Studies

Numerical Experiments. In addition to the radiative/convective model experiments described above and the GCM experiments discussed elsewhere, a number of climate sensitivity experiments have been performed with Energy Balance Models (EBMs). Coakley (with Gerald North, NASA) completed their work with a land/sea one-level EBM to simulate the seasonal cycle of temperature and the influence of orbital element variations.

(1) Influence of oceans on energy balance models. Schneider (with Thompson and Michelle Vidal) extended the Schneider/Gal-Chen zonal EBM to two layers by including a thermodynamically interactive lower layer. This model has been used to simulate the seasonal cycle of temperature, the effect of orbital element variations (i.e., the Milankovitch mechanism), and the effect of coupling between upper and lower oceanic thermal reservoirs on the approach to equilibrium of the zonal surface temperature after an external perturbation to radiative input. They find that, depending on the strength of this coupling, the e-folding time to reach equilibrium from a step-function increase in solar constant is delayed by some five to 20 years by the thermal effects of deep layers of the oceans. This could have important implications for the CO_2 problem, since all present CO_2 studies are equilibrium results.

(2) Validity of EBM Parameterizations. Schneider (with Warren) has examined the relative validity of heat transport, albedo, and infrared radiative parameterizations in the Budyko model through seasonal simulations. They find that the heat transport parameterization of Budyko is able to reproduce much of the observed seasonal cycle of heat transports in midlatitudes, but it has no predictive skill in the tropics. They conclude that uncertainties introduced into estimates of climatic sensitivity using a Budyko-type EBM are comparable for

each of these three parameterizations. The overall uncertainty remains at about an order of magnitude.

Data Analyses: Climatic Sensitivity to Volcanic Dust Veils. Schneider, Tzvi Gal-Chen (University of Toronto), and Billie Taylor (University of Toronto) extended the superposed epoch analyses of Clifford Mass (University of Washington) and Schneider (1977) using long-term temperature data to search for volcanic dust signals. This extended study used anomalies rather than absolute temperatures and considered seasonal and latitudinal resolutions. The study reconfirmed the Mass/Schneider conclusion that weak (i.e., 0.3°C) volcanic signal is present in long-term temperature records.

Studies of the General Circulation

ESG examines features in the global circulation through statistical analysis, numerical experiment, and large-scale observational programs to improve the description of atmospheric phenomena on wide scales of space and time: from convective clouds and fronts to the Southern Oscillation, large-scale traveling waves, and variability of climate. Newton has thus reviewed meanders in the Gulf Stream and compared them with the presumably dynamically similar waves in the atmospheric jet streams, and he conducted numerical simulation of fronts and frontogenesis. Paul Julian continued his participation in the Tropical Wind, Energy Conversion, and Reference Level Experiment (TWERLE), and together with Dennis Shea (Atmospheric Technology Division), Julian has analyzed the observations from this project (near 150 mb mainly on the tropics of the southern hemisphere). Special features of their analysis include a study of the characteristics of balloon dispersion and of inertial oscillations. At present Julian is also engaged in the field operations of the Global Weather Experiment.

Roland Madden has continued work on the following two problems: observational identification of large-scale traveling Rossby waves and estimation of the expected sampling variability of meteorological time averages. Most of his effort in the first of these has been directed at isolating the structure of westward-propagating zonal wavenumber one disturbances. The results of this work indicate that these disturbances behave in many respects like external Rossby waves that are predicted by tidal theory. Madden is now attempting to determine to what extent these waves contribute to daily variations in the large-scale general circulation.

The second problem relates to our efforts to recognize and understand climate change. The estimates of the sampling variability of time-averaged temperature, for example, provide a measure of a component of interannual variation that is unpredictable. Madden and Shea have pinpointed areas where the actual interannual variability exceeds this unpredictable component. While it may be that this additional variability is similarly unpredictable for the present, we can consider it to be at least potentially predictable. Madden is now expanding this work based on grid point data to include large-scale patterns in the hope that this analysis will minimize the unpredictable sampling variability and maximize the potentially predictable components. This further work may also provide insight into the nature of interannual climate change.

Harry van Loon, with two graduate students from the University of Colorado, Jeffery Rogers and Gerald Meehl, continues to examine interrelations of anomalous features of climate in different regions. As mentioned last year, they demonstrated that the well-known tendency for winter temperatures to be low over northern Europe in winter when they are high over Greenland and the Canadian Arctic, and conversely, is linked with well-defined pressure anomalies over most of the northern hemisphere, almost completely described by eigenvector one in the pressure pattern. Statistically significant, concurrent anomalies in surface winds, intertropical convergence zone, sea levels in the Gulf Stream, sea ice, and other features were identified, and clear associations were established between the anomalies and sea surface temperature before, during, and after the specified period.

In addition, van Loon examined variations in horizontal eddy heat transfer and their relations to meridional temperature gradients and linked them to the pressure and temperature trends at the surface observed since the 1940s. Jill Williams joined this investigation, which was extended to include regional connections in transfer of sensible heat by the quasi-stationary waves and regional relations between the eddy transfers and the zonal wind in the troposphere.

During the colder months, temperature trends over polar regions and continents at middle and high latitudes tend to be large at the surface but small and sometimes opposite in the middle troposphere. The large regional surface temperature trends often dominate the size and sign of the trend over the hemisphere. Williams and van Loon are examining the connection between stability of the near-surface layer and the size of surface temperature trends.

Development and Use of NCAR General Circulation Models

Development of atmospheric GCMs is being led by Dickinson, and the preliminary results of the third-generation GCM will soon be published by Washington, Dickinson, Ramanathan, Thomas Mayer, David Williamson (Large-Scale Dynamics), Gloria Williamson (Atmospheric Technology Division), and Richard Wolski.

The third-generation GCM replaces the second-generation GCM. Many deficiencies of the previous model have been substantially lessened, including aspects of the dynamical framework, numerical approximation, and treatment of physical processes. In the new version of the model, we use a generalized vertical coordinate with eight layers (3 km thick in the absence of mountains) and a

5° latitude and longitude grid over the globe. Near the poles, computationally unstable modes are eliminated by Fourier filtering in the longitudinal direction. The treatment of radiation by Ramanathan and Dickinson has been thoroughly revised and updated to include improved solar absorption functions, orbital eccentricity factors, more accurate treatment of H_2O continuum and e-type bands, ozone 9.6 μm bands, CO_2 bands, cirrus cloudiness, differences in surface emissivity, and more accurate integration of radiative transfer. Low, middle, and cirrus clouds and their variation with height and latitude have been included. Other substantial changes have been made in the treatment of boundary-layer processes through the incorporation of a method developed by James Deardorff (Oregon State University) and Dickinson for calculating surface temperature moisture and vegetation parameters. This parameterization includes computation of surface canopy wind, leaf temperature, leaf evaporation and transpiration, and prediction of dew formation on foliage. Snow and soil moisture are predicted from a parameterized surface hydrological cycle. Dickinson has coupled the lower troposphere to the boundary layer by including turning of the boundary-layer wind with height and a bulk Richardson number dependence for the surface transfer coefficients of sensible heat, moisture, and momentum.

The January and July results demonstrate that the third-generation NCAR GCM is a significant improvement over the second-generation model. The temperature and wind structure are much closer to observations. One of the major improvements is that the transports of momentum and sensible heat by large-scale horizontal eddies are up to observed levels. A seasonal run of the model through the annual cycle is presently under way.

We continue the development of experimental and special purpose versions of the model, in particular the 12-layer boundary-layer resolving version, the 16-layer stratospheric version, and the hemispheric dishpan version.

The 16-layer model is expected to be used to study the couplings between stratospheric chemistry, transport, and climate change, in collaboration with Julius Chang (visitor from Lawrence Livermore Laboratory). This model will (a) provide more realistic coupling to the dynamic processes to study the detailed interactions of chemical kinetics and atmospheric dynamics and (b) provide the proper basis for studying the climatic impact of ozone changes and the feedback to the atmospheric chemical balances including ozone and other relevant trace gases.

Work by Claire Parkinson (NASA) and Washington has resulted in the construction of a large-scale sea ice model capable of being coupled with atmospheric and oceanic models of comparable resolution. The sea ice model itself simulates the yearly cycle of ice in both the northern and the southern hemispheres. The horizontal resolution is approximately 200 km, and the model includes four layers in the vertical: ice, snow, ocean, and atmosphere. Both thermodynamic and dynamic processes are incorporated, the thermodynamics being based on energy balances at the various interfaces and the dynamics being based on the following five stresses: wind stress, water stress, Coriolis force, internal ice resistance, and the stress from the tilt of the sea surface. The model results produce a reasonable yearly cycle of sea ice thickness and extent in both the Arctic and the Antarctic.

Washington has begun development of a coupled atmospheric and ocean GCM. The ocean model was adapted from Albert Semtner (Oceanography Section), who used the primitive equations for an ocean with a rigid lid following the scheme developed at GFDL. The hydrostatic and Boussinesq approximations are also made in the system of equations. Along with the rigid-lid assumption, which eliminates surface gravity waves, a semi-implicit approximation was applied to the Coriolis term in the equations of motion which allows a 12 h time step. This latter numerical procedure slows down the inertial oscillations and the barotropic Rossby waves. The model resolution is 5° in latitude and longitude, and the four layers in the vertical have thicknesses of 50, 450, 1,500, and 2,000 m from the surface to the bottom. Bottom topography has been included on a scale consistent with resolution.

General Circulation Model Statistical Analysis and Sensitivity

Robert Chervin has continued to develop methods for describing the climate simulated by the NCAR GCM from a sampled ensemble point of view. In particular, during the past year Chervin used sets of realizations from a previous version of the model for January and July and for 5° and 2.5° horizontal resolutions to estimate the first and second moments of the time-lagged autocorrelation of a large number of model fields for several lags. For these four different sampled climate ensembles, considerable variation, both geographically and across realizations, was found in the autocorrelation for all model fields investigated.

The analysis of several experiments to assess the climatic response of previous versions of the NCAR GCM to a variety of prescribed changes was completed last year. In order to determine the statistical significance of the prescribed change response for each experiment, the methods developed by Chervin and Schneider which take into account the model's inherent variability were used.

Washington and Chervin performed parallel January and July experiments with a 5° version of the model to assess the potential climatic impact of the thermal energy released from a projected United States east coast megalopolis. Statistically significant increases in temperature and precipitation were found over the prescribed change region, with little evidence of any downstream response in both seasons. These experiments also demonstrated the seasonal dependence of the model's sensitivity, a conclusion that will likely carry over to other climatic impact studies.

Dickinson and Chervin, using the earlier preliminary analysis of Dickinson, Shaw Liu (National Oceanographic and Atmospheric Administration, NOAA, Boulder), and Thomas Donahue (University of Michigan) as a point of departure, completed a detailed analysis of the sensitivity of the 12-layer tropospheric/stratospheric NCAR GCM on a zonal, global, and regional basis to changes in global radiative balance due to an atmospheric burden of 10 ppb of chlorofluoromethanes (CFMs). Large changes in both the amplitude and phase of northern hemisphere winter planetary waves were a consequence of the prescribed change in external forcing. Also, large and statistically significant changes in the regional distribution of mean surface temperature and precipitation patterns resulted. However, many of the regional details of the model's response appear to be sensitive to the change in ocean surface temperature, which was imposed in the model run with CFM added.

OCEANOGRAPHY SECTION

The objectives of the Oceanography Section are, broadly stated, to contribute to an understanding of the important processes in global ocean circulation and to determine the relationship of these processes to those in the atmosphere. This work contributes to NCAR's research objective of improved understanding of climatic trends and their causes. More specifically, research carried out during the last year has been concerned with developing an understanding of (i) mesoscale eddies and their role in the general circulation of midlatitude oceans, (ii) the equatorial ocean circulation and the Antarctic Circumpolar Current, and (iii) large-scale air-sea interaction in the tropics and midlatitudes. We believe that these are logical and necessary steps towards constructing valid models of large-scale ocean circulation and air-sea interaction.

Our strategy in attacking these problems is shown by the work discussed below. Four broad approaches have been taken: (1) the use of eddy-resolving numerical models to examine questions of eddy origin, propagation, and decay and to determine the role played by these eddies in establishing the large-scale time-averaged circulation; (2) the use of analytical/numerical models to examine local eddy processes such as those occurring in the Local Dynamics Experiment of POLYMODE, in the Gulf Stream (and Gulf Stream rings), and the broad ocean interior; (3) the use of models of varying complexity to study large-scale air-sea interaction; (4) the analysis of field data with regard to theoretical issues and to the design of future experiments.

Since the Oceanography Section is a small group, collaboration with our university colleagues has been a vital part of our efforts in the last year. Therefore, this collaboration is indicated in the following discussion.

Eddy-Resolving Numerical Studies

William Holland has carried out a large number of numerical experiments with eddy-resolving models to examine the role of the eddies in the large-scale circulation in midlatitude, closed gyres. It is now quite clear that mesoscale eddies can, in a plausible manner, limit the growth of large-scale current systems and, furthermore, alter their characteristics in ways not consistent with homogeneous friction. Work on this problem during the last year has been aimed at developing increased understanding of local dynamical behavior in these complex simulations, exploring the relevant parameter space, isolating special problems (Gulf Stream separation from the western boundary, the role of Gulf Stream rings in the general circulation), and preparing for studies of the North Atlantic basin. The work has been carried out by Holland with collaborations on various aspects of the problem by Albert Semtner, Peter Rhines (Woods Hole Oceanographic Institution--WHOI), Edward Harrison (MIT), and Dale Haidvogel (WHOI).

James McWilliams and Holland have studied the results from similar models applied to jets in partially open basins (analogs of the Antarctic Circumpolar Current). The eddy contributions are as important there as in the closed basins but of a different nature: the dominant scales are larger, the vertical structures are equivalent barotropic, and the eddy/mean energy conversions are more baroclinic.

This work has been expanded to studies of channel turbulence, with a focus on the transition to turbulence and the parameter sensitivities of solutions (McWilliams). In addition, the channel model has recently been revised for an atmospheric application (McWilliams with Melvin Shapiro and Louis Gidel, Stratospheric-Tropospheric Exchange Project). This work involves studies on the influence of small-scale potential vorticity perturbations on the evolution of large-amplitude baroclinic waves. The object of these studies is twofold: first, to examine the sensitivities of downstream wave amplification to potential vorticity implants in the upstream wave; and second, to familiarize oceanographers with relevant and interesting atmospheric model behavior for the purpose of developing coupled models.

Several experiments on the general circulation of equatorial oceans have recently been completed (Semtner and Holland). A first study examined the natural variability of a steadily forced ocean and showed that baroclinic instability occurs in the westward currents to the north and south of the equator and barotropic instability occurs in the equatorial undercurrent. The transient phenomena found are similar to those observed in nature, and their structures are remarkably similar to equatorially trapped free waves in a resting ocean. A second study is under way to examine the spinup phase, the onset of instability, the response to anomalous forcing, and the effects of parametric changes. Considerable attention is being paid to the breakdown of linear theory whenever forced waves (as opposed to free waves) are important.

Further studies of equatorial ocean dynamics are under way. These involve studies of the special equatorially trapped standing modes which exist for a finite set of pairs of ocean width and frequency (Peter Gent and Semtner). This study is intended to test Gent's theoretical results for oceans without meridional boundaries in the numerically calculable situation of totally bounded basins where the modes will be slightly modified. Such experiments are important for designing and interpreting results of the extensive observational programs in the equatorial oceans which are planned for the next decade.

Analytical/Numerical Models of Local Eddy Processes

In recently completed work, McWilliams and Glenn Flierl (MIT) have studied isolated, highly nonlinear vortices, with applications to Gulf Stream rings. The nonlinearity, as well as the more familiar large-scale baroclinic nondispersion, can indeed provide a "glue" which gives these isolated vortices great persistence (as observed in rings). In addition, particular isolated vortex solutions called modons have been derived which are planetary-scale analogs of solitary waves. This work is being pursued further, with a particular focus on the question of modon stability and robustness. Modons have also been examined as a model for the persistence of midlatitude atmospheric blocking.

Gent and McWilliams have nearly completed work on the theory of semigeostrophic, isentropic coordinates. They plan to provide a diagnosis concerning which processes are omitted and which retained (and what approximations are made) in a hierarchy of equations, from the primitive equations to quasi-geostrophic equations in various coordinate systems.

Variations in the dynamical nature of different western boundary currents give us an opportunity to test our models. The East Australian Current is one such current that has distinctly different behavior from the Gulf Stream and, as such, provides an additional prototype. Model studies were begun this last year in collaboration with Australian scientists to examine the dynamics of that current (Holland with Stuart Godfrey, Commonwealth Scientific and Industrial Research Organization).

Studies of local dynamical balances have been made using Francis Bretherton (UCAR) and Michael Karweit's (Johns Hopkins University) mid-ocean model (Bernard Durney). Several problems were examined: the interaction of a large-scale flow with mesoscale topography, eddy-eddy interactions in the absence of topography, and eddy-eddy interactions in the presence of mesoscale topography. The results show that baroclinic north-south large-scale flows generate eddies vigorously in the presence of topography while east-west large-scale flows do not. It seems clear that actual ocean-bottom topographic relief is of such a magnitude as to have a pronounced effect on mid-ocean eddies.

Models of Air-Sea Interaction

Studies have been started using low-order models of large-scale air-sea interaction, with a focus on the seasonal cycle in the tropics and Galerkin techniques of derivation of the relevant equations (Gent and McWilliams). The intention is to investigate and simulate long space and time scale interannual variations in the tropical Pacific with a defensibly derived model. Such a model is being developed by expanding lower atmospheric and upper oceanic variables in complete basis sets in the space dimensions (choosing the sets carefully so that the variables are well represented by one or two members of the set). The resulting model is one of coupled, nonlinear ordinary differential equations in time for the amplitudes. The equations will be integrated over as much of a parameter space as possible to investigate the resulting coupled oscillations.

Semtner and Holland this last year have begun a second kind of air-sea study, complementary to the one above. Making use of the full equatorial ocean model, a hierarchy of studies will examine the interaction between ocean and atmosphere on the seasonal to decadal time scale, by coupling the ocean model to various atmospheric models such as that developed by Held and Suarez or the even lower order one of McWilliams and Gent. Our intention is to examine the ocean and atmospheric components separately (with fixed boundary conditions) and then to introduce the coupling in order to understand the interaction of the inherent variabilities of each part.

The Analysis of Field Data and the Design of Future Experiments

In order to verify the results or calibrate the models discussed above, a number of analyses of observed data have been started. Gent and McWilliams have begun an examination of data on the seasonal cycle in the tropics in all three oceans, finding out what the seasonal cycle in the atmosphere and upper ocean is like and identifying testable hypotheses about the mechanisms whereby the atmosphere drives the ocean and vice versa. Where large-scale coherency is evident in the cycle, as in the east Pacific and west Indian oceans, they will attempt to model it using a low-order model. If smaller space scale features dominate, as in the Atlantic, it will probably be necessary to use a much more complex numerical model.

Data from the POLYMODE program are becoming available. Holland (with William Schmitz, WHOI) has begun to examine long-term current meter observations, primarily from the North Atlantic Ocean, for the purpose of testing basin-scale eddy results from numerical models. The observations have been used to make decisions about which physical processes are most important in the North Atlantic basin and to evaluate and calibrate our models appropriately. A number of new numerical experiments have been carried out using this guidance. In addition, from the Local Dynamics Experiment, data on mesoscale potential vorticity balances are being analyzed by McWilliams and various university colleagues.

McWilliams (with Bretherton) has completed a theoretical study of spectral estimation from irregular arrays and the optimal design of such arrays. In addition, he has completed a study of observed model coupling between the barotropic and first baroclinic mode for mesoscale eddies (with Colin Shen, University of Washington).

Finally, efforts have continued (McWilliams) to help organize a national program of experiments on phenomena in the surface layers of the ocean and their influence on the atmosphere. This involves efforts to help establish a surface drifting buoy facility at NCAR (with David Bargen, Research Systems Facility), and will be pursued in part as a UCAR initiative in this area of research.

LARGE-SCALE DYNAMICS SECTION

Overview

In last year's Annual Scientific Report, we pointed out the existing gap between what we know from theories of atmospheric dynamics and what we obtain from the output of numerical weather prediction models. Present-day numerical prediction models aim at the faithful simulation of the evolution of atmospheric flow and are based on the primitive equations, which are the complete Eulerian equations of motion modified only by the hydrostatic assumption. On the other hand, theories of large-scale atmospheric dynamics are typically built upon much simpler foundations, known as quasi-geostrophic models.

The large-scale motions of the atmosphere are predominantly horizontal, and the wind field is approximately balanced by the mass field. This approximation, called the quasi-geostrophic assumption, simplifies the dynamics of the atmosphere by filtering out gravity waves from the primitive equation model. Since the role of gravity waves is considered minor, this simplification yields a deeper understanding of meteorologically significant motions which are quasi-geostrophic in nature. This simplification, however, introduces certain deficiencies which are detrimental to accurate prediction of the atmospheric motions. This is why advanced numerical prediction models adopt the primitive equations.

This year we have achieved substantial progress in understanding the role of gravity waves in the primitive-equation model, and this understanding has essentially resolved one of the outstanding problems in numerical weather prediction, known as data initialization for the global primitive equation model, as we will discuss later. The atmosphere as an oscillating system, similar to musical instruments, possesses certain preferred modes of oscillations, called normal modes. By projecting actual motions onto the normal modes of the atmosphere, we can identify the types of wave motions in the atmosphere. This projection process is referred to as normal-mode expansion, or decomposition.

Although the idea of using normal-mode expansion for analysis and prediction has been known for many years, it had not gained much popularity among numerical modelers until recently because they have been relatively unfamiliar with the nature of the normal modes of the global atmosphere and their application to nonlinear problems. These obstacles are being removed and, with the increased capacity of electronic computers, the normal-mode approach appears to offer a new method for meteorological data analysis and advanced atmospheric modeling.

Application of Normal-Mode Analysis

Dickinson (Climate Section) and Williamson proposed earlier a method of initializing observed data by expanding them into the normal modes of a primitive equation model. Once the data are expanded by the normal-mode functions, the gravity wave mode amplitudes may be set to zero. However, the initial elimination of all the gravity wave modes still leads to generation of gravity waves due to nonlinear interactions of the remaining modes. The procedure of Bennert Machenhauer (University of Copenhagen) and Ferdinand Baer (University of Maryland) is to retain small-amplitude gravity waves initially to offset further growth of the gravity waves resulting from the nonlinear interactions and other forcings. This type of initialization is now referred to as nonlinear normal-mode initialization.

Roger Daley has extended the nonlinear normal-mode initialization technique to a full baroclinic primitive equation, spectral model. The initialization procedure is shown to be capable of completely removing high-frequency oscillations from model integrations, even in the presence of orography. The procedure also produces a consistent and physically realistic initial vertical motion field.

Williamson and Clive Temperton (European Centre for Medium-Range Weather Forecasts, ECMWF) completed development of a nonlinear normal-mode initialization routine for the ECMWF grid point model. The procedure, when applied to the adiabatic version of the model, works extremely well, providing forecasts with no sign of high frequency oscillations. The choice of the mean state which determines the normal modes is not crucial to the procedure. The approach is superior to dynamic initialization in terms of both computer time and elimination of unnatural oscillations in the forecast.

Williamson, working with student visitors Dick Dee (Courant Institute, NYU), Dale Duran (MIT), and James Sethian (University of California, Berkeley) has also developed the normal-mode initialization procedure for the global model developed at NCAR by Richard Somerville and Boris Shkoller. This work is continuing.

Information on the three-dimensional spectral distribution of atmospheric energy is important to a proper selection of the computational resolution for solving prognostic equations of the atmosphere. In the past, spherical harmonics were used extensively to decompose horizontal flow fields, and empirical orthogonal functions were adopted to represent the vertical structure of atmospheric flow. A drawback to this approach is the absence of relationships between the expansion functions in the horizontal and vertical directions. Therefore, it has not been possible to map a complete spectral energy distribution in three indices: zonal wavenumber, meridional index, and vertical mode. Akira Kasahara and Kamal Puri (visitor from the Australian Numerical Meteorology Research Centre) formulated completely orthogonal three-dimensional normal-mode functions (NMFs) to represent the velocity and mass field simultaneously. Hemispheric data from NMC are expanded in the NMFs in the framework of the Australian forecast model. The atmospheric energy spectral distributions thus obtained provide useful information on the choice of a vertical resolution consistent with given horizontal resolutions.

As another application of the normal-mode expansion, Daley and Puri examined the four-dimensional data assimilation process using the normal modes of the assimilating model. The inserted data were artificial, but had a realistic spatial and temporal distribution; and the assimilating model was a spectral shallow water equations model. The normal modes of the model were used in two ways. First, they were used in a variational formulation which allowed wind or height information to be inserted directly into the slow manifold (the low-frequency solution) of the model. Second, the normal modes were used as a diagnostic tool to examine the assimilation process itself. Experiments were conducted with height insertion, wind insertion, and mixed insertion. The use of model normal modes permitted the separation of the inserted data into its projection onto the slow manifold (the desirable part) and its excitation of transient gravity waves (the undesirable part). The spatial and frequency spectra of the excited gravity waves could also be examined. The use of model normal modes gave considerable insight into the four-dimensional data assimilation process and suggested some ways in which it could be made more effective.

Daley also investigated the use of model normal modes for increasing the computational efficiency of primitive equation models. Because they permit high-frequency gravity wave solutions, primitive equation models are required to use very short time steps, which is costly. An examination of the model normal modes indicates the group of high-frequency gravity waves which will be computationally unstable for a given model time step. The idea is to treat these unstable modes using special time integration methods, while the remainder of the flow is treated by a conventional explicit leapfrog scheme. The method was tested in a baroclinic spectral primitive equation model with time steps much longer than that possible with the explicit leapfrog scheme and was found to be computationally stable, efficient, and accurate.

Spectral methods have proven to be useful for horizontal approximations in atmospheric models. However, there are only a few attempts to use spectral approximation in the vertical. Williamson and Jean-Pierre Volmer (visitor from the French Meteorological Office) are examining the use of Laguerre functions (Laguerre polynomials multiplied by an exponentially decreasing factor with height) for the vertical representation in a global spectral model. Preliminary examination shows that these basis functions have many desirable properties.

Forecast Performance Tests and Model Improvements

David Baumhefner has continued work involving a direct comparison of forecasts produced by several large-scale numerical weather prediction models. In particular, two models have been added to the analysis--the Somerville-Shkoller model, which is numerically similar to the Goddard Institute for Space Studies (GISS) model, and the Australian spectral model. Both models are similar to those previously compared, with the only exception being that the Somerville-Shkoller model has about twice the computational resolution of the original GISS model. All models differ chiefly in vertical coordinate systems, mountain blocking, numerical formulation, and physical parameterizations.

The new model additions produced no dramatic changes from the previous conclusions. Most forecast phase speeds were slower than observed, forecast amplitudes were weaker, and storm development/decay was poorly handled. The forecasts were again more similar to one another than any one was to the observed atmosphere. Close examination of one case using the Somerville-Shkoller model, however, showed an unexpected sensitivity in the influence of an equatorial wall and initial data in the tropics upon forecast skill of the ultralong waves.

The Somerville-Shkoller model is a new primitive equation prediction model which has been used to make hemispheric and global real-data forecasts. Somerville and Shkoller adopted the Arakawa "B" grid and a numerical method which approximately conserves enstrophy and kinetic energy with implicit Euler time differencing. Horizontal resolution is 2.5°, and there are nine equal layers in sigma. Orography is included, as are a convective adjustment and a simple bulk aerodynamic surface layer with a variable drag coefficient. Otherwise the model is inviscid, dry, and adiabatic. The present 2.5° grid model with relatively simple physics yields 500 mb forecasts which compare favorably with those of the original GISS model with a 4° x 5° grid and elaborate parameterizations of physics.

Preliminary results from experimental five-day forecasts suggest that the model is capable of skillfully forecasting the evolution of the ultralong waves (zonal wavenumbers one to three), despite the lack of comprehensive parameterizations of source/sink terms. However, this skill can be markedly degraded by poor initial data or an inadequate computational domain. Limiting the domain to the northern hemisphere apparently produces substantial errors at 40°N by late in the five-day period, while the use of interpolated initial data south of 20°N seems to cause significant midlatitude errors very quickly. These midlatitude effects of tropical deficiencies in domain and data are striking and appear to be confined mainly to ultralong waves, with higher wavenumbers displaying no sensitivity. These preliminary results, if substantiated, may help to explain the poor skill of typical model predictions of ultralong waves, relative to the skill expected on the basis of predictability theories.

Baumhefner, along with Donald Perkey (Mesoscale Research Section), has initiated a limited domain model forecast intercomparison to benchmark the forecast skill of several limited-area models. Those models already scheduled to participate include the limited-area version of the NCAR second-generation GCM (LAM), the Drexel-NCAR model (Carl Kreitzberg, Drexel University), the Anthes model (Richard Anthes, Pennsylvania State University), an NMC nested grid model (Norman Phillips, NMC), and a finite-element model (Andrew Staniforth, Canadian Meteorological Service and Daley). The initial data, including geopotential, wind components, sea level pressure, and relative humidity, have been given to each modeler.

Baumhefner and Perkey have also collaborated on work comparing lateral boundary conditions schemes using the LAM. Forecasts were produced at 2.5° resolution, using both 5° and 2.5° hemispheric model forecasts to specify boundary information. The Perkey/Kreitzberg diffusion-type, one-way interaction boundary formulation was used. While boundary errors were not insignificant, they were not overwhelming. Generally, the error from specifying the boundary values was equal to or greater than errors from the boundary formulation.

Baumhefner and Thomas Bettge have further studied the effects of increases in horizontal and vertical resolution upon prediction of a baroclinic wave by separating spatial scales of each forecast. The predictions were made by varying horizontal resolution from 2.5° to 0.625° and vertical resolution from 3 km to 0.75 km within an 18 km domain using the LAM. The limited forecast domain was centered over data-rich North America and the scales verified were long waves (wavenumbers three to five), medium waves (wavenumbers eight to 12) and short waves (wavenumbers 20-24). Increases in horizontal resolution had a much greater effect than increases in vertical resolution at all scales. While the finer resolutions more accurately predict scale amplitudes, scale phase errors are as large as with the coarser resolutions. While better skill is achieved during a 24 h forecast with the finer resolutions, errors in phase produce equal or lower skill by 48 h.

Baumhefner, working with Frederick Sanders and John Sheldon (both from MIT) completed a study on the effect of mountains and moisture on east coast cyclogenesis for one case using the LAM. The low-level cyclone development was found to be very sensitive to the initial moisture distribution. The inclusion of terrain (i.e., the Appalachian Mountains) had only a slight positive impact upon the forecast.

Although the nonlinear normal-mode initialization procedure discussed earlier is successful, the approach requires the construction of normal modes for the prediction equations. While this requirement creates no difficulty for a global model, the construction of normal modes for a limited-area model is difficult unless the boundary conditions are periodic or fixed. Hence, at present the prospect of applying normal-mode initialization to limited-area primitive equation models is uncertain. Gerald Browning (Computing Facility), Kasahara, and Heinz Kreiss (California Institute of Technology) formulated a new approach to the initialization of a primitive equation model with a limited forecasting domain, and demonstrated its application to the shallow water equations including the dynamical effect of orography.

Somerville, in collaboration with Robert Gall and Richard Blakeslee (both from the University of Arizona), used a GCM to study baroclinic instability. Because the linear growth rates of baroclinic waves on realistic zonal flows are largest at relatively high zonal wavenumbers, say 15, the observed peaks in the transient kinetic energy spectrum cannot be explained simply by peaks in the linear growth rate spectrum. When the growth rate spectrum is fairly flat, as suggested by recent studies, then, as the waves evolve, the decrease of the instability of the zonal flow and the increase of dissipation in the developing waves become important in determining which wavelength will dominate after the waves are fully developed. In particular, the stabilization of the zonal flow because of northward and upward eddy heat transport causes the instability of the short baroclinic waves (wavenumber >10) to decrease more rapidly than that of the intermediate-scale waves (wavenumber <10). In addition, dissipation, as it is usually modeled, increases with time more rapidly in the short waves. Therefore, the growth of the short waves is terminated by these two processes before the growth of the intermediate-scale waves, which can thus achieve greater equilibrium amplitudes. These results were obtained in a numerical experiment with a simplified GCM, in which waves of all wavelengths are allowed to develop simultaneously from small random perturbations on a flow that is initially zonally symmetric. The kinetic energy spectrum in this experiment does not display a minus-three power law in the wavenumber band from ten to 20. This result may support the recent hypothesis of David Andrews (MIT) and Brian Hoskins (University of Reading) that atmospheric fronts rather than quasi-geostrophic turbulence are responsible for the observed minus-three spectrum at wavenumbers higher than ten.

Analysis of Meteorological Data and Verification

In a further attempt to determine the sources of forecast error, Baumhefner and Bettge have made a preliminary study of the large-scale transients during the first Special Observing Period (SOP-1) (15 January-15 March 1979) of the Global Weather Experiment. The 500 mb geopotentials at two latitudes, 40°N and 60°N, were digitized daily from facsimile products and spectrally decomposed to examine planetary wavenumbers one to two, large-scale wavenumbers three to five, and synoptic wavenumbers six to ten. The planetary waves showed a high degree of instability with at least four rapid changes in amplitude and phase within two months. Regimes of ten to 14 days in the large-scale waves were distinct. In general, forecasts were accurate when the planetary waves were strong and stationary, and forecasts were poor during transitions. The SOP-1 data set will provide very useful information concerning planetary wave activity and its relation to medium-range forecast skill.

Thomas Schlatter and Grant Branstator have reassessed earlier findings about Nimbus 6 temperature retrieval errors. They compared layer-mean virtual temperatures derived from Nimbus 6 radiance measurements with those inferred from analyses of geopotential height based upon European radiosonde data. There are two major differences between their earlier study, reported last year, and the current one:

(1) In the earlier study, Nimbus 6 temperature profiles were compared with unsmoothed multivariate statistical analyses of the radiosonde data; now they are compared with smoothed analyses.

(2) In the earlier study, all Nimbus 6 temperature profiles between 30° and 70°N and 10°W and 44°E were included in the error computations; now only those profiles retrieved in the vicinity of radiosonde stations are included.

The new results are interesting. The smoother the analysis used as a standard for comparison, the smaller the root-mean-square errors estimated for Nimbus 6. It is apparent that the size of the estimated errors depends upon the scales of motion resolved by the verifying analysis. Nimbus 6 temperature data agree better with smoother analyses because they are themselves smooth. Another result, in disagreement with an earlier finding, is that the retrieval errors are significantly correlated between adjacent isobaric layers. The earlier lack of correlation is explained by poor vertical consistency of the verifying analyses in data-sparse areas.

Last year, we reported acquisition of an interactive graphics system (IGS) to be used for the analysis and quality control of meteorological data. The equipment is very similar to that now being installed at National Weather Service offices around the country under the Automation of Field Operations and Services program. Linda Thiel (Computing Facility) and Stephen Whitaker have been working on software to facilitate the manipulation and display of meteorological data. Joseph Wakefield has adapted a contouring algorithm and written a new vertical cross-section code for the IGS.

Intended primarily for processing selected data from SESAME and the Global Weather Experiment, the IGS is already being used for other purposes. Walter Roberts (UCAR Research Associate), Roger Olson (University of Colorado), and John Wilcox (Stanford University) are examining the relationship between solar storms and the movement of mid- and upper tropospheric troughs. Julian (Climate Section) and Shea (Atmospheric Technology Division) are processing data from tropical constant-level balloons. Also, Wakefield is using the terminal in connection with two studies, one by Williamson of nonlinear normal-mode initialization of a numerical prediction model, and the other by Daley of the accuracy of the initial atmospheric state as specified from analysis of available data.

A Fourier decomposition is a common method of representing the structure of atmospheric disturbances. Weather systems, however, consist of cyclones and anticyclones and thus, say, the 500 mb height field may be characterized by a collection of vortices, rather than waves, superimposed upon a global-scale background flow. Williamson developed a method of representing individual high- and low-pressure systems by using mathematical functions with a few parameters for each system. The parameters for a representation at any time are determined by a nonlinear least-squares fit to the observed data at that time. The difference in the parameter values between a forecast and corresponding observations will be used to define various verification scores providing objective measures of errors in amplitude, size, shape, and location of vortices.

Baumhefner completed a joint project with Phillip Smith and John Ward (both from Purdue University) concerning the sensitivity of the data analysis method and initialization procedural changes on short-range forecast skill.

The Internal Dynamics of Climate Change

During the past six months, Philip Thompson has developed a simple statistical theory of the internal dynamics of climate change on time scales of seasons to decades. The key hypotheses are that changes on those time scales are due to the internal adjustment of the atmosphere-ocean-earth-ice system to a prescribed input of solar energy, and that the statistical state of the atmosphere adjusts almost instantaneously (quasi-statically) to slowly changing conditions in the subsurface layers--whether solid surface, ice or the mixed layer of the oceans. This hypothesis is justified by the great disparity in the "relaxation" times of the atmosphere and its underlying surface.

According to this view, the atmosphere plays a rather passive role in climate change, being mainly an agency for transporting heat and moisture and acting as a "valve" to regulate the flux of incoming and outgoing infrared radiation. The predictive element of this theory is contained in the thermodynamic energy equation for the subsurface layers. The latter includes the effects of evaporation, convective heat transfer to the atmosphere, large-scale horizontal transport by the great gyres and western boundary currents of the oceans, and exchange of heat between the oceanic mixed layer and deep ocean. It also includes the effects of radiative transfer and the dynamical response of the atmosphere.

The interactions between atmosphere, oceans, ice, and exposed ground are summarized in two "flow-diagrams," which show that the time-evolution of surface temperature is governed by a closed system of three coupled nonlinear ordinary differential equations, in which the dependent variables are two temperatures (representative of conditions in the subtropics and in higher latitudes) and the extent of the polar ice sheets.

This model is within a few months of numerical tests and is only awaiting the evaluation of empirical transport coefficients from existing synoptic data, both meteorological and oceanographic.

MESOSCALE RESEARCH SECTION

Administration and Planning

The Mesoscale Research Section (MRS), formed out of the previously separate GATE and Small-Scale Analysis and Prediction projects, included on 31 March ten Ph.D. scientific positions and about the same number of supporting staff. Most research activities can be classified into one of three categories, convective storms, boundary layers, and subsynoptic meteorology, with significant interaction among all of these. Last year and this year involve a transition between the diminishing activities of the GATE Project and related tropical studies and an acceleration of midlatitude convective storm and boundary layer research, for which Project SESAME represents a principal observational focus. The section relocation to 30th Street has been successful in enhancing interaction with scientists at the Cooperative Institute for Research in Environmental Sciences (CIRES) (University of Colorado-NOAA) and NCAR's Field Observing Facility. A move to a nearby building, in which the Convective Storms Division and MRS will be collocated, is anticipated in 1980.

During the last year the Mesoscale Research Section has undertaken, and largely completed, procurement of a satellite computer system (to be known as MRSSC). Projected uses of the system include development and preliminary testing of software to be run on the CRAY-1 computer, analysis of output from CRAY-1 runs, and a local execution of smaller programs. It is anticipated that the highly interactive nature of this system will increase software development efficiency in addition to providing more scientific insight into the meteorological processes being studied. Current plans are for the system to be fully installed by the end of June 1979.

Convective Storm Studies

Numerical Simulation. Convective storm research using a three-dimensional numerical model has continued by Joseph Klemp in collaboration with Robert Wilhelmson (University of Illinois). In simulating the strong, supercell-type storms the model has demonstrated a striking ability to produce right- and left-moving storms which arise through a splitting process and which bear good qualitative agreement with observed storm structures. Recently, several particular cases have been investigated to determine the potential for simulating the basic features of specific storms from initializations based on environmental sounding data. Here we have found an encouraging agreement with observed cases although the results are often sensitive to moderate changes in the environmental conditions or model physics. One of these cases is from the 1977 National Severe Storms Laboratory (NSSL) Spring Data Collection Program and is part of the Cooperative Observational and Modeling Project for the Analysis of Severe Storms (COMPASS). We are currently working with Peter Ray and others at NSSL to compare simulated results with analyzed Doppler data for these tornado-bearing storms. Other comparisons are anticipated from storm data collected during this spring's SESAME program. Collaboration has also begun with Richard Rotunno of CIRES in simulating subcloud-scale tornado dynamics. Initial experiments with rotational flow in a higher resolution version of the cloud model have generated strong concentration of low-level rotation and associated warm downdrafts along the central core. Simulations will soon be conducted in which the model is initialized with a rotating updraft obtained from a cloud-scale simulation.

During 1978, John Brown, in collaboration with Anthony Hansen (Iowa State University), analyzed the life history and mass and water budget of four disparate mesobeta-scale thunderstorm clusters over south Florida. The life history of these systems is broadly similar to the typical life cycle of some large mesoscale systems observed during Phase III of GATE. That is, mesoscale convergence in the surface wind field precedes (by at least an hour) and accompanies cumulonimbus development. Individual cumulonimbi have a relatively short lifetime, probably because of severe water loading in updrafts. The precipitation-induced, cloud-scale downdrafts spread out near the surface and those from adjacent storms interact, leading to further cumulonimbus development until the supply of potentially buoyant, near surface air is locally exhausted. There follows an hour or so of diminishing rainfall from nimbostratus cumulonimbogenitus and horizontally diverging airflow at the surface.

Each case examined developed in a weakly sheared environment. Rainfall efficiency (defined as surface rainfall divided by the upward flux of water vapor through cloud-base level, both integrated over the lifetime of the mesosystems) is strongly correlated with the 900-400 mb mean relative humidity prior to convection. Turbulent diffusion between the clouds and their environment appears primarily responsible for this relationship, with evaporation in the downdraft playing a lesser role.

Brown and Kevin Knupp (Colorado State University) also completed analysis of a unique anticyclonic-cyclonic tornado pair and its parent severe thunderstorm. Despite the apparent rarity of strong anticyclonic tornadoes, the gross aspects of the parent thunderstorm in this case appear to fit the supercell model proposed by Browning and others and reproduced numerically by Klemp and Wilhelmson. A strong low-pressure area of $\sim$50 km scale induced by the convection and centered south of the tornadoes appears to be associated with their unique tracks and with the development of the anticyclonic tornado.

<u>Aircraft Observations of Tropical Cumulonimbus Clouds</u>. Most studies of convective clouds and mesoscale convective systems implicitly depend upon some knowledge of the nature of individual cumulonimbus cells as a kind of basic "unit." Over 30 years ago, the Thunderstorm Project produced a basic data set for continental cumulonimbus clouds that has still not been surpassed. The GATE aircraft data set, including hundreds of penetrations of oceanic cumulonimbus, is a treasure trove of quantitative information about such clouds

that deserves exploration. A major effort to analyze these data was initiated by Edward Zipser, Margaret LeMone, and Alan Miller, and despite some personnel changes, a number of results are emerging. For example, the distributions of draft diameter and draft strength have been analyzed, and appear to be log-normal in most instances. Updrafts are typically stronger and narrower than downdrafts. The distribution of mass flux may also be log-normal much of the time. There is little doubt now that the GATE cumulonimbi usually have weaker drafts than their continental counterparts. Further results on fractional draft coverage, height dependence, and momentum fluxes in drafts can be expected. Preliminary results have been presented by LeMone, Miller, and Zipser in four papers given at two technical conferences. Among the more intriguing results is that the momentum in updraft cores sometimes behaves as if it were being "shoveled" out of the boundary layer like coal, although great variations are noted from case to case.

A Possible Solar Weather Linkage

The evaluation of the role of thunderstorms growing in the electric field of the atmosphere, E_0, which responds to solar particulate emissions continued to receive considerable attention by Doyne Sartor and collaborators as a physical linkage for solar weather interactions. It is an attractive hypothesis because direct energy transfers are not required and the energy is supplied by cloud processes through the solar modulation of the small global electric field E_0.

Repeated runs with the recently developed two-dimensional slab thunderstorm model of Joachim Kuettner, Zev Levin (Tel-Aviv University), and Sartor were made to investigate the sensitivity of convective clouds with selected (because of this sensitivity) microphysical properties to changes in E_0. Sartor finds from these results that the maximum changes in E_0 observed thus far (70%) are sufficient to cause some convective clouds that would have reached only a weakly electrified state to become highly electrified. In order to evaluate the importance of highly charged clouds to atmospheric circulation, Sartor has computed the vorticity produced or destroyed through the motion of these highly charged cloud and precipitation particles in the electric fields they create. The vorticity produced this way on the thunderstorm anvil scale is found to be of a magnitude comparable to that produced dynamically on the anvil scale, mesoscale, and synoptic scales and on the mesoscale with the dynamic production on the mesoscale and synoptic scales in the tropics.

Boundary Layer Research

Nocturnal and Inhomogeneous Boundary Layers. During April 1978 Donald Lenschow and Borislava Stankov conducted a site evaluation study around the BAO with one of the NCAR Queen Air aircraft. This initial BAO experiment attempted to determine the extent to which the BAO tower measurements are representative of the surrounding area. Initial analysis of the aircraft data has revealed that terrain inhomogeneities can cause significant horizontal variations in the boundary layer, particularly when it is not well mixed by convection.

Similarly, analysis of aircraft, tower, and balloon data from the Haswell, Colorado, experiment of 1975 by Lenschow, Stankov, and Lawrence Mahrt (Oregon State University) show that even slight terrain inhomogeneities can cause significant horizontal variations in the stable nighttime boundary layer. In valleys or depressions, these inhomogeneities can result in a very abrupt transition from the nocturnal to the daytime convective boundary layer caused by advection of an upstream mixed layer. Criteria necessary for this transition to occur are evaluated and generalized for application to other situations.

Data from the Haswell experiment, as well as three other boundary layer experiments, were used to construct mean vertical profiles of temperature, wind, and Richardson number in the nocturnal boundary layer. The inversion layer was typically found to extend above the low-level nocturnal jet, so that the Richardson number reaches a maximum at the level of the jet and then decreases again with height. As a result, turbulence is observed to be a minimum at the jet level.

Analysis of the GATE fair weather days by LeMone and Steven Nicholls (UK Meteorological Research Flight) is now complete. Data were primarily from the three gust probe aircraft used: the British C-130, the NOAA DC-6, and the NCAR Electra. The GATE boundary layer has turbulence intensities an order of magnitude less than those in the daytime boundary layer over land. Perhaps for this reason air entrained into the mixed layer from above shows up clearly in data taken throughout the mixed layer, introducing excursions in temperature (T), humidity (q), and horizontal velocity (u,v) larger than those produced near the surface. These excursions do not show up, however, in vertical velocity (w), and they are only slightly detectable in the cospectra of w with u, v, T, or q. Thus the profiles of the transports of these quantities are similar to those over land, as are the cospectra and the budget of turbulence kinetic energy.

The effect of cumulus clouds over the mixed layer was evident. Cloudier days were characterized by cloud base moisture fluxes similar to and sometimes larger than surface evaporation. Temperature fluxes at cloud base were more strongly negative than in clear periods.

Mass flux across cloud base increased with cloudiness. Buoyancy fluxes were remarkably consistent, however--decreasing roughly linearly with height to about -0.2 times the surface value.

Using these relationships and neglecting radiation, it was found that the GATE mixed layer being dried out the fastest could persist for over 10 h, even if extra moisture was not supplied by horizontal advection. Thus, fair weather cloud patches observed in the GATE area may have occurred without supporting mesoscale circulations.

In closely related work, the Deardorff-Sommeria computer model has now been converted to the CRAY by Eugene Myers, Robert Ubelmesser, and LeMone. Jean-Luc Redelsperger (Laboratoire de Météorologie Dynamique, Paris) has developed a version of the model which includes precipitation physics and has initiated a simulation of a GATE day with small raining cumulus.

Results of the simulation of a fair weather GATE day using an earlier version of the model were in reasonably good agreement with observations except for an underestimate of the turbulence intensity by the model. The flux profiles are comparable, and the buoyancy flux profile was insensitive to cloudiness, two results expected from observational results discussed above.

The relationship of cloudiness, cloud mass flux, and thermodynamic fluxes at cloud base is being explored, using both model and observational results.

Cloud-topped Mixed Layers. Douglas Lilly, together with James Deardorff (Oregon State University), Joost Businger (University of Washington), and Wayne Schubert (Colorado State University), has re-examined the radiative cooling region near the top of a cloud layer. Although the most nearly correct specification is somewhat debatable, the sensitivity of cloud layer characteristics to distributed radiative cooling has been determined through a series of time-dependent and steady-state calculations. The results will be reported in submitted joint papers.

Analysis by Sartor of the MONEX 1977 Somali Jet data for convective and boundary layer transports in clouds, at cloud boundary and in the cloud-free air has been slowed by difficulties in obtaining representative measurements of cloud droplet distributions from the small droplet probe. Correction factors are being sought using data from the previous Stratospheric Exchange Experiment (STRATEX) experiment, on which work continues. This work again shows the futility of using the Johnson-Williams liquid water content meter for cloud transports and underlines the considerable effort sometimes required to acquire representative data from highly valuable and sophisticated instruments, e.g., the Particle Measuring System's cloud particle probes.

Downslope Windstorm Observation and Prediction. A joint program has begun with NOAA-Environmental Research Labs for upgrading the Boulder-Denver-Front Range area anemometer network for detection of severe downslope winds. The upgraded network will include telemetry and display equipment suitable for centralized real-time evaluation. It is expected that this network will become an element of the Prototype Regional Observing and Forecast Service, a NOAA-sponsored program aimed at upgrading meteorological observation and prediction on local and regional scales. The network will also be used as a data source for continuing evaluation of various prediction schemes for downslope winds.

Subsynoptic Analysis and Prediction Research

NCAR-Drexel Prediction Model. During the past year the analysis/prediction system developed as part of a joint project between Perkey and Kreitzberg and associates (Drexel University) has undergone a complete upgrading. All computer codes beginning with the consistency checks on the observations to post-simulation verification and evaluation have been rewritten for the CRAY-1 and converted from a variety of codes to a system of codes. In addition to the conversion, several enhancements have been made to the analysis/initialization and prediction codes. The system upgrading has made use by other researchers much easier. In addition to NCAR and Drexel personnel, all or part of the system has been used by the following researchers: Elford Astling (University of Utah), Douglas Boudra (University of Miami), Martin Leach (Brookhaven National Laboratory), David Houghton and Dong Lee (University of Wisconsin), and Fritz Hassler (Goddard Space Flight Center).

Studies reported on by Perkey and Clark Smith at the Conference on Meteorology over the Tropical Oceans, in London, indicated that model-predicted precipitation regions compared very well with the radar patterns associated with a closed vortex embedded in a larger scale easterly wave observed during the Barbados Oceanographic and Meteorological Experiment. Mass and moisture budgets immediately surrounding convective clusters show a 1 h to 2 h phase lag between the peak low-level mass convergence and the peak convective rainfall. These budgets also show a 2 h to 4 h lag between the development of low-level inflow and convection-induced upper level outflow. These relationships have also been noted in budget studies using analyses of GATE multilevel aircraft data to be presented at the 12th Technical Conference on Hurricanes and Tropical Meteorology in New Orleans.

Organized Cumulonimbus Lines in the Tropics. The quasi-two-dimensional cumulonimbus line has a very convenient characteristic: the horizontal mass fluxes on the mesoscale can be measured and related to vertical mass fluxes on the mesoscale, in circumstances where they can be closely identified with cumulonimbus cloud transports. In GATE, there were numerous repetitive multi-aircraft crossings of such lines. One of the ultimate goals is to distinguish between the squall line and the "ordinary" cumulonimbus line. Zipser and Rebecca Meitín reported on one of the best examples of an "ordinary" GATE line, in which mesoscale mass fluxes were computed at seven different times in cross section from across the line. One gratifying result, not anticipated before the fact, is that detailed mesoscale wind fields can be drawn that do not change wildly from one line crossing to the other, so there is confidence in the results over the 3 h period of the analysis. The updraft mass flux turned out to be at least twice the net mass flux. We have reason to believe that the ratio will be greater for strong squall lines. An aspect of the life cycle of mesosystems was illustrated by the observation that the net boundary layer convergence decreased to zero late in the period, but the mass flux associated with deep convection did not decrease immediately. Similar time lags (usually a few hours) are being noted by others from budget studies. We believe that improved quantitative understanding of the life cycle of mesoscale convective systems could be one of the most significant outcomes of the GATE aircraft program.

MONEX Observations and Analysis. During the year the research on MONEX-77 data continued. Using the preliminary data set, Henry van de Boogaard and his scientific co-workers concentrated their efforts on the analyses of the west-east cross section of the East African low-level wind regime. The four cases analyzed showed two important types of variability; (1) variations associated with the regional day-to-day variations of the synoptic situation, particularly in association with the west-east migration of the southern hemisphere high pressure systems, and (2) the diurnal variations primarily associated with strong convective mixing during the late morning and nocturnal radiative stabilization in the evening.

In the meantime, the winter MONEX field phase took place during December 1978. As one of the participants, van de Boogaard undertook research flights with the NOAA P-3 in the vicinity of the equatorial regions of Indonesia. The flights and the data collections were successful and analysis of the flights with the preliminary data set has commenced.

A numerical method for prediction models on nested grids has been developed by Katsuyuki Ooyama, and one-dimensional tests with the shallow water waves have demonstrated its remarkably clean handling of interface problems. The method, tentatively called a quasi-pseudo-spectral method, is a theoretical spin-off of his objective data analysis method, based on the spectrally controlled representation of fields by local cubic splines. His continued work on the objective analysis of GATE upper air winds is nearly completed.

AAP DIVISION STAFF AND VISITORS

DIVISION OFFICE

Staff

Meg Carr
Jackson Herring
Barbara Hill
Holly Howard
Cecil Leith (Director)
John Masterson
Ann Modahl

Visitors

VLADIMIR ALEKSANDROV, USSR Academy of Sciences: May to December 1978

RICHARD GROTJAHN, Florida State University: January 1977 to June 1979

TAROH MATSUNO, Tokyo University: August 1977 to July 1978

VLADIMIR SERGIN, Pacific Institute of Geography, Vladivostok: May to December 1978

JOHN TUKEY, Bell Laboratories: November to December 1978

CLIMATE SECTION

Staff

Climate Section

Eileen Boettner
Julius Chang (long-term visitor)
Robert Dickinson (Section Head)
Christine Kingsland
Eric Pitcher (long-term visitor)
Jill Williams (long-term visitor)
Richard Wolski

Climate Sensitivity Group (CSG)

Bruce Briegleb
James Coakley
Ann Gayton
Laurence Goldberg
William Kellogg
Shaw Liu (to 1 June 1978)
Randi Londer
V. Ramanathan
Takashi Sasamori (to 1 October 1978)
Stephen Schneider (Acting Group Leader)
Bruce Wielicki
Warren Wiscombe

Empirical Studies Group (ESG)

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

Global Climate Modeling Group (GCMG)

Robert Chervin
Thomas Mayer
Warren Washington (Group Leader)

Visitors

ROBERT CESS, State University of New York: CSG, January and June 1978, January 1979

PETER CHÝLEK, Harvard University: CSG, June to August and November 1978

ANVER GHAZI, Institut f. Geophysik u. Meteorologie: CSG, July to October 1978

JEFFREY KIEHL, Harvard University: CSG, June to August 1978

KARIN LABITZKE, Freie Universität Berlin, Federal Republic of Germany: ESG, July to August 1978

CLAIRE PARKINSON, Ohio State University: GCMG, March to July 1978

BRIAN TUCKER, Division of Atmospheric Physics, CSIRO, Australia: ESG, May and June 1978

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

OCEANOGRAPHY SECTION

Staff

Julianna Chow
Bernard Durney
Peter Gent (long-term visitor)
William Holland (Section Head)
Christine Kingsland
James McWilliams
Albert Semtner, Jr.

LARGE-SCALE DYNAMICS SECTION

Staff

David Baumhefner
Thomas Bettge
Grant Branstator
Mary Chambers
Roger Daley
Patrick Downey
Akira Kasahara (Section Head)
Mary Niemczewski
Thomas Schlatter
Richard Somerville
Philip Thompson
Joseph Wakefield
Stephen Whitaker
David Williamson

Visitors

RICHARD BLAKESLEE, University of Arizona: April to summer 1978

DICK DEE, Courant Institute of Mathematical Science, New York University: June to August 1978

GEOFFREY DOMM, Massachusetts Institute of Technology: June to August 1978

DALE DURRAN, Massachusetts Institute of Technology: June to August 1978

TZVI GAL-CHEN, University of Toronto: July to August 1978

ROBERT GALL, University of Arizona: April to summer 1978

MATTHEW HITCHMAN, University of Washington: June to August 1978

EUGENE KELLY, University of Miami: July to August 1978

KAMAL PURI, Australian Numerical Meteorological Research Centre: April 1978 to March 1979

JAMES SETHIAN, University of California, Berkeley: October 1978 to January 1979

JEAN-PIERRE VOLMER, French Meteorological Office, Paris: August 1978 to August 1979

ROBERT WALKO, University of Arizona: June to August 1978

MESOSCALE RESEARCH SECTION

Staff

William Bergen
Raymond Bovet
John Brown
Chia-Bo Chang (long-term visitor)
Robert Enk (long-term visitor)
Dorene Howard
Patricia Jones
Jean Kelley
Joseph Klemp
Margaret LeMone
Donald Lenschow
Douglas Lilly (Section Head)
Mark Lutz (long-term visitor to November 1978)
José Meitín
Rebecca Meitín
Dennis Miller (long-term visitor)
Katsuyuki Ooyama
Yunn Pann
Donald Perkey
Nadine Perkey (long-term visitor)
Gary Rasmussen (long-term visitor)
Herbert Riehl
Doyne Sartor
Clark Smith
Borislava Stankov
Robert Ubelmesser
Henry van de Boogaard
Patricia Waukau
Edward Zipser

Visitors

LANCE BOSART, State University of New York: July to August 1978

J. H. CHU, University of Wisconsin: July and August 1978

STEVEN ESBENSEN, Oregon State University: July and August 1978

DAVID FRITTS, NCAR's Advanced Study Program Post-doctoral Program: April and May 1978

TZVI GAL-CHEN, University of Toronto: June through August 1978

ANTHONY HANSEN, Iowa State University: April and May 1978

FRED HOUSE, JR., Drexel University: September through December 1978

ZEV LEVIN, Tel-Aviv University: June and July 1978

JEAN-LUC REDELSPERGER, Laboratoire de Météorologie Dynamique, Paris: August through October 1978

ATMOSPHERIC QUALITY DIVISION

INTRODUCTION

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

- To derive and explain the chemical composition of the earth's atmosphere, particularly the relatively long lived constituents which have global significance, because of their effects on climate and the stratospheric ozone layer. We are also interested in smaller scale processes (urban and regional chemistry) because they are significant in defining the global distribution.

- To determine the composition (including chemical conversions) and dynamical features (including their interactions with chemistry) of the atmosphere from global observations. This will be accomplished through involvement in satellite programs, global in-situ sampling measurements from aircraft, balloons, and rockets, and participation in 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.

During the last year our investigations in the upper atmosphere have contributed substantially to present knowledge of the composition and dynamic structure of the upper atmosphere through the employment of a variety of observational techniques on balloons, aircraft, and satellites. Along with the observational work, we actively pursued photochemical and dynamical modeling efforts, so that theoretical and observational activities were supportive of each other. We have also called attention to the important role of CO, NO_x, CH_4, and non-methane hydrocarbons in the tropospheric ozone budget. Our work has again emphasized the importance of biospheric processes in determining the composition of the atmosphere. We have identified biomass burning as an important source for the atmospheric trace gases CO, H_2, N_2O, NO_x, and COS.

An important new AQD program, the Acid Precipitation Experiment (APEX), was organized by Allan Lazrus. APEX is aimed at studying the acid precipitation problem in North America. Instrumentation has been developed in collaboration with university scientists to study the precursors of, and transformations to, acidic rainwater. Two flight series were flown this year on the NCAR Queen Air aircraft.

Another important aspect of AQD work is the interpretation of chemical observations and the design of field experiments within the context of meteorological phenomena. For example, stratosphere-troposphere exchange processes are investigated through the development of meteorological models of tropopause folding and chemical and optical instrument development in a number of projects is aimed at supporting this effort. A water vapor sensor was constructed and was flown on the NCAR Sabreliner in this program.

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

IN-SITU MEASUREMENTS AND PHOTOCHEMICAL MODELING

Numerical modeling efforts in the In-Situ Measurements and Photochemical Modeling (ISPHOM) project have concentrated on the determination of the sources and sinks of trace constituents from global observations. It was emphasized that a substantial source of tropospheric ozone, caused by the oxidation of hydrocarbons and carbon monoxide in the presence of nitric oxide, is found within the troposphere. The measurements which were made during the Global Atmospheric Measurements Experiment on Tropospheric Aerosols (GAMETAG) were especially useful in these studies. Tropospheric modeling capabilities for studies of this type are continuously updated. The photochemistry of chlorine-containing gases has now been added to the tropospheric-stratospheric version of the existing two-dimensional model.

The principal objective of the Stratosphere-Mesosphere Measurements component of ISPHOM is to contribute to knowledge of the temporal and spatial distribution of a number of atmospheric gases through measurement and analysis. Emphasis is placed on those gases important to the earth's radiation budget and ozone balance and to the dynamics of the stratosphere and mesosphere.

As a part of the long-range goal of monitoring latitudinal changes in stratospheric concentrations of trace gases, Leroy Heidt, Richard Lueb, and Walter Pollock successfully completed two balloon profiles from Fairbanks, Alaska (65°N). Samples were collected cryogenically, and returned to the laboratory, where measurements were performed for CF_2Cl_2, $CFCl_3$, N_2O, CO_2, CO, CH_4, H_2, and water vapor. The balloon flights were a continuation of the global measurements being partially supported by the High Altitude Pollution Program of the Federal Aviation Administration (FAA).

Heidt and Joseph Krasnec participated in the GAMETAG series of flights to map global troposphere abundances of those gases active in the photochemistry cycles both in the boundary layer and in the free troposphere. A mobile gas chromatograph was developed and installed on the Electra aircraft which was used to obtain real-time in-situ measurements of CO, CH_4, CH_3CCl_3, CCl_4, CF_2Cl_2, and $CFCl_3$. In addition, grab samples were collected and returned to the laboratory for measurements of H_2, CO_2, and N_2O. These data were presented at the fall conference of the American Geophysical Union (AGU) in San Francisco. An addition to the mobile gas chromatograph now enables measurement of the C-C_3 hydrocarbons and CO_2 in real-time aboard the Electra.

A portable gas chromatograph has also been developed to be included in a balloon-borne payload to measure in-situ stratospheric concentrations of CH_3CCl_3 and other chlorinated species which cannot be collected and stored for later analysis in the laboratory.

A major addition to the laboratory last year was a gas chromatograph/mass spectrometer (GC/MS). The GC/MS will be used to measure hydrocarbons (C_3-C_{18}) and other organics in both the troposphere and stratosphere.

Research efforts within ISPHOM have also included measurement of the total amount of chlorine in the stratosphere. AQD visitor, Walter Berg, has refined methods for accurately measuring the total chlorine mass mixing ratio in the stratosphere. He developed and tested two separate analytical procedures for determining chlorine content at parts-per-billion levels in stratospheric air samples. A balloon package for stratospheric chlorine sampling was designed, built, tested, and launched on two successful flights. Total-chlorine samples were collected and analyzed for specific gas concentration levels. Initial results from the first flight suggest that the total chlorine mass mixing ratio was 4.2 ± .9 ppbm at 21 km over Alamogordo, New Mexico, in early October 1978. Freon-11 and -12 levels were measured at 55 ± 2 pptv and 154 ± 5 pptv, respectively. Four future flights are scheduled to examine variations in the Cl mass mixing ratio as a function of latitude, altitude, and season.

During February 1978, Richard Cadle, William Rose (a visitor from Michigan Technological University), and several scientists from other organizations sampled the eruption clouds from three Guatemalan volcanoes, to determine the effects of explosive volcanic eruptions on the stratosphere. After analysis of the samples, the scientists concluded:

(1) Most of the sulfur entering the stratosphere from very explosive eruptions is in the form of sulfur dioxide, which, by reaction with OH, may produce sulfuric acid droplets that affect the earth's radiation balance.

(2) Explosive eruptions introduce almost as much hydrogen chloride as sulfur dioxide to the atmosphere. Possibly HCl is largely removed by rain accompanying many large eruptions.

(3) Magmas containing a large percentage of crystals probably produce a much larger proportion of very fine particles that remain in the stratosphere for many months than magmas containing small percentages of crystals.

(4) Volcanoes _may_ contribute significantly to the carbonyl sulfide content of the stratosphere.

During the spring of 1978 ozone and condensation nuclei concentrations in the vicinity of jet stream maxima were measured as part of the AQD study of the exchange of air between the troposphere and stratosphere. The measurements were made from the NCAR Sabreliner and a WB-57F high altitude capability aircraft. The operation of the latter was financed by NASA. During the past year Melvyn Shapiro, Cadle, and others have been analyzing and interpreting the results.

For the last two years Cadle has been collecting information from various sources to compare volcanic with other fluxes of atmospheric trace gases. This comparison was completed during the last year with some surprising results. For example, estimated values of annual global emissions of sulfur dioxide (SO_2) from volcanoes have increased in magnitude and those of biogenic emissions have decreased, so that volcanic and biogenic sources of sulfur are now estimated to have similar rates of emission to the atmosphere as averaged over the entire earth and many years. Furthermore, volcanoes may contribute as much as a third of the amount contributed to the atmosphere by mankind and 15% of the total sulfur emitted to the atmosphere when all sulfur-containing gases are calculated as SO_2.

BIOSPHERE-ATMOSPHERE INTERACTION

The Biosphere-Atmosphere Interaction project has concentrated during the past year on the estimation of the effects of biomass burning (for agriculture, land clearing, and fuel) on atmospheric composition. A detailed survey was made of the worldwide extent of such burning, which takes place especially in the tropics (for example, in the savanna, and in areas of shifting cultivation). It was shown that burning contributes importantly to the atmospheric budgets of CO_2, CO, H_2, N_2O, COS, NO_x, and particulate matter. The production of charcoal (elemental carbon) may also provide a significant sink for atmospheric CO_2, as charcoal is very resistant to microbial decay. Experimental observations were made of the composition of combustion gases from forest and grass fires in the Rocky Mountain area. Future work in this area of research will be conducted with the U.S. Department of Agriculture Forest Service at Macon, Georgia. Contributors to our studies were Paul Crutzen, Leroy Heidt, Walter Pollock, Joseph Krasnec, and Wolfgang Seiler (a visitor from the Max-Planck Institute of Chemistry, Mainz, West Germany).

GAS AND AEROSOL MEASUREMENTS

The Gas and Aerosol Measurements project has placed a considerable emphasis on the measurement of tropospheric ozone during the past year. Projects were designed to measure the global distribution of ozone, to define its stratospheric flux, and to determine its destruction flux to the ground. A stable and well-calibrated airborne ozone measurement system has been created for use on the Electra, and a laboratory long-path ultraviolet (UV) absorption cell is being developed to achieve primary standardization of our instruments. Measurements were made during GAMETAG '78 and winter MONEX to investigate tropospheric ozone distributions across the Pacific Ocean and as far south as 58°S. Of particular note are the ozone bands, regions of elevated ozone concentration which have been found over the Pacific. Analysis of the data is being carried out in cooperation with Frank Routher, William Sedenberg, Roger Dennett, and Douglas Davis of the Georgia Institute of Technology and Edwin Danielsen of Oregon State University.

As an integral aspect of the investigation of the dynamics of troposphere-stratosphere exchange, Melvyn Shapiro has taken measurements to determine the effective troposphere-to-stratosphere transfer of water vapor and the stratosphere-to-troposphere transfer of ozone. These measurements, together with the better understanding of the mechanism of exchange, will allow a better definition of the contribution of stratospheric ozone to the troposphere.

The destruction of ozone at the ground is a major sink for tropospheric ozone. In cooperation with Donald Stedman of the University of Michigan, a fast ozone detector was designed and fabricated and, as part of a boundary-layer flux program by Donald Lenschow (Atmospheric Technology Division), correlations were made between vertical air motion and ozone at frequencies to 5 Hz. Tentative values for the destruction flux of ozone for the dry grasslands of Colorado were determined. Future work is planned to repeat this measurement and to investigate the destruction fluxes into other ground surfaces. The photolysis rate of ozone yielding the excited oxygen atom $O(^1D)$ is an extremely important parameter in the photochemistry of the troposphere for defining the participation of ozone in the degradation of trace gases. Russell Dickerson designed and fabricated an aircraft-mounted chemical photometer with which he measured this parameter at various altitudes and latitudes during the Winter MONEX Electra flights.

Further development of airborne nitrogen oxide detectors has been undertaken and work has commenced on a second system incorporating many of the desirable design features discovered during work on the cooperative AQD - University of Michigan system. Thomas Kelly (University of Michigan) made measurements of NO, NO_2, HNO_3, and O_3 on Niwot Ridge. During periods of northwesterly winds, he routinely observed values of $(NO+NO_2) \sim 100\text{-}300$ ppt, with $NO/NO_2 \sim .25$, and $(NO+NO_2)/HNO_3 \sim 5$ to 20. An investigation has now begun of the photostationary state of NO, NO_2, and O_3 incorporating the $j(NO_2)$ chemical photometer which Dickerson created for use aboard the Electra.

Measurements of aerosol size and number distributions, optical properties, and composition have been made in remote continental and oceanic regions during GAMETAG '78 and Winter MONEX in cooperation with Edward Patterson of the Georgia Institute of Technology and Barry Huebert of Colorado College. In midtropospheric continental background air agreement could be made between the optically defined small particle mass and the mass of the integral of chemically defined sulfate, ammonium, nitrate, and halide. In the continental boundary layer in the arid Southwest, the contribution of large particulates to degradation of visibility was equal to that caused by the small particulates over the ocean. A study was also made of the sea salt size distribution variation with wind speed. A background intercept of small particle mass was found for these studies and further data analysis will take place in cooperation with Robert Charlson of Washington State University. The aircraft aerosol measuring system has now been enhanced with a specially constructed airborne integrating nephelometer. This system will allow direct measurement to be made of aerosol optical scattering and will later be modified to include humidity and thermal treatment stages to allow compositional information to be obtained for aerosol populations.

GLOBAL OBSERVATIONS, MODELING, AND OPTICAL TECHNIQUES

The goals of the Global Observation, Modeling, and Optical Techniques project are to understand the interactions among atmospheric dynamical processes (including transports), chemical composition, and radiative effects; to study the response of the middle atmosphere to natural and anthropogenic perturbations; and to develop new optical techniques for the measurement and identification of atmospheric gases at all levels. Activities are concentrated in the areas of global data acquisition, global data analysis, modeling, and optical technique development.

In the area of data acquisition, the outstanding events last year were the preparations for and the launch of the Limb Infrared Monitor of the Stratosphere (LIMS) experiment on board the Nimbus 7 spacecraft on 24 October 1978. John Gille is co-leader of the science team, which has the responsibility for the development of algorithms for the calibration, inversion, and mapping of the data. Other science team members are co-team leader James Russell III (NASA/Langley) and Roland Drayson (University of Michigan), Hebert Fischer (University of Munich), Andre Girard (Office National d'Etudes et de Recheres Aéronautiques, Paris), John Harries (National Physical Laboratory, England), Frederick House (Drexel University), Conway Leovy (University of Washington), Walter Planet (National Oceanic and Atmospheric Administration (NOAA) and Ellis Remsberg (NASA/Langley).

A group of special project personnel, including Paul Bailey, Douglas Roewe, and Raja Tallamraju, has worked with Gille on the development of algorithms to produce calibrated radiances, vertical profiles of atmospheric quantities, and maps and cross sections of them.

Because of NCAR's expertise in limb scanning, NASA asked NCAR to carry out the operational reduction of the data. Bailey, with Stanley Nolte and Verrill Rinehart (also special project personnel), has implemented the algorithms developed by the experiment team for operational use on a SEL 32/35 minicomputer located at NCAR.

The results to date are preliminary but appear to be very good. Temperature retrievals, which agree well with simultaneous rocket soundings, have been obtained from 200 mb (12 km) to 0.05 mb (70 km). These clearly show the tropopause at low and middle latitudes. James Vickroy has developed special software to produce these data for the Global Weather Experiment Land II-b data sets.

Similarly, profiles of ozone, water vapor, nitric acid, and nitrogen dioxide are in reasonable agreement with climatology and a few in-situ comparison records, although the algorithms are still being refined. The first maps show very interesting features in the latitudinal distributions of nitric acid and water vapor emission.

Gille, Bailey, Nolte, and Roewe were awarded the NCAR Technology Advancement Award for their work on the LIMS sounding system.

In other activities looking toward the future, Gille, Bailey, Michael Coffey (visitor), and Mankin have begun to work closely with the University of Colorado and Laboratory for Atmospheric and Space Physics (LASP) scientists on the design of the limb scanning infrared radiometer for the Solar Mesosphere Explorer (SME). This is a small satellite carrying five instruments (to be built at LASP) which will focus on the response of the mesosphere to solar variations. The infrared instrument will measure temperature, ozone and water vapor in the stratosphere and mesosphere. The principal investigator for SME is Charles Barth (LASP); co-investigators include Julius London (University of Colorado), Ian Stewart and Gary Thomas (LASP), Paul Crutzen and Robert Dickinson (NCAR), Shaw Liu and John Noxon (NOAA), and C. Bernard Farmer (Jet Propulsion Laboratory).

Gille was team leader for the Instrument Definition Team for the Cryogenic Limb-scanning Interferometer and Radiometer (CLIR), a multi-user instrument designed for use on the Space Shuttle. Team members included Coffey and Mankin, D. J. Baker (Utah State), Farmer, Paul Feldman (Johns Hopkins University), Virgil Kunde (NASA/Goddard), David Murcray (University of Denver), and A. T. Stair, Jr. (Air Force Geophysical Laboratories (AFGL)).

Proposals were also submitted for consideration for the Upper Atmosphere Research Satellite program.

Analysis and Interpretation of Global Data

Most of the activity in this area has been in the reduction and interpretation of data from the Limb Radiance Inversion Radiometer (LRIR), which flew on Nimbus 6. This was the first satellite-borne limb scanner, and it was necessary to develop many algorithms to permit detailed analysis of the data.

A two-stage inversion process, in which an initial nonlinear algorithm is followed by a linear method, had been developed earlier by Bailey and Gille. This was first applied to the winter data, from late October 1975 to early January 1976. Extensive studies of the repeatability or precision of the results is better than 1 K through most of the stratosphere. Agreement with rocket soundings is better than 1 K at almost all levels, including the stratopause, although the LRIR results are 1 to 2 K cooler than the rocket data at about 10 mb. Ozone retrievals now extend from 100 mb to 0.4 mb (1556 km), with repeatability between 1-10% in the stratosphere, and with less than 10% rms differences for the rockets.

Gail Anderson has specially processed the ozone profiles to determine day versus night differences at levels above 1 mb. These results are still preliminary but show essentially no variation at 1 mb, with diurnal differences growing up to 20% for the total between 0.4 and 0.1 mb. This is in general agreement with photochemical theory.

To make maximum use of the LRIR data, especially for dynamical studies, a mapping routine has been developed and applied by William Kohri (graduate assistant from Drexel University). It produces Kalman-filtered estimates of the Fourier coefficients to represent a best estimate of the field at any map time, using observations obtained before and after that time. Thus, synoptic maps are produced from asynoptic data. Quantities mapped include temperature, ozone, and geopotential height for the winter data.

From the geopotential heights, geostrophic zonal and eddy winds may be calculated. These have been used to determine cross sections of eddy transport of heat, momentum, and ozone. Kohri is using the data to study the propagation of planetary waves in the stratosphere.

The data have also provided an interesting test of photochemical theory. Based on the mechanistic model of ozone transport developed by Hartmann and Garcia (see below), the ozone variations should be in phase with the geopotential, where transports dominate its distribution, but out of phase with the temperature when photochemistry dominates. For wave one at 60°N in autumn, the top of the dynamically controlled region appears to be at 5 mb, with the base of the photochemical region at 2 mb. This confirms the qualitative pictures used to understand the ozone distribution and provides observational evidence for the levels involved.

Co-investigators on the LRIR experiment are Frederick House (Drexel University) and the late Richard Craig (Florida State University).

Modeling

A significant amount of effort was devoted to modeling in three main areas: mechanistic modeling of ozone transports, three dimensional global modeling, and modeling of radiative heating and cooling processes.

Rolando Garcia collaborated with Dennis Hartmann (University of Washington, formerly a NCAR visitor) on a mechanistic model of ozone transport by planetary waves. Because of the noninteraction theorem, one would expect eddy transports of ozone to be counteracted by meridional transports, with no net transport under stationary conditions, assuming adiabatic and nondissipative conditions. They showed that when the ozone photochemistry (which has dissipative characteristics in the transition region between dynamic and photochemical control) is included, planetary waves are capable of producing large net ozone transports. These results appear to be consistent with the available satellite ozone observations (see above).

Progress on the three-dimensional primitive equation spectral model, with an orthogonal function representation of vertical variations, was not as rapid as hoped. Because of the financial stringencies, further development of this model was dropped. We plan to cooperate with Akira Kasahara in the use of a three-dimensional model of the stratosphere which was developed under his guidance.

Modeling of the radiative heating and cooling rates has two purposes: putting more sophistication into the code in the model mentioned above, and providing a tool that can be used to deduce the complete stratospheric circulation and energetics from satellite observations. In this case, calculations will be based on satellite-measured temperature and ozone distributions.

The model uses parameterizations of flux transmittances based on the line-by-line calculations done for satellite retrieval purposes. So far, the flux transmittance parameterization has been completed for CO_2, and a program to calculate infrared heating/cooling by CO_2 is being tested.

Optical Techniques

The Optical Techniques group utilizes infrared spectroscopy as a principal technique in the measurement of trace gases in the atmosphere. Last year Mankin and Coffey completed measurements of the latitudinal distribution of a number of trace gases in the stratosphere using absorption spectroscopy with the sun as a source. They flew the airborne high resolution Fourier transform spectroscopy system developed by AQD in the last few years to measure the column abundance above the 12 km flight altitude of the NCAR Sabreliner. A series of flights covering latitudes from 0^o to 55^oN was made in the winter and summer of 1978 to look for seasonal differences in photochemically active species. Flights were made at both sunrise and sunset to measure diurnal variations.

The spectra have been analyzed for column abundances of N_2O, NO, NO_2, and HNO_3. The analysis method requires the calculation of synthetic spectra for a specified distribution of absorbing molecules. The distribution is adjusted to obtain the best fit to the observed spectra, and the total amount of absorber in the line of sight is derived.

The synthetic spectra are calculated using the algorithm developed by Mankin, which he has extended to the nonplanar geometry of nearly horizontal atmospheric paths. The spectroscopic parameters are taken from AFGL compilations or other sources. Spectroscopic parameters for individual lines of nitric acid are not available, and only relative amounts of HNO_3 have been determined. A program is under way to obtain comparison spectra of HNO_3 in the laboratory using the same spectrometer used for flight.

The ratio of NO to NO_2 appears to agree with theoretical predictions. The sum of NO and NO_2 exhibits a minimum at the equator and a maximum at high latitudes in the summer and at midlatitudes in the winter. Nitric acid shows large day-to-day variability clearly related to stratospheric dynamical processes, but, in general, it has a minimum at the equator and a high latitude maximum in both seasons.

The data may be analyzed for a number of other trace gases, including the halogen family members such as CF_2Cl_2, CF_4, HCl, and HF. These analyses are proceeding.

The technique of solar absorption spectroscopy is very sensitive but measures only the integrated quantity of absorber along the line of sight. For many problems of atmospheric chemistry, such as identifying sources and sinks of atmospheric chemicals, it is necessary to measure the local concentration of the substance. For this purpose Mankin and Coffey have built a long-path multiple-traversed absorption cell which fits into the Sabreliner. During flight, outside air is continuously drawn through the absorption cell and the transmission of the sample is measured with the Fourier spectrometer.

The cell is of the design by White. Its base length is 2.5 m, the largest which could be fitted into the available space in the aircraft. A maximum of 64 passes of the radiation through the cell is possible, which gives a total path length of 160 m. For a gas with typical strength of absorption, this leads to a measurable absorption for mixing ratios of the order of 50 ppb. In clean air, H_2O, CO_2, CO, and CH_4, N_2O can be measured, while other gases can be measured in the vicinity of strong sources where the concentrations are greatly increased over background levels.

The White cell and spectrometer were flown in three test flights in January 1979. Except for some vibration problems, which have been corrected by strengthening certain mirror mounts, the performance was about as designed. The time required for a measurement leads to a spatial resolution near 1 km at typical aircraft speeds.

The instrument may be used for a number of purposes, such as the planned measurements in summer 1979 of emissions from agricultural burning in South America and measurements of the transfer of species such as H_2O and O_3 between troposphere and stratosphere.

The White cell provides an in-situ infrared technique, but it has rather low sensitivity and requires large samples. Techniques are under development to provide increased sensitivity from small samples such as may be collected on balloon or rocket flights. David Griffith (AQD visitor from the Commonwealth Scientific and Industrial Research Organisation) is developing the technique of cryogenic trapping and matrix isolation spectroscopy. By removing the bulk of the sample (O_2, N_2, water, and Ar make up more than 99.9% of the sample) and using micro-techniques with the remainder, sensitivity of a few parts per billion or less on a sample of a few standard liters may be obtained.

Griffith has constructed matrix isolation cells in which the trace gases are frozen into a CO_2 matrix at 77 K, thus hindering rotation and vibration and concentrating the absorption in narrow spectral features. Thus far, on samples of laboratory air he has achieved detection limits of a few parts per billion. There is also the possibility of seeing free radicals in the samples.

In related work, Mankin is developing microcells for gas-phase spectroscopy of the cryogenically condensed samples. Sensitivity comparable to that of the matrix rotation technique is expected.

A version of the Kley water vapor sensor was built and flown on the NCAR Sabreliner during the Stratospheric-Tropospheric Exchange Project jet stream experiment. The water vapor sensor is based on the observation of OH (310 nm) fluorescence produced by photodissociation of water vapor at Lyman alpha (122 nm). The instrument, which measures mixing ratio directly, is capable of detecting somewhat less than 1 ppmv. Values were observed between 3 and several hundred parts per million by volume during the jet stream flights. On the presumption that dry air comes from the stratosphere and wet air from the troposphere, the instrument elucidated clearly the tropopause fold and the mixing along the jet. Two jets were mapped, one over the Pacific Ocean and one along the Atlantic seaboard. The latter showed considerably more mixing of moisture into the stratospheric tongue than the former. The instrument was found to be self-calibrating in an unexpected way: occasional aircraft maneuvers caused contamination of the sample by fuselage air; the resulting spikes in the fluorescence and absorption signals gave evidence of the instrument sensitivity directly.

It is anticipated that the fluorescence technique can be used to observe other atmospheric trace species, including hydrogen peroxide, mercury vapor, and carbon monoxide.

REACTIVE GASES AND PARTICLES

Stratospheric Research

Since April 1978, Allan Lazrus and the Reactive Gases and Particles (RGP) Project personnel have completed construction and testing of two balloon-borne models of the multilevel chemisorption sampler. This instrument was used to obtain five vertical concentration profiles of stratospheric nitric acid vapor at Palestine, Texas, and Cold Lake, Canada, as part of the NASA effort to provide "ground truth" for the LIMS launched on the Nimbus G satellite as part of the Global Observations, Modeling, and Optical Techniques Project. The HNO_3 profiles observed with the chemisorption sampler agreed well with those obtained by Wayne Evans of the Atmospheric Environmental Service using infrared spectrometry and present the first careful intercomparison study of these two methods. Both techniques provided positive confirmation of the satellite results. In addition, successful winter and spring missions were flown to obtain concentration profiles of stratospheric halogen compounds. Two similar flights in summer and fall are planned, in order to complete our commitment to the Stratospheric Halogen Compound Investigation performed in cooperation with NASA.

A chemisorption filter sampler has been constructed for use on the NASA Ames U-2 aircraft. This instrument will be used for experiments in various studies of stratosphere-troposphere exchange processes in NASA's Aerosol Climatic Effects program, and to provide ground truth for the Stratospheric Aerosol and Gas Experiment and Stratospheric and Mesospheric Sounder Experiment satellite aerosol measurements.

The RGP group provided consultation and research support for Walter Berg, in his experiment to obtain total chlorine measurements in the stratosphere.

Tropospheric Research

Cooperative measurements with Barry Huebert of Colorado College have continued throughout the second series of GAMETAG global flights, yielding refinements and confirmation of earlier results regarding the global distributions of tropospheric nitric acid and nitrate aerosol. In addition, global distributions were obtained of tropospheric hydrochloric acid vapor, as well as several aerosol constituents including sulfate, chloride, sodium, and ammonium ions, in both the boundary layer and free troposphere.

In cooperation with Cadle, Huebert, and William Rose (Michigan Technological University), the RGP group conducted a study of chlorine, fluorine, and bromine in both the gas and particle phases in eruption plumes of several Guatemalan volcanoes. This effort was directed toward studying the chemical fractionation of these materials within volcanic plumes in order to explain observed effects of major eruptions on stratospheric trace chemistry.

The research team of the Acid Precipitation Experiment (APEX) completed two field programs dedicated to the study of the total acidity of tropospheric air and its influence on cloud water and precipitation.

During the autumn APEX field program, a general survey of acidic and basic constituents was made in the Midwest and in the northeastern United States. A relatively stationary high-pressure area caused severe pollution in this region during part of the mission, permitting comparative studies of atmospheric acidity in a source region (the Ohio River Valley) and a sink region (the Adirondack Mountains).

During the spring program, several frontal cyclonic storms were investigated. Pertinent measurements were made of cloud water, of rainwater at the surface, of low-altitude cold air north of the warm front through which the precipitation fell, and finally of the warm overriding air, which affects the cloud chemistry. In addition, several missions were flown over the ocean downwind of the New York metropolitan area to study the interaction of an urban plume with the more alkaline maritime atmosphere. A study of H_2O_2 in both cloud water and precipitation was made to reveal the role of this reagent in cloud chemistry.

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

THERMOSPHERIC DYNAMICS AND AERONOMY

The primary goals of THE Thermospheric Dynamics and Aeronomy 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 has emphasized numerical modeling.

Work toward the long-range goals of this project, which are described in the AQD multi-year plan, progressed in four separate but interconnected areas: (1) thermospheric dynamics, (2) midlatitude ionospheric dynamics and auroral processes, (3) electrical coupling between the upper and lower atmospheres, and (4) the study of minor neutral constituents in the lower thermosphere.

In studies of thermospheric dynamics, NCAR's third-generation-fourth-order general circulation model (GCM) of the lower atmosphere was modified for thermospheric heights (90-500 km). The main modifications of the GCM code included the incorporation of implicit differencing in the vertical to account for the fast molecular diffusion of heat and momentum at thermospheric heights and also the incorporation of thermospheric physics within the model. The model is currently being used to examine the thermospheric circulation and temperature structure for equinox and solstice conditions during solar cycle maximum and minimum, respectively. This work is a collaborative effort among Raymond Roble, Robert Dickinson (Atmospheric Analysis and Prediction Division), and Cicely Ridley (Atmospheric Technology Division).

The zonally symmetric thermospheric dynamic model was used by Roble, Dickinson, Ridley, and Y. Kamide (Kyoto Sangyo University, Japan) to investigate the time-dependent thermospheric response to heating by auroral substorms. In this time-dependent calculation the high-latitude heat source was determined from a parameterization of the global equivalent current system flowing in the ionosphere as determined from the magnetic recordings of 82 northern hemisphere magnetic observatories. The calculations showed that impulsive heating at high latitudes due to auroral substorms launches large horizontal scale waves that propagate equatorward, dissipating auroral energy globally. The results also suggest that the time-dependent properties of the high-latitude heat source can be determined from the variations of the global equivalent current system.

To obtain data to verify model predictions, collaborative efforts have been maintained with Gonzalo Hernandez (NOAA), Paul Hays (University of Michigan), Manfred Rees (University of Alaska), John Evans (Massachusetts Institute of Technology), and James Walker (Arecibo Observatory). These investigators determine thermospheric winds and temperatures from ground-based stations for a variety of geophysical conditions.

In studies of midlatitude ionospheric dynamics, the ionospheric model was used to investigate the postmidnight collapse of the ionosphere over Arecibo, Puerto Rico. This study was done by Emery in collaboration with Roble and Walker (Arecibo). Various data obtained by the incoherent scatter radar at Arecibo were used to derive the ionospheric properties and plasma drift that in turn were used to specify input parameters to the ionospheric model. The results show that the postmidnight collapse of the ionosphere is related to a global wind system. Before midnight the meridional winds are blowing equatorward, which forces ionization upward along the geomagnetic field line over Arecibo. Near midnight the equatorward-directed winds become weak or reverse to poleward-directed winds; the ionospheric plasma that has been lifted to high latitudes suddenly loses the wind support, and the plasma flows downward to low altitudes where rapid recombination occurs. The postmidnight collapse is a regular feature over Arecibo and is related to the global circulation pattern that in the future will be studied using the thermospheric general circulation model.

The aurora model was used to investigate the build-up of the minor neutral constituents NO, $N(^2D)$, and $N(^4S)$ produced by the aurora. This study was done in collaboration with Manfred Rees (University of Alaska). The results showed that NO densities in the lower thermosphere build up in response to repeated substorm activity and the aurora should be considered as a strong global source of NO production in the upper atmosphere. The aurora model was also used to calculate the ionospheric properties during an aurora event, and these results were compared with satellite measurements. The results show that good agreement between the measured and calculated ionospheric properties is obtained at the time of the satellite crossing that occurred about 12 minutes after the auroral arc suddenly appeared.

The global model of atmospheric electricity was used to examine the influence of upper atmospheric generators, such as the ionospheric dynamo and the high latitude generator associated with magnetospheric convection, upon the global electrical circuit. This modeling effort was made in collaboration with Hays (University of Michigan). The model includes the effects of orography, and it represents thunderstorms as dipole current generators randomly distributed in areas of known thunderstorm frequency. The electrical conductivity in the model increases exponentially with altitude, and the model solves for the electric potential on the basis of an assumed distribution of thunderstorm current sources. The large horizontal scale potential differences at ionospheric heights that are associated with the ionospheric dynamo and magnetospheric convection during geomagnetic quiet times map effectively downward into the lower atmosphere, where perturbations of $\pm$ 20% in the ground electric field and air-earth currents are superimposed upon the high latitude variation that is established by worldwide thunderstorm activity. During geomagnetic storms and auroral substorms the perturbations are highly variable but are generally greater and occur further equatorward. Any current imbalance caused by the superimposed ionospheric potential patterns requires a readjustment of the global fair-weather potential difference between the ground and ionosphere to maintain the divergence of the global air-earth current equal to zero. Changes in upper atmospheric conductivity due to solar flares, polar cap absorption events, and Forbush decreases were also shown to alter the downward mapping of the high-latitude potential pattern and the global distribution of fields and currents. Roble and Gary (University of Colorado) have developed a time-dependent, two-dimensional numerical model of the minor neutral constituents in the thermosphere to examine the effect of winds in altering the distribution of NO produced in the aurora. The calculations show that global scale thermospheric winds flowing through regions of enhanced local auroral production produces a "plume" of enhanced NO densities downward from the aurora. Accompanying the downwind maximum in NO densities is a "hole" in the $N(^4S)$ density. The maximum NO densities calculated with and without horizontal winds differ by a factor of 2.6 for the case considered, indicating the importance of horizontal transport in controlling NO densities within the auroral zone. The results also show that aurora-produced NO can diffuse to lower altitudes.

STRATOSPHERIC-TROPOSPHERIC EXCHANGE

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

The numerical model of jet stream development and tropopause folding by Louis Gidel and Melvyn Shapiro has been further refined to include parameterizations for turbulent-scale mixing of heat, momentum, ozone, and tropospheric trace constituents. The importance of along-front thermal gradients in promoting deeply penetrating tropopause folds has been demonstrated through this modeling effort. Current research with this model is attempting to simulate the effects of turbulent mixing processes as a mechanism for chemical exchange between the stratosphere and troposphere during tropopause folding events.

The STEP continued its utilization of the NCAR Sabreliner research aircraft to investigate the turbulent-scale and chemical characteristics of upper level jet streams and associated tropopause folds. In collaboration with Leroy Heidt, (in-situ) grab samples of air were taken within tropopause folds which contained tropospheric concentrations of CO and CH_3CCl_3. Simultaneous in-situ measurements of water vapor, taken in collaboration with Edward Stone, documented large concentrations of water vapor within the stratosphere near regions of tropopause folding. Detailed analysis of these aircraft measurements by Shapiro and Patrick Kennedy established the importance of turbulent mixing within tropopause folds as an essential mechanism for exchanging stratospheric ozone and tropospheric condensation nuclei across the tropopause.

Philip Haagenson and Shapiro have developed a three-dimensional objective isentropic trajectory analysis procedure that will be used to investigate stratospheric tropospheric exchange in the vicinity of extratropical weather systems. Quantitative estimates of air flow across the tropopause as defined by potential vorticity are being made with this routine. In addition, low-level air-trajectory motions are being calculated in support of the Acid Precipitation Experiment (in collaboration with Allan Lazrus).

Gidel and Shapiro have used the NCAR general circulation model to investigate the possibility of asymmetrics between the northern and southern hemispheres with respect to vertical ozone flux from the stratosphere to the troposphere. Results suggest that the downward flux of ozone is twice as large in the northern hemisphere as in the southern hemisphere.

This installation of a high-altitude radar altimeter on the NCAR Sabreliner has permitted for the first time the direct measurement of the geopotential gradient at jet stream levels ($\sim$ 9 km) of the atmosphere. Given these geopotential and the internal wind measurements, it was possible to evaluate the magnitude of the ageostrophic and geostrophic wind field for two intense cases of upper level jet streams. Initial results suggest that commercial aircraft could provide much-needed height data over oceanic regions by this means.

APPENDIX

RADIOACTIVE AEROSOLS AND EFFECTS

Introduction

The Radioactive Aerosols and Effects project exists as an organizational entity within the AQD and is funded through it. Its research objectives, however, depart from those of the mainstream of the division and are generated and directed by its project leader, Edward Martell. Because of the divergence of its research from the main thrust of the division and the project's unique character within the divisional framework, its research history for the past year is presented as an appendix rather than as an integral part of the division report.

Edward Martell, Stewart Poet, Veryl Frahm, and Ellie Doykos have continued the experimental investigation of airborne alpha radioactivity and its atmospheric and biological effects. Main emphasis of the work over the past year has been the assessment of the contributions of alpha emitters to the incidence of natural, or "spontaneous", mutations in living organisms. These experiments involve *Drosophila melanogaster* (fruit flies), their exposure to natural and elevated levels of alpha radiation, and the quantitative assessment of the corresponding mutation rates using standard sex-linked recessive lethal test procedures.

Drosophila Experiments

Surprisingly, the contribution of natural alpha radiation to mutation rates in living organisms has never been assessed. Early experiments, involving X-ray- and radium-induced mutations in *Drosophila* and other organisms, gave results which seemed to indicate that the natural background of ionizing radiation makes only a minor contribution to the "spontaneous" mutation rate. Thus, for example, Muller and Mott-Smith reported that it required an X-ray dose of 100 rads (one thousand times the natural background radiation dose of 100 mrem per year) to equal the natural mutation rate in *Drosophila*. Such results, as well as the temperature dependence of *Drosophila* mutation rates and other considerations, suggested that most natural mutations must be attributable to agents and mechanisms other than ionizing radiation.

The natural mutation rate may very well be accounted for by natural alpha-emitting radioisotopes. The important isotopes, present in all living organisms, are radium and thorium and their radioactive decay products. Alphas, charged helium nuclei of high energy, deposit their energy in short, straight tracks of high ion density, with a path only 40 to 80 μm long in tissue--only a few cell diameters. The average radiation dose to a cell which is hit by a single alpha particle is 10 rads, or 100 rem, about one thousand times the average annual background radiation dose. Thus, "spontaneous" mutations in *Drosophila* could be accounted for if each germ cell receives an average of one alpha hit within the reproductive life span. There is abundant evidence to indicate that natural alpha-emitting radioisotopes are highly concentrated on epithelial surfaces of organisms, including the inner epithelial surfaces and the germ cell sites of higher organisms.

A promising approach to the quantitative assessment of the alpha radiation contribution to the natural incidence of mutations in *Drosophila* involves radioisotope tracer experiments of the following type. The concentrations of the important natural alpha-emitting radioelements, radium-226, thorium-228, and polonium-210, are determined for both natural food mixtures and food mixtures tagged with an elevated level of one of these radioelements. The increased yields of sex-linked recessive lethal mutations at elevated levels for each radioisotope provide a quantitative measure of the contribution to the natural mutation rate. This stems from the fact that the incidences of both dominant and recessive lethal mutations in *Drosophila* are linear with dose for various types of ionizing radiation. Because of variations in the chemical form and distribution of the natural and added radioisotope in the food mixture, there are variations in the uptake of each radioisotope in the yeast cells and fruit flies cultured on the food mixture. For this reason it is also necessary to determine the fractionation factors which are applicable in each case.

Experimental determinations of thorium isotopes and polonium-210 involve radiochemical separation procedures and alpha spectroscopy of plated samples. Radium-226 is determined by radon gas counting. Sex-linked recessive lethal mutations are determined using standard procedures. However, in our experiments, the pattern of irradiation for the treated male flies is identical to that which occurs naturally in the controls--continuous internal alpha irradiation from zygote to one-week-old adult.

Preliminary sex-linked recessive lethal tests were carried out with food mixtures tagged with elevated levels of thorium-228 in the form of soluble thorium nitrate. Radiochemical measurements indicated that in this form the thorium is not taken up very effectively in yeast and flies. More effective tagging methods, involving the application of thorium in the form of inorganic phosphate and/or as organic phosphate are being developed.

There is abundant evidence that alpha-emitting radioisotopes are highly nonuniform in the biosphere and may be concentrated internally on epithelial surfaces and in the germ cell environs. Preliminary results for experiments in which fruit flies were cultured on food mixtures with elevated levels of alpha-emitting radioisotopes indicated a substantially increased frequency of alpha interactions with germ cell nuclei. It is tentatively concluded that internal alpha radiation contributes substantially to natural mutation rates. This important possibility will be evaluated quantitatively in future experiments, including:

(a) Radiochemical studies to develop and test improved radioisotope tagging methods and to evaluate the fractionation effects involved in uptake by *Drosophila* of radioisotopes in their natural and added form, and

(b) Sex-linked recessive lethal tests of sufficient scale to provide statistically significant results for the contributions of (1) thorium-228 and its decay products, (2) radium-226 and its decay products, and (3) polonium-210.

STAFF

Division Director's Office

Nancy Birkenheuer
Peter Crooimans
Paul Crutzen (Division Director)
Teresa DiMarco
Nelder Medrud, Jr.
Frank Melchior
Mary Molinar
Donna Sanerib

In-Situ Measurements and Photochemical Modeling Project (ISPHOM)

Walter Berg (LTV)
Richard Cadle
Paul Crutzen (Leader)
Russell Dickerson
Gerald Dolan
Sonia Gitlin
Leroy Heidt
Bruce Henry
Joseph Krasnec
Richard Lueb
Randolph Payne
Walter Pollock

Gas and Aerosol Aircraft Measurements Project (GAME)

Anthony Delany (Leader)
Frank Grahek
Arthur Wartburg

Biosphere-Atmosphere Interaction Project (BAI)

Gerald Dolan
Dale Gillette (Leader until December 1978)
Leroy Heidt
Jospeh Krasnec
Walter Pollock

Reactive Gases and Particles Project (RGP)

Lawrence Beaman
Bruce Gandrud
James Greenberg
Allan Lazrus (Leader)
Paulette Middleton
Paul Sperry

Stratospheric-Tropospheric Exchange Project (STEP)

Philip Haagenson
Patrick Kennedy
Melvyn Shapiro (Leader)

Thermospheric Dynamics and Aeronomy Project (TDA)

Barbara Emery
Raymond Roble (Leader)

Global Observations, Modeling and Optical Techniques Project (GOMOT)

Gail Anderson
Paul Bailey
Michael Coffey (LTV)
Rolando Garcia
John Gille (Leader)
William Kohri
Stanley Nolte
Verrill Rinehart
Douglas Roewe
Raja Tallamraju
James Vickroy
W. Roy Wessel (to February 1979)

Optical Techniques Subproject (OT)

William Mankin (Leader)
Edward Stone

Radioactive Aerosols and Effects Subproject (RAE)

Ellie Doykos
Veryl Frahm (up to 1 February 1979)
Edward Martell (Leader)
Stewart Poet

VISITORS

Fausto de Almeida, April 1978 to October 1978, ISPHOM

William Bernardo, University of Michigan, April 1978 to March 1979, GAME

Robert Chatfield, Colorado State University, June 1978 to September 1978

George Dawson, University of Arizona, September 1978 to November 1978, ISPHOM

Roger Dennett, University of Michigan, April 1978 to March 1979, GAME

Ron Ferek, Florida State University, September 1978 to September 1979, RGP

Jack Fishman, Colorado State University, April 1978 to March 1979

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

Lou Gidel, Colorado State University, April 1978 to March 1979, ISPHOM

David Griffith, CSIRO, July 1978 to March 1979, GOMOT

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

VISITORS (cont)

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

Manfred Rees, University of Alaska, July 1978 to August 1978, TDA

Henning Rodhe, Stockholm University, Sweden, August 1978 to December 1978, ISPHOM

William Sedlacek, Los Alamos Scientific Labs, November 1978 to March 1979, ISPHOM

Wolfgang Seiler, Max-Planck Institute, Germany, June 1978 to November 1978, ISPHOM

Knut Stamnes, University of Alaska, December 1978 to March 1979, TDA

Stacy Walters, University of California, March 1979 to January 1980, ISPHOM

HIGH ALTITUDE OBSERVATORY

INTRODUCTION AND PERSPECTIVE

The research activities of the High Altitude Observatory are directed towards two major NCAR objectives: an understanding of solar processes and their influence on the interplanetary medium, and an understanding of climatic changes and their origins. These efforts are carried out under G.A. Newkirk, Director, within a structure of four scientific sections: Solar Atmosphere and Magnetic Fields (R. G. Athay, head), Coronal Physics (R. MacQueen, head), Interplanetary Physics (A. J. Hundhausen, head), and Solar Variability (P. A. Gilman, head), abetted by Administration and Support (E. M. Reeves, head). The following summaries detail the activities within each of the observatory scientific sections, but, as has been noted in the past, the sectional distinction is no barrier to the pursuit of research questions that call for a broad, varied attack encompassing several sub-disciplines. As stressed in last year's Annual Scientific Report, solar variability provides the most vivid example of problems that consistently cross normal disciplinary lines and require the synthesis of results from numerous areas.

In gathering a few highlights to provide a perspective for viewing research activities within the observatory, we note that several new and exciting results with potentially major implications for future research directions have surfaced in the Solar Variability Section, despite the fact that the section remains "sub-critical" in size and scope as a result of limited funds. First, model calculations of the solar global circulation have progressed to the point that they give insight into the differential rotation to be expected in several classes of stars with convection zones. The incorporation of compressibility into the model has achieved increased realism, and the new results represent a distinct departure from many previous dynamo models whose applicability is now called into question. Moreover, the modeling work has uncovered a hitherto unnoticed mechanism for limiting magnetic field amplitudes.

Next, historical observations of the solar diameter made with transit telescopes have been reanalyzed. They show an apparently continuous decrease in solar diameter of about 1-2 seconds of arc per century for the period 1836-1953. At least one eclipse record from the sixteenth century suggests that such a decrease may have been occurring for a few hundred years. At present, terrestrial atmospheric causes for this apparent change cannot be completely ruled out. But if the change is a true solar effect, it would represent a heretofore unknown contraction of the photosphere and underlying convection zone, with major implications for the variable nature of the sun. Finally, changes in cosmic-ray flux seen at the earth have been shown to correlate much better with the presence and size of polar coronal holes than with the classical solar cycle index, the sunspot number. Abrupt changes in cosmic-ray flux and coronal holes are observed to occur at times when the sunspot number shows a much more gradual evolution.

This new result has major implications for understanding the mechanism of cosmic ray modulation and consequently the influence of the sun on the production of radioisotopes used to infer past levels of solar activity.

Planning for a major new thrust in our solar variability program at HAO is under way with the development of a Fourier Tachometer to be used to measure global velocities on the sun to an accuracy and stability never before achieved. As currently envisioned, the instrument will include a small (3-5 cm) telescope feeding a Michelson interferometer, with an iodine-stabilized helium-neon laser providing the critical wavelength standard. The instrumentation will provide two-dimensional velocity pictures of the sun every minute; and many such pictures can then be averaged to reduce short-time-scale solar noise. HAO plans to deploy the instrument by the end of FY-1981, beginning observations of global velocity fields soon thereafter.

Within the Lower Solar Atmosphere and Magnetic Fields Section, a major effort over the past year has been devoted to the interpretation of the vector solar magnetic fields observed by the joint HAO/Sacramento Peak Observatory (SPO) Stokes Polarimeter. HAO staff members and visitors have used instrumental results to study height gradients of the magnetic field, to compare fields in sunspots and active regions, and to derive the three-dimensional magnetic structure of quiescent prominences.

After several years of development, successful simultaneous observations of the corona in electron-scattered white light and the proton-scattered ultraviolet Lyman-alpha hydrogen line were recently carried out in a joint rocket experiment by the Harvard/Smithsonian Center for Astrophysics and HAO. These direct measurements promise to provide a new and potentially more accurate method of measurement of the coronal temperature and over a range of heights heretofore inaccessible. The experiment may also make possible a direct measurement of the coronal outflow velocity. The technique should open new perspectives on our knowledge of the physical parameters of the near solar corona.

Finally, during the past year, the last of the successful Skylab Workshop series under the general directorship of Gordon Newkirk was held, on the subject of Energy Balance and Physical Conditions in Solar Active Regions. Frank Orrall (University of Hawaii) acted as the workshop director and R. Grant Athay, Robert W. Noyes (Harvard/Smithsonian Center for Astrophysics), and Gerard van Hoven (University of California, Irvine) acted as workshop advisors. Approximately 60 scientists from the United States and several foreign countries participated in this series. Following the pattern established by the first workshop on coronal holes, both the second workshop on solar flares and the latest workshop on active regions will be represented by separate books, now in preparation, summarizing the current state of the art in these areas.

SOLAR VARIABILITY SECTION

The broad goal of the solar variability effort is to describe and understand the fundamental operation of the solar cycle and its influence on the sun's output--radiation, magnetic fields, and particles--over a broad range of time scales, from weeks and months to tens of thousands of years. This goal is obviously central to the NCAR objectives of understanding solar processes and their influence on the interplanetary medium and of understanding climatic trends and their causes. It is clearly related to research activities sponsored by other agencies, such as NASA and NOAA, to monitor solar luminosity and other radiative outputs (with the satellites OSO-8, Nimbus 6 and 7, and the Solar Maximum Mission) and to monitor the solar wind and magnetospheric and ionospheric variations. HAO research in solar variability is also closely related to other solar investigations at Sacramento Peak Observatory, Kitt Peak National Observatory, the Hale Observatories, the University of Arizona, and observatories elsewhere in the world, as well as to dendrochronological, geochemical, and climatological research at a variety of institutions.

Solar variability research carried out during 1978 may be conveniently described in five interrelated areas; the complex nature of the topic has dictated that we pursue several lines of research in parallel. The areas are:

(1) Modeling and observations of the global circulation and the dynamo
(2) Documentation and diagnosis of solar radiative variability
(3) Development and verification of indirect measures of long-term solar variability
(4) Understanding the long-term evolution of the corona and solar wind
(5) Understanding the geomagnetic response to solar variability.

Modeling of Global Circulation and Dynamo

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

Extrapolations of present global circulation models to the sun or other stars are of uncertain validity, since the model physics is much simpler than the real stellar physics. Gilman and graduate assistant Gary Glatzmaier have moved one step closer to the real physics during 1978 by implementing a linear version of the governing equations for convection of a compressible fluid in a deep rotating spherical shell. (The parent model is for a stratified liquid.) Studies with this new model will be the basis of Glatzmaier's Ph.D. thesis for the University of Colorado. Preliminary results have been obtained for convection zones of up to 40% of the solar radius in depth, across which the density varies by as much as a factor of 240 (about eight pressure scale heights). Glatzmaier and Gilman have found that as the density stratification is made larger, the dominant scale of global convection becomes smaller, and the convection cells become quite asymmetric with respect to the middle of the layer. The center of the cell moves closer to the bottom boundary, and the velocities become larger at the top than the bottom. Nevertheless, the cells still reach all the way from the bottom to the top of the layer. Under the strong influence of rotation, these cells still show a predominant transport of angular momentum toward the equator from high latitudes, so maintenance of an equatorial acceleration is still expected. The precise rotation profile to be expected from nonlinear calculations and other related questions should be answered within the next year.

One of the most interesting new effects seen in the dynamo results is the large role played by time changes in the velocity fields in determining the rate at which magnetic field is dissipated. Recent model calculations indicate that relatively rapid changes in the velocities responsible for induction of magnetic fields can prevent the fields from growing to a point where they feed back substantially on the motions. Thus, such feedback may not be necessary to limit the field. Apparently, this process has not been noticed in previous dynamo calculations, probably because time-dependent motion fields are rarely studied. However, they are the rule in nature, so this effect may be of general importance for all kinds of dynamos.

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

Observations of Global Circulation

A major development during 1978 in observations of global circulation on the sun is being sparked by Timothy Brown, who came to HAO from Sacramento Peak in September. He has begun plans for the development of a new instrument, called a Fourier Tachometer, to measure global velocities with an accuracy and stability never before achieved. The combination of interferometric techniques, two-dimensional imaging, and high wavelength accuracy is required for studies of the solar global circulation, since the flows are expected to be of small amplitude and large spatial extent. The development of this instrumentation will be one of the cornerstones of the expanded program in the solar variability area.

In addition to his instrument design effort, Brown has been studying brightness fluctuations in photospheric radiation using observations from Sacramento Peak Observatory. The measurements reveal peak ridges of power in frequency-wavenumber space which had been seen previously by Franz Deubner in the doppler shift and which were used by Deubner, Ed Rhodes, George Simon, and Roger Ulrich to deduce various properties of the layers below, including rotation and convection zone depth. It should be possible to use the brightness information as a powerful additional tool for diagnosing properties of the outer layers of the sun, such as distinguishing between inward- and outward-moving waves in the low photosphere. Also, features of longer period seen in the power spectra may correspond to gravity waves trapped in the photosphere and low chromosphere, which can also be used for determining atmospheric structure. Brown also has continued to develop image reconstruction techniques for small-scale features on the sun, such as flux tubes and granulation, which are obscured by atmospheric seeing. Part of this work is in collaboration with Jack Harvey (Kitt Peak).

Diagnostic Measures of Solar Radiative Variability

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

The solar observations have much higher spectral resolution than any stellar measurement, so the detailed profile changes involved in the change of the K index can be seen. Besides the strengthening of the chromospheric emission, White and Livingston also expect to see the line core narrow slightly, because this is a common property of K line profiles in plages and there are more plages at solar maximum. Thomas Ayres (JILA) has derived scaling rules to relate line-width changes to changes in the nonradiative energy input to the chromosphere; consequently, White and Livingston are also watching for confirmation or refutation of this theory. The average disk profiles do not yet show a measurable decrease in width.

Measures of Long-Term Solar Variability

The longest continuous series of direct observations of the sun is that of the apparent solar diameter, made with transit telescopes at noon meridian passage. The observations were begun at the Greenwich Observatory in 1750--more than a century before a dedicated program of observations of the sunspot number was initiated--and are continued at several observatories to this day. Primary data are of the apparent horizontal diameter, expressed as an interval of time. Since 1836, the Greenwich data have included a concurrent measurement of the sun's vertical diameter, made with a micrometer. At Greenwich, as at other observatories, the data were taken to determine accurate celestial coordinates of the center of the apparent solar disk for studies of celestial motions.

They are now being applied in the area of long-term solar variability indicators. Many previous studies, notably a series of papers from 1870-1910, have searched these data sets for evidence of possible 11-year cyclic changes, to determine whether the sun's average diameter, or its figure, oscillates in step with surface activity. The results have been inconclusive, as have subsequent searches for 22-year oscillations. In a program supported jointly by HAO and the Harvard/Smithsonian Center for Astrophysics, Jack Eddy has made a study of the historical solar diameter data for possible secular changes of long term. The study, begun in 1977, tested whether solar diameter changes accompanied changes in the long-term envelope of solar activity, under the hypothesis that envelope changes in turn represented secular changes in solar luminosity.

The longest and most accurate data series, from Greenwich for the years 1836 through 1953, shows a statistically significant secular decrease in solar diameter that exceeds errors of observation and likely observer bias. The same secular trend, toward ever-decreasing solar diameter, has been noted before by others who examined all or part of the Greenwich data set, and it has been attributed to secular atmospheric effects or personal equation. It is not so obvious a feature in the less continuous series of meridian transit measurements made at the U.S. Naval Observatory between 1862 and 1945, and it does not appear in the less precise measurements made at Campidoglio and Monte Mario in Italy between 1874 and 1937.

The Greenwich decrease is a nearly monotonic feature of both horizontal and vertical diameters: a least-squares fit gives 2.25 seconds of arc per century in D_H and 0.75 seconds of arc per century in D_V. If this measures a real change in the solar diameter, it amounts to about 0.1% per century, which is two orders of magnitude more than the rate originally proposed by Helmholtz in 1854 to explain the total solar luminosity by gravitational contraction. It could result, however, from a temporal contraction of the photospheric and convection layers of the sun.

On the other hand, the apparent contraction could result from a secular change in the atmospheric conditions at Greenwich, through changes in the effect of irradiation. The brighter the surrounding sky, the smaller the sun's disk appears. In this case, the change required is severe, equaling the summer-to-winter change in irradiation noted as a clear, annual effect in the Greenwich data and far surpassing any effects owing to volcanic loading of the atmosphere in the same period of time, including the eruption of Krakatoa, west of Java.

Eddy has looked at historical eclipse observations as a possible method of sorting out the two effects. A slightly larger solar diameter in the past, as opposed to an atmospheric trend, would shorten the duration of eclipse totality at any point; the change would be most dramatically noted at past eclipses which, using the present diameter of the sun, should have been "ring-total," or barely total. A case in point is the eclipse of 9 April 1567 that was observed by Clavius in Rome, near the point of maximum calculated totality. There the modern diameter of the sun would have made the moon larger by 6 seconds of arc on the diameter, resulting in a brief total eclipse at that point. Had the contraction indicated in the Greenwich data continued since the sixteenth century, Clavius would have seen instead an annular eclipse, for the sun would have been about 2 seconds of arc larger than the moon. Clavius, who had seen and described a longer, unquestionably total solar eclipse in Portugal seven years earlier, described the Rome eclipse as unique; "a certain narrow circle was left on the Sun, surrounding the whole of the Moon on all sides." In this case his description seems to fit an annular eclipse very well. Further studies of other meridian transit data are underway, as are further searches of descriptions of "ring-total" eclipses.

The best known long-term record of solar activity is, of course, the classical Wolf sunspot number. Richard Bogart (ASP Postdoctoral Fellow) in consultation with White, has been reexamining this record, particularly to find out what evidence of recurrence of solar activity it contains. The principal technique is simply to compute the auto-correlation function for the sunspot number record. This is done for the time period 1850-1977 for which this number is best defined. While not finding any true periodicities, Bogart finds strong evidence for the existence and persistence of active longitudes for periods of up to a year. He also finds that the rotation period of active longitudes in different solar cycles can vary by as much as 2 days, or about 7%. Active longitudes are seen to be more pronounced in some cycles than others, although the strength of active longitudes in a cycle is not clearly related to the amplitude of the cycle. Finally, he also sees that in some cycles active longitudes have recurred at intervals of 250-400 days.

Long-Term Evolution of the Corona

Observations of the corona with the HAO Mark II K-coronagraph ended in October 1978, in order that the Mark III instrument (described under activities of the Coronal Physics section) could be installed. The complete Mark II data set now covers all of solar cycle 20, except for about one year near solar maximum, as well as the ascending phase of the new cycle, 21. Basic reduction of the data has been completed for the years 1965-1975, while that for 1976-78 is nearly complete. The recent observations and their reduction have been carried out primarily by Richard and Shirley Hansen, working with Arthur Hundhausen.

The 1977 report described a number of preliminary results concerning the evolution of the corona, particularly coronal holes, obtained from this data. Coronal holes near the sun's poles have proved to be particularly important for understanding changes in the solar wind and geomagnetic activity. To aid in developing this understanding, Hundhausen and the Hansens have defined and calculated an index of polar hole area, which quantifies the state of the corona and illustrates clearly the rebirth of polar holes in 1970-71, just past the maximum of solar cycle 20. This index has now been related to another index of solar activity, the sunspot number.

The flux of galactic cosmic rays measured near the orbit of earth shows a well-known 11-year modulation that is correlated (but 180° out of phase with) sunspot number. However, the cosmic-ray flux observed during cycle 20 showed an abrupt change from the low value characteristic of sunspot maximum to a high value characteristic of sunspot minimum in 1970-1971. In contrast, the decline in sunspot number took six more years. Hundhausen, the Hansens and David Sime noticed that the rebirth of the polar coronal holes occurs at this same time and with a similar abruptness. In fact, the area index for polar holes calculated for all of cycle 20 cited above shows a far better correspondence to the observed cosmic ray intensities than the familiar sunspot number. This correspondence suggests cosmic rays have easy access into the solar system via the polar solar wind, subsequently diffusing and drifting in the general, dipole-like interplanetary magnetic field thought to exist when polar holes are prominent. Refinement of the hole area index and further comparison with observation and theoretical models is underway.

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

Geomagnetic Response to Solar Variability

To understand the physical links between the interplanetary medium and the earth's ionosphere and magnetosphere, one needs to identify which of the physical characteristics of the interplanetary medium correlates best in its time changes with geomagnetic storms and various geomagnetic indices. Sadami Matsushita has found that the well-known high correlation between the presence of a southward component of the interplanetary magnetic field and geomagnetic storms actually holds only near maximum in the solar cycle. On the other hand, the well-known correlation between solar wind speed and geomagnetic indices is true only in the declining phase of the cycle and near solar minimum. In each case, the magnitude of the correlation depends also on the interval over which the data is time-averaged. Work is currently under way to find out what time-averaging period is optimum. In a study motivated by some of these results, Matsushita and Yohsuke Kamide (visitor from the University of Kyoto) have been able to simulate geomagnetic substorm effects that arise as a result of a southward-directed interplanetary magnetic field, using a model that calculates ionospheric currents and electric fields (given boundary or *in situ* forcing by an assumed interplanetary magnetic field or solar wind.) Expected changes in ionosphere electrical conductivity distributions are also included. Success with this model in several cases has led Matsushita and Kamide to plan to use it to study geomagnetic events of short duration, as well as sudden interactions between low latitudes and high.

SOLAR ATMOSPHERE AND MAGNETIC FIELDS SECTION

Research carried out within the Solar Atmosphere and Magnetic Fields section of HAO encompasses a variety of topics related to the energy balance and structure of the solar atmosphere. The broadly based approach to these problems includes four general categories of effort: observational programs from ground-based and orbiting observatories, interpretive analyses of observational data, development of diagnostic techniques, and theoretical modeling of solar features and events. Each individual scientist in the section is working on or has experience in at least two of the four categories; and activities are adjusted in response to priorities determined by opportunities for data acquisition, interpretation, and theoretical modeling.

Priorities during the past year have been determined to a large extent by the opportunities afforded by observations and analyses with the Stokes and KELP instruments, by analyses of the data from the eighth Orbiting Solar Observatory (OSO-8), and by the accelerating demands of the upcoming launch of the Solar Maximum Mission (SMM). Specific topics of research lie within the following areas: magnetic field morphology and dynamics, active region studies, spatial and temporal fluctuations in atmospheric structure, and radiative transfer. The highlights of the achievements in each of these areas follow.

Magnetic Field Morphology and Dynamics

In the photosphere and chromosphere, magnetic fields are distorted from their minimum energy configuration. One consequence of this is that the full field topology cannot be reconstructed from observations of a single field component. Instead, vector field measurements are required, preferably at several levels in the atmosphere. Since the observations are never complete, it is important to build theoretical models of both the field topology and the associated thermodynamic and fluid-dynamic structure.

The measurement of vector magnetic fields requires precise polarimetric observations coupled with a detailed understanding of the polarizing and depolarizing processes and the transport properties of the polarized radiation. Modeling of the field topology, in the absence of complete data coverage, requires understanding of the physical processes influencing the topology. Acquisition of observational data and understanding of the physical processes involved in polarized radiation and magnetic field topology are still in their developmental stages.

The Stokes polarimeter, which is operated at the focus of the 40 cm coronagraph at SPO, was used by a number of observers in a variety of programs. The objective of the Stokes program is the observation of both orientation and magnitude of magnetic fields in the solar atmosphere. Efforts in support of this objective have included observational, instrumental, and interpretive work.

Lewis House (HAO) and Ray Smartt (SPO) gathered data over 35 quiescent and active prominences. Supplementary observations were made on the same prominences from the University of Hawaii, Mees Observatory (by Donald Landman and Charles Lindsey) and from Pic du Midi (Jean Louis LeRoy). A preliminary analysis of the Stokes data has resulted in vector field determinations. These were possible because the spectral lines chosen for the observations respond differentially to magnetic influence, specifically exhibiting (or not) the Hanle effect (depolarization of the radiation under the influence of weak fields). Fields of the order of 3-7 Gauss have been found, and azimuthal angles of the field are found to vary systematically with height.

An observational program for measuring vector magnetic fields in sunspots has been completed by Joseph Gurman (graduate assistant) for his Ph.D. thesis. He has established a radial (to the sunspot axis) variation of the properties of the vector field. Polarization measurements in the Na lines are being used to derive height gradients of the field parameters. David Rees (visitor from the University of Sydney, Australia) and Egidio Landi Degl'Innocenti (visitor from Arcetri Observatory, Italy) observed polarization profiles in several lines of MgI in sunspots and active regions.

A number of observations by Jan Stenflo (visitor from Lünd University, Sweden), using the Stokes polarimeter and the Fourier spectrometer at KPNO, have addressed problems both in the measurement of magnetic fields and the properties of resonance fluorescence in many lines at the solar limb. The latter observations, in the Na D and Ca II H and K lines, have shown unexpected quantum-mechanical interference phenomena between different total angular momentum states. This new interesting result has now been explained by Stenflo and can be used as an aid in the detection of weak magnetic fields. The observed polarization in these lines is nonmagnetic in origin and is destroyed when weak fields are present. The study of resonance fluorescence provides, also, a measurement of coherent scattering effects and thus contributes to the development of appropriate diagnostics for spectral lines.

For the purpose of intercalibrations and comparisons of magnetograph and polarimetric data, Thomas Baur has made observations with the Stokes polarimeter simultaneously with magnetograph observations at KPNO and Huntsville. These data are expected to show the interrelationships among the different instruments that will be used to provide supporting observations for the Solar Maximum Mission.

A significant improvement in speed of the Stokes polarimeter will result from the replacement of the photomultiplier tubes by reticon detector arrays. This effort, headed by Baur, will be completed by July 1979, and the arrays will be used during the period of SMM to measure vector fields over entire active regions.

The presence at HAO of several individuals (Landi Degl'Innocenti, Rees, Stenflo, and House) working on various aspects of the theory of transport of polarized radiation has afforded opportunities for many interactions, including a series of special seminars among HAO staff and scientists at JILA, LASP, and the University of Colorado. In the future, we hope to collaborate with the experiment team for the ultraviolet polarimeter to be flown on the SMM, using it to determine magnetic fields in the chromosphere and transition region.

Landi Degl'Innocenti has investigated magneto-optic effects in the interpretation of linearly polarized light with a vector magnetograph. Stenflo's work involves the interpretation of quantum-mechanical interference between different total angular momentum states in a given energy level. House has developed density matrix methods in preparation for more detailed analysis of Stokes data.

The KELP instrument, also located at SPO, is designed for measurement of coronal magnetic fields at the limb. This instrument has been developed by Charles Querfeld, and he and Joseph Hollweg have used it to search for evidence of periodic temporal fluctuations in coronal magnetic fields of the type expected for Alfvén waves propagating radially outward. Using the best of several time series of polarizations in the λ10747 line of Fe XIII, they find an upper limit to the energy flux in Alfvén waves in a closed field region of 10^3 erg cm^{-2} sec^{-1}, which is far too low to be an important factor in coronal heating. Unless the flux is orders of magnitude higher in difficult-to-observe open field regions (coronal holes), then Alfvén waves are not important within the corona in driving the solar wind.

Querfeld has reduced the temperature- and density-dependent equilibrium of Fe XIII, including polarizing and depolarizing properties, to an analytic form suitable for use in interpretation of KELP data. A similar reduction for Fe XIV was completed by Querfeld and Rees. Polarization in Fe XIV is observed at Pic du Midi, and collaborative simultaneous observations using KELP and the Pic du Midi instruments have been made by Querfeld and Jean Arnaud. Use of the two ions provides added capability for determining the field topology as well as density and temperature. Collaborative studies to observe line intensities in several iron ion stages are being carried out by Querfeld and David Elmore (HAO) with John Zirker and Ray Smartt at SPO.

One of the major puzzles of the magnetic field topology in the photosphere is the concentration of the field into small flux tubes of kilogauss intensity. The fields are concentrated to such an extent that the magnetic pressure approaches the ambient gas pressure.

Hendrik Spruit has shown that magnetic flux tubes of less than kilogauss strength in a static atmosphere and in temperature equilibrium with their surroundings are unstable if the plasma β is less than a critical value β_c. Spruit and Ellen Zweibel (HAO) have calculated that $\beta_c \simeq 1.8$ (B = 1350G at $\tau_{5000} = 1$) and computed the growth rate and instability thresholds for several modes of oscillations. Spruit has since found new equilibrium states in which matter in unstable tubes cools and descends and the field increases to maintain horizontal pressure equilibrium. This tendency of flux tubes to collapse to kilogauss strength suggests that most of the magnetic flux will be concentrated in such fields, which is consistent with observations. This work is being extended in collaboration with David Galloway (visitor from England) in a model that allows for radiative heat exchange between the flux tube and the surrounding atmosphere and for nonlinear fluid flow along the tube.

Galloway, Christopher A. Jones (University of Newcastle-upon-Tyne), and Michael R. E. Proctor (Cambridge University) are investigating the effects of horizontal convective rolls in the penumbral regions of sunspots, where the magnetic field is predominantly horizontal. The roll tubes tend to concentrate the magnetic field into horizontal flux tubes resembling the dark penumbral filaments and to drive an outward flow similar to the observed Evershed flow.

Joseph Hollweg has extended his theoretical study of Alfvén waves to include open and closed field configurations. In the open field case, the results suggest that long-period waves could be present with sufficient flux to help drive the solar wind and could exert upward forces sufficient to drive spicules. This latter possibility is being investigated by Hollweg and Galloway. In the case of closed loops, most of the Alfvén energy in the loop is carried by short-period waves resonating with the loop, something like an organ pipe. The theory suggests that ample energy is present to heat the loops; but the model does not include dissipative effects, so it is still not clear whether these resonant waves, are, in fact, viable sources of heat energy.

Active Region Studies

The last of the series of Skylab workshops organized by HAO under NASA sponsorship was designed to study the energy balance and physical processes in active regions. As a contribution to the workshop, Hendrik Spruit collaborated in a study of methods for dealing with inhomogeneous structure of the chromosphere resulting from magnetic flux tubes, and Grant Athay and Oran White collaborated with Bruce Lites (LASP) and Elmo Bruner (Lockheed, Palo Alto) in a study of bursts observed in EUV transition region lines. EUV bursts, first discovered in Skylab data and later observed with OSO-8 and rocket-borne instruments, are small flare-like events showing brightness increases in excess of an order of magnitude for periods from a few minutes to less than a minute. Athay, White, Lites, and Bruner used OSO-8 data for C IV to show that bursts occur every few minutes in some active regions and have doppler shifts in excess of the sound speed at the temperatures producing the C IV radiation. They suggest that the blue-shifted bursts are small surge-like features and the more common red-shifted bursts are descending, condensed coronal matter passing through the field of view of the spectrometer.

The French spectrometer on OSO-8 was employed extensively in the study of a few well-isolated active regions. A two-ribbon flare occurring on 19 April 1977 was well observed by OSO-8 as well as by ground based instruments. In a preliminary analysis of this flare, Andrew Skumanich, William Ku (Columbia University), who provided X-ray data from OSO-8, and Victor Gaizauskas (Herzberg Institute, Canada), who provided Hα observations, studied the compatibility of the flare with the sheared magnetic arcade model proposed by Ulrich Anzer (Max-Planck Institute). Using the Hα data to define the size and separation of the foot points of the arcade, they were able to estimate the flare volume. By comparing the volume and the observed X-ray flux for this flare with those of other flares at the solar limb, for which the geometry was directly observed, they concluded that the sheared arcade model was compatible with the X-ray data. Skumanich subsequently initiated and extended the analysis of the 19 April 1977 flare using the data acquired by the French spectrometer on OSO-8. Data from the French experiment were collected and reformatted by Skumanich, working through the computing center of the Centre National des Etudes Spatiales in France. The data are now at HAO being prepared for to analysis.

Spatial and Temporal Fluctuations

Diagnostics of the chromosphere, transition region, and corona rely almost entirely upon the intensities and shapes of spectral lines. It is commonly assumed throughout stellar astronomy that line intensities and profiles are essentially constant in time and across the stellar disk. Solar astronomers have recognized for some time, however, that the line intensities and shapes vary with the supergranule cell network structure and between quiet and active solar areas. Even so, the line shapes were believed to be essentially steady in time.

OSO-8 time series data provided a unique opportunity to study the temporal behavior of line shapes. Athay and White have discovered from these data that widths as well as intensities of lines formed in the chromosphere and transition region fluctuate more or less continually on time scales of minutes. In fact, the amplitudes of temporal fluctuations in width are of the same order as the amplitudes of spatial fluctuations. These rather surprising results provide a valuable new clue to the understanding of the microscopic motions that broaden the lines beyond their thermal widths, and they force a reevaluation of the line profile analyses commonly used in solar and stellar studies.

Radiative Transfer

Analyses of line widths, asymmetries, and positions to infer such properties of motion as microturbulence, macroturbulence, rotation, and expansion occupy much of the effort in stellar astronomy. Most such analyses proceed under fairly simplistic assumptions.

Dimitri Mihalas has made a series of detailed computations of curves-of-growth and line profiles in expanding atmospheres in order to investigate the diagnostic techniques normally employed and to seek better diagnostics where needed. He finds the curve-of-growth techniques to be unreliable changes in the shape of the curve-of-growth as a result of expansion and microturbulence are essentially identical; moreover, the same changes can also result well from from the details of the line formation mechanism, which are not well known in most stellar cases. Mihalas suggests that these difficulties might be overcome by a careful study of line asymmetries and doppler shifts, using several lines of differing line strengths.

Mihalas also finds that the basic assumptions about line profile changes across a stellar disk used in all Fourier techniques for extracting microturbulence, macroturbulence, and rotation velocities from line profiles are incompatible with the theoretically computed profiles, thereby rendering the velocity information meaningless. More computations of the type carried out by Mihalas for a range of stellar spectral types may provide a basis for an improved description of the center-to-limb changes in the profiles that could be used to reinstate the Fourier technique as a useful diagnostic.

The study of radiative transfer effects in multidimensional media was continued by Skumanich in collaboration with Harrison Jones (NASA/Goddard Space Flight Center). They investigated the effects of density stratification (using an exponential scale height) on the lateral exchange of radiation between inhomogeneities. The results show that density stratification reduces the lateral interaction between inhomogeneities in the deeper layers and restricts smoothing effects to scales of the order of the scale height. However, substantial multidimensional effects persist, even for lateral scales as large as five times the density scale height.

Other Work

Mihalas is collaborating with James Binney (Oxford University) on a two-volume work on galactic astronomy, the second volume of which is expected to be complete in mid-1979. From April to September 1978, Mihalas was on leave at University College, London. While there, he lectured on spectral line formation and gave numerous colloquia in Great Britain and Germany.

Activities related to the final preparation for operational planning and data handling for the coronagraph/polarimeter on the Solar Maximum Mission have required considerable effort by House, who is principal scientist, and to a lesser extent by Querfeld, who is a co-investigator. Athay has been involved in similar planning for the ultraviolet spectrometer experiment, on which he is a co-investigator.

CORONAL PHYSICS SECTION

The broad goals of the Coronal Physics Section are to achieve an understanding of the physical conditions determining the steady-state acceleration of the corona and solar wind, the role of magnetic fields in influencing this flow, and the role of transient disruptions in both the flow of the plasma and the balance of magnetic flux on the sun. It is probably not inaccurate to state that the corona remains the least well observed region of the solar atmosphere; thus, substantial efforts within the section are directed towards a broadening of the observational data base from which an understanding of the physical conditions in the solar corona may be deduced. The research program takes the form of new experimental efforts using a ground-based coronameter (called the Mark III K-coronameter) and space-borne coronagraphs (rocket, Solar Maximum Mission, and Solar Polar Mission). The accumulation of such a data base, however, has little meaning without analysis and interpretation of the observational results. Substantial efforts continue toward the interpretation of the most extensive coronal data base yet obtained, that from the HAO coronagraph flown on the Skylab mission. At the same time it may also be said that theoretical interpretation of this observational data base has barely begun; efforts in this direction require continued emphasis in the coming years. Within this report are summarized some of the studies elucidating the observational data bases and, more broadly, a variety of studies of the near solar wind flow.

Coronal Heating and Steady Flows

The nature of the mechanisms responsible for heating the solar coronal region remain one of the major unsolved problems of solar physics today; several theoretical studies have been directed toward this area. Energy addition mechanisms in closed and open coronal regions have been studied quantitatively by Shaddia Habbal (visitor from the University of Cincinnati), Egil Leer (visitor from the University of Tromsø, Norway), and Thomas Holzer (HAO). Specifically, they have studied the properties of fast-mode waves in coronal loops and coronal holes. In the coronal loop study they have examined the propagation (by ray tracing) and dissipation (by collisionless Landau damping) of fast-mode waves in closed coronal magnetic geometries with three types of density distributions: uniform coronal base density, enhanced density at the foot of a loop, and depleted density at the foot of a loop. They find that an isotropic energy flux from fast-mode waves at the coronal base can supply the energy required to maintain typical hot coronal loops. Qualitative arguments indicate that fast-mode waves, owing to their focussing into and preferential damping in high β coronal regions, are probably capable of both the production and maintenance of many observed coronal loop-like structures.

In the case of coronal holes, Habbal, Leer, and Holzer have examined the possibility that fast-mode waves are preferentially guided into and damped in the central portion of a coronal hole. As is the case for the study of loop structures, ray tracing has been used and collisionless damping considered, but in this case the waves become non-linear before a significant fraction of the energy flux is dissipated, requiring that nonlinear damping also be included. For a particular class of coronal magnetic field models, preferential energy addition in the center of the hole can be deduced for the case of a spatially uniform energy flux and fast-mode waves at the coronal base; the energy addition is primarily in the region of supersonic flow, so that one consequence of the waves would in fact be higher solar wind speeds from the center of the coronal hole. However, the scientists find that the structure of the coronal magnetic field is a crucial factor in determining whether or not the focusing occurs, so one primary implication of this study is that a better representation of the coronal hole field structure is needed.

Leer and Holzer have studied Alfvén waves in magnetically open coronal regions, an effort motivated by their studies, described below in the Interplanetary Section discussion of the role of energy addition in modifying the solar wind mass flux, energy flux, and flow speed at 1 AU. A simple analytic treatment can provide a surprisingly complete picture of just what Alfvén waves can and cannot do in driving the solar wind, and, indeed, other stellar winds. Employing near-earth observations of the solar wind mass flux, flow speed, and radial magnetic field and observations of the coronal base electron pressure, Leer and Holzer have determined that the analytic treatment can predict coronal base density and temperature as well as the Alfvén wave amplitude at the coronal base, under the assumption that the solar wind is driven by thermal pressure and Alfvén waves alone. One interesting result of this study is that, if the amplitude of Alfvén waves is steadily increased at the coronal base, then for small amplitudes the solar wind speed at 1 AU increases with increasing amplitude; but as the amplitude becomes large, the flow speed at 1 AU decreases with increasing amplitude. Thus it appears that there may be a maximum speed at which Alfvén waves can drive the solar or stellar wind. Very large Alfvén wave energy fluxes serve only to drive very large mass fluxes.

David Sime (visitor from Swiss Federal Institute of Technology, Zurich), and Barney Rickett (University of California, San Diego) completed a series of studies using interplanetary scintillation observations over a number of years to build a picture of the distribution of the solar wind velocity in latitude and longitude. These observations have been compared with coronal X-ray, EUV, XUV and white-light observations during the period. The average distribution of velocities is not isotropic or even symmetric about the rotation axis of the sun; rather, the average distributions are found to be similar to, and evolve as, the distributions of low coronal density. These results provide a positive test of the result that high-speed streams flow from low-density coronal hole regions of the sun.

Sime has also investigated the apparent contradiction between cometary and interplanetary scintillation data on the variation of the average velocity gradient with heliographic latitude, and he has concluded that the distribution of samples in the comet data, together with the uncertainties in the method of their analysis, effectively prevent the detection of any such gradient. Finally, Ellen Zweibel has begun to consider the role of shear flow instabilities in the presence of velocity gradients such as those that might appear across the boundaries of coronal streamers. Her calculations can be compared to Skylab coronagraph observations of streamer distortions.

The Role of Magnetic Fields

In recent years, it has been recognized that the coronal magnetic field geometry is a dominant factor in influencing the outward flow of the solar wind. Recently this realization has stimulated the elucidation of the magnetic field geometry on both small and large scales.

Gerald Pneuman, Shirley Hansen, and Richard Hansen, have examined the global potential field approximation, comparing K-coronameter observations of bright coronal features and soft X-ray coronal hole results from the Skylab period with calculations of the potential magnetic field. The agreement found is reasonable. In particular, they have noted that the calculated neutral lines at a given longitude seem be be systematically closer to the solar poles than the coronal brightness maximum; better agreement between observations and calculations occurs when the difficult-to-determine polar magnetic fields in the calculations are increased to about 30 Gauss.

Coronal Transient Activity

Observations from the Skylab epoch have clearly demonstrated the central role that transient phenomena in the corona may play in the energy balance of the solar flare process, coronal evolution, and coronal mass loss. Thus the study of those transient phenomena has remained a topic for several researchers during the past year.

Sime has continued the examination of a number of mass ejection transients observed by the Skylab instrument toward the goal of determining their three-dimensional structure. Through careful examination of the observed polarization signals of a number of transients, he has concluded that the events are generally best described as loops (including a component of interior coplanar material) as opposed to spherical bubbles. Dean Smith and Sime have made initial estimates of the role of coronal density inhomogeneities in damping the linear stream-plasma interaction from Type III sources. They find significant effects for inhomogeneity scales of approximately 50-100 kilometers but not for larger scales.

Monique Pick and Gérard Trottet (Observatoire de Paris) and Robert MacQueen have examined the characteristics of the coronal structure overlying a Type-III-producing active region, employing Skylab coronagraph observations, and they find that large structural and density variations occur on time scales of hours; thus workers using density models of the Type-III-exciting regions must employ them with caution, if at all.

Richard Munro and Arthur Poland, in collaboration with Tomas Gergely and Mukul Kundu (University of Maryland), have examined simultaneous decametric and Skylab white-light coronal observations for a specific transient event. In this case, the continuum metric radio burst was found to be coincident with a secondary, outwardly moving white-light loop. From these combined observations they deduced a plasma $\beta \sim 1$ in the lower legs of the transient in question; they noted that this result is inconclusive with regard to the present controversy concerning the magnetic control of transient events.

Finally, Pneuman has carried out analytic modeling of transient phenomena through the assumption of a magnetic configuration involving the lifting or eruption of an underlying prominence field. He suggests that such a process could be carried out through the generation and emergence of new magnetic flux and could drive out the overlying coronal structure to produce the observed characteristics of white-light transients. His model, wherein the overlying field is compressed and then driven out, shows qualitative agreement with the velocity profile observed for a number of coronal transients during the Skylab epoch.

Experimental Studies

A major highlight of the section's activities during the past year was the successful initial flight of a rocket-borne experiment. An HAO white-light coronagraph flew with a companion instrument supplied by the Harvard College Observatory to measure the intensity and profile of the coronal Lyman-alpha spectral line. The goal of this dual coronagraph package is to provide a new and relatively unambiguous measurement of the coronal temperature and velocity, through measurements of the profile of the Lyman-alpha line and the ratio of the "doppler-dimmed" Lyman-alpha intensity to the white-light radiance. The HAO instrument was constructed by a subcontractor--American Science and Engineering (Cambridge, Massachusetts)--under the supervision of Munro. The initial flight yielded a completely successful operation of the dual coronagraph package. Lyman-alpha intensities and profiles have been recorded to beyond 3.5 $R_\odot$; Munro and the Harvard group have begun interpretation and analysis of the results.

A second highlight of the experimental efforts in the section was the delivery of the next-generation (Mark III) K-coronameter instrument to the Mauna Loa Observing Station. The experimental program, led by Richard Fisher, has engaged nearly the complete engineering and technical resources of the observatory over the past several years and is the largest in-house experimental effort ever undertaken by HAO. With delivery of the K-coronameter instrument to the observing site, initial testing and alignment has begun. The instrument should be operational in the summer of 1979. Arthur Poland has led in the development of the necessary software for the digital processing of results and for the initial analysis of the polarization-brightness products generated by the K-coronameter.

Another central element of the program for observations of coronal activity at the upcoming solar maximum is an orbiting coronagraph/polarimeter for NASA's Solar Maximum Mission. The team includes William Wagner, Ernest Hildner, Lewis House, and Robert MacQueen. During the past year, the instrument hardware program was successfully completed by the subcontractor, Ball Aerospace Division, and the instrument was delivered to NASA. Completion of the definition and testing of the properties of the instrument, development of the necessary software procedures for the handling of telemetry from the SMM spacecraft, monitoring of the integration and test programs at the Goddard Space Flight Center, and the development of observing plans among the complex of SMM instruments will permit the mission to operate at the observatory level. The launch is currently scheduled for October 1979.

Finally, Thomas Holzer, Arthur Hundhausen, Charles Querfeld, and Robert MacQueen have joined with scientists from American Science & Engineering (Allen Krieger and John Davis); the Naval Research Laboratory (Martin Koomen, Don Michels, Russell Howard, and Neil Sheeley); Stanford University (Arthur Walker and James Underwood); and the Observatoire de Paris (Bernard Fort and Jean-Pierre Picat), in developing a white-light coronagraph and X-ray/XUV telescope package for the Solar Polar Mission (formerly the Out-of-the-Ecliptic Mission). The instruments will enable scientists to observe the three-dimensional structure and evolution of the solar corona from the solar surface outward, to study the evolution of low coronal and chromospheric forms, and to examine the differential rotation of the sun through the motions of chromospheric traces. Current plans call for launch in 1983 and an initial polar passage in mid- to late 1986. A second polar passage will follow approximately six to eight months later. The HAO group, joined by David Sime as Experiment Scientist, is currently involved in the detailed definition of the experiments--which must be considerably smaller and lighter instruments than any yet put in space--and in the preliminary development of the scientific goals and observational programs for the mission.

INTERPLANETARY PHYSICS SECTION

Interplanetary research at HAO covers a broad range of topics, from the formation of the solar wind in the expanding corona through the propagation of the wind through the interplanetary region and the interaction of the solar wind plasma and magnetic fields with the earth, cosmic rays, and the interstellar medium. This report will focus on several studies published or undertaken by members of the interplanetary physics section during the April 1978-March 1979 period, selected to illustrate the aspects of breadth and interaction with the entire observatory program.

MHD Waves in the Solar Wind

The study of microscopic physical processes occurring in the corona and solar wind is essential to understanding of the basic phenomena of solar wind formation. The accessibility of the interplanetary plasma to *in situ* probes makes it an ideal laboratory for such analyses; the properties of the particles and the electric and magnetic fields in interplanetary space can be observed in great detail with high time resolution and then compared with theoretical studies of plasma processes. An important example of this approach is the discovery, a decade ago, that Alfvén waves propagating outward from the sun are common features of the solar wind. These waves, their propagation through interplanetary space, their probable origin near the sun, and their effects on the expanding solar corona have all become important topics in interplanetary research here at HAO as well as in the larger scientific community. Joseph Hollweg has reviewed the effects of Alfvén waves on lower layers of the solar atmosphere in an extensive discussion published in *Reviews of Geophysics and Space Physics*, with emphasis on the possibility that the acceleration of coronal plasma by an interaction with MHD waves is responsible for the fast flow of the solar wind in coronal holes. Hollweg quantifies the effects of adding momentum and energy from such waves to the expanding plasma by incorporating them into a model that also includes a "nonclassical" electron heat conduction and a rapidly diverging flow geometry suggested by studies of coronal holes. Comparison of the predictions of this model with coronal and interplanetary observations reveals considerable agreement. Hollweg and Paul Dusenbery (NCAR Advanced Study Program postdoctoral fellow) are currently extending earlier studies of the effects of Alfvén waves on minor constituents of the solar wind in a continuing effort to understand the dissipation of waves in the interplanetary plasma.

The work described above is based on the assumption of a relatively large flux of MHD waves into the lower corona. Attempts at direct confirmation of the existence of these waves have proceeded on several fronts. The derivation of an upper limit on the Alfvén wave flux in some regions of the lower corona, on the basis of KELP observations by Querfeld and Hollweg, is described in the report of the Lower Solar

Atmosphere and Magnetic Fields Section. Hollweg has also collaborated with Michael Bird and Hans Volland (both of the University of Bonn) and Peter Edenhofer (University of Bochum) in the interpretation of observed Faraday rotations of radio signals from spacecraft occulted by the solar corona. The rotation of the polarization plane by transmission through the corona depends on the product of electron density and the magnetic field intensity and is thus sensitive to the presence of waves. Observed long-term fluctuations are consistent with large Alfvén wave fluxes in the region from 2 to 10 solar radii.

Thomas Holzer and Egil Leer undertook a more general study of the effects of momentum and energy addition to the expanding corona that has some important implications with respect to MHD waves. They considered several different electron heat conduction laws and diverging flow geometries and used observed values of the solar wind mass flux density at 1 AU and the electron pressure at the base of the corona as boundary conditions. For reasonable coronal temperatures, their model gives an upper limit on the amount of momentum that can be directly added to the solar wind by waves. They also argued that the production of high-speed solar wind streams requires a significant addition of energy in the outer corona, where the flow is supersonic; addition of energy in the lower region of subsonic flow raises the mass flux so efficiently that the energy per unit mass, or the speed of the solar wind, actually decreases.

Large-Scale Structure of the Solar Wind

The study of solar wind streams, sectors, and shock waves, the largest scale structures superposed on the general expansion of the corona, has been another important theme in interplanetary research at HAO. The recognition of the dominant role of the coronal magnetic field in the origin of these structures and the identification of coronal holes as their observable manifestation in the corona have been described in earlier reports. Two closely related problems have assumed new prominence in the past few years, namely, the understanding of the coupled variations in coronal and solar wind structure with the sunspot cycle and the inference of the three-dimensional nature of the interplanetary structure from detailed observations that are largely confined to the ecliptic plane, or to a range of $\pm 7.5^{\circ}$ in heliographic latitude.

Some recent work on the first of these topics, solar cycle variations, is described in the Solar Variability Section report. Arthur Hundhausen has recently discussed a paradox raised by the suggestions, based on coronal hole and radio scintillation observations, that for much of each sunspot cycle the polar regions of the sun (or polar cap holes) are the sources of a rather uniform, very fast solar wind. This strong spatial dependence of solar wind speed is held to be associated with simple organization of the magnetic structure of interplanetary space by a near-equatorial neutral surface, a concept originally suggested by the observation of changes in the magnetic sector pattern within the earth's ±7.5° annual excursion in solar latitude. However, searches for related changes in average solar wind speeds inferred from comet tails observed over a wider range of latitudes and over a 75-year period showed no increase in solar wind speeds with heliographic latitude. Hundhausen pointed out that both techniques involve the search for a latitude gradient in the speed averaged over solar longitude. Several simple examples show that reasonable spatial distributions of the solar wind speed with high values over the poles cannot be detected in longitude averages unless the distribution is nearly symmetric about the solar equator.

Another aspect of large-scale solar structure that has gained increasing attention is its relationship to cosmic-ray modulation. The intensity of galactic cosmic rays is known to vary inversely with the sunspot cycle, an effect widely attributed to some solar-activity-related change in the penetration of these energetic particles into the inner solar system through the solar wind. However, the most popular theories of this modulation encountered increasing difficulties as more observations of both the spatial distribution of cosmic rays and the long-term variations in the solar wind have become available. A correspondence between the evolution of polar coronal holes and the cosmic ray flux in sunspot cycle 20 (see a description in the Solar Variability Section report) has been noted and suggests that the three-dimensional structure of solar wind streams or magnetic fields plays a role in cosmic ray modulation. As most of this effect occurs well beyond the orbit of earth, Len Fisk (visitor from the University of New Hampshire), Holzer, and Hundhausen have modified earlier models of the evolution of streams in the distant solar system, adding the effects of heating by interstellar neutrals in a manner suggested by earlier work of Holzer. The rise in "background" temperature produced by this heating permits more rapid dissipation of the streams and a major change in their structure beyond ∿5 AU. The effect on incoming cosmic rays is now being studied.

The Astrophysical Connection

As in any area of solar physics, any new understanding of the nature of the solar wind or the physical processes occurring in it finds immediate application to other, similar astrophysical systems. In the past we have noted several extensions of solar wind theory to the problems of stellar winds and mass loss. A different example of this connection has been pointed out by Ellen Zweibel in a discussion of the effects of Alfvén waves on energetic particles in the material ejected by supernovae. In collaboration with Russel Kulsrud (Princeton), she has examined the hypothesis that supernovae are the major source of cosmic rays. They show that the emission of the required number of energetic particles is in itself sufficient to excite Alfvén waves. The scattering of the cosmic rays by these waves is then strong enough to significantly cool the latter by a factor of 10 to 100. This in turn requires a larger initial energy in the cosmic rays, so much that most of the energy released in a supernova would have to go into the energetic particles. As this is unlikely, these authors argue against the origin of most cosmic rays in supernova explosions.

High Altitude Observatory 31 March 1979

Gordon Newkirk, Jr., Director

Solar Atmosphere and Magnetic Fields

Scientific Staff

R. Grant Athay (Section Head)
Lewis House
Dimitri Mihalas
Yoshinari Nakagawa (to 17 Nov. 1978)
Charles Querfeld
Andrew Skumanich
Oran White (½)

Support Staff

Joseph Gurman

Solar Variability

Scientific Staff

Timothy Brown
John Eddy
Peter Gilman (Section Head)
Art Hundhausen
Sadami Matsushita
Oran R. White

Support Staff

Richard Hansen

Coronal Physics

Scientific Staff

Richard Fisher
Robert MacQueen (Section Head)
Gerald Pneuman
Arthur Poland

Support Staff

William Bradley
Franklin Everts
Charles Garcia
Gregory Muir
Paul Seagraves
Kevin Shoemaker
Gregory Siedelberg
Frank Telang
Eric Yasukawa

Interplanetary Physics

Scientific Staff

Joseph Hollweg
Thomas Holzer
Arthur Hundhausen (Section Head)
Dean Smith (to 30 Sept. 1978)
Ellen Zweibel

Graduate Students

Gary Glatzmaier
Stanley Owocki

Administration and Support

Engineers

Howard Hull
Leon Lacey
Loren Laramore
Robert Lee
Stephen Rogers
Ackley Smith
Robert Wendler

Support Staff

Jane Aschenbrenner
Lawrence Auer
Thomas Baur
Jay Chalmers
David Elmore
Richard Faulmann
Michael Fricklas
Ada Greenwood
Shirley Hansen
Robert Hanson
Steven Jackson
Barbara Kirwin
Mark Lankton
Carl Lilliequist
Jack Miller
Edmond Reeves (Section Head)
Kristine Rock
Birdian Rogers
Donald Roholt (to 15 Nov. 1973)
Lynn Schick
Kathryn Strand
Victor Tisone
Rebecca Toevs
Keith Watson

Special Project

Scientific Staff

John Cook(to 30 April 1978)
Ernest Hildner III
Richard Munro
David Sime
William Wagner

Engineers

Harold TePoel

Special Project Support Staff

Steven Bankes
Stuart Bingham
Thomas Blaschko
Jennifer Caine
Adam Csoeke-Poeckh
Richard Dutton
Karen Ellis
Diane Friend
Jane Olson
Rose Reynolds
Charles Ross (to 1 Feb. 1979)
Andrew Stanger

HAO Visitors, 1 April 1978-31 March 1979

Richard S. Bogart
Cornell University
6 Feb 1979 - present
Solar Variability

L.A. Fisk
University of New Hampshire
2 July - 1 August 1978
Interplanetary Physics

Eric Fossat
Observatoire de Nice
13 Sept. - 12 May 1978
Solar Variability

David J. Galloway
Sussex University
Falmer Brighton
12 Oct. - present
Solar Atmosphere & Magnetic Fields

Douglas O. Gough
Institute of Astronomy
University of Cambridge, England
15 Jan. - 12 Feb. 1979
Solar Variability HAO

Jean-Claude Hénoux
Observatoire de Paris, Meudon
11 July - 26 Aug. 1978
Solar Atmosphere & Magnetic Fields

Bernard Jackson
CSIRO, Australia
dates unknown
Coronal Physics

Sylvan Jacques
University of Colorado
1 Nov. 1977 - present
Interplanetary Physics

James Klimchuk
Kalamazoo College
Kalamazoo, Michigan
1 Sept. - 30 Nov. 1978
Interplanetary Physics

Paul Kunasz
JILA, University of Colorado
1 Jan. 1976 - 1 July 1978
Solar Atmosphere & Magnetic Fields

Egidio Landi degl'Innocenti
Osservatorio Astronomi di Arcetri
Florence, Italy
14 Sept. 1978 - present
Solar Atmospheres & Magnetic Fields

Egil Leer
University of Tromsø
Tromsø, Norway
10 Oct. 1977 - 9 Oct. 1978
20 Nov. - 19 Dec. 1978
Interplanetary Physics

Peter Noerdlinger
Michigan State University
East Lansing, Michigan
1 Aug. 1977 - 28 Dec. 1978
Interplanetary Physics

Alan H. Nye
Rochester Institute of Technology
Rochester, New York
7 June - 21 Aug. 1978
Interplanetary Physics

David Rees
University of Sydney
29 Aug. 1978 - 23 Jan. 1979
Solar Atmospheres & Magnetic Fields

Edward C. Shoub
JILA, University of Colorado
1 Oct. 1978 - present
Interplanetary Physics

David G. Sime
Federal Institute of Technology
Zurich, Switzerland
14 Nov. 1978 - 14 Nov. 1978
Coronal Physics

George Skadron
Drake University
Des Moines, Iowa
5 June - 4 Aug. 1978
Interplanetary Physics

H.C. Spruit
Astronomical Institute
Utrecht, The Netherlands
1 Oct. 1977 - present
Solar Atmospheres & Magnetic Fields

J.O. Stenflo
Lund Observatory
Lund, Sweden
1 Dec. 1977 - present
Solar Atmospheres & Magnetic Fields

D. Summers
Mem. University of Newfoundland
9 June - 3 Aug. 1978
Interplanetary Physics

Gérard Trottet
Observatoire de Paris, Meudon
2 July - 30 Sept. 1978
Coronal Physics

Hirokazu Yoshimura
Tokyo University
1 Sept. 1977 - 31 Aug. 1978
Solar Variability

Ellen Zweibel
Princeton
10 April - 31 Aug. 1978
Interplanetary Physics

CONVECTIVE STORMS DIVISION

INTRODUCTION

The major activity of the Convective Storms Division (CSD) has been continued analysis of the comprehensive and excellent data sets obtained during 1976 and the preparation of a final report on the research conducted in the National Hail Research Experiment (NHRE). That report, written by both CSD and participating university scientists, will discuss not only the observed characteristics of hail storms but also modeling and modification, including its societal aspects. It is expected to be completed in draft form in the fall.

A short field season was conducted at Grover, Colorado, during June 1978, partly to investigate some aspects of the initial formation of precipitation and partly for the purpose of testing systems in preparation for the next major field season, which had been planned for 1979. However, the effort required to analyze and interpret the 1976 data proved to be so large that we have since altered our plans and will space field programs three years apart, the next being scheduled for 1981. For the same resason, the analysis of the data obtained in 1978 has been deferred pending the completion of the NHRE Final Report.

In order to consult with the community about our future field programs, a workshop was held at Winter Park in November. Some 45 scientists from universities and government agencies attended, and a report (NCAR Technical Note TN/133, March 1979) has been distributed. It included the reports of seven workshop panels which provided valuable guidance to the division. A major topic of discussion was the location of the next field program; earlier informal discussions with High Plains Experiment (HIPLEX) scientists had indicated that their Montana site at Miles City could be considered as a possibility. The general sense of the workshop discussions was that the best choices would be either to move to this site or to remain at Grover, Colorado, in view of the perceived relative simplicity of the precipitation-forming processes in both these regions. Obvious advantages were also to be gained by combining the facilities of two groups which have virtually identical scientific objectives.

In subsequent discussions, it was established that if CSD were to collocate with HIPLEX, both groups would be willing to give priority to the conduct of a research program employing their total resources in an integrated fashion. On this basis, the decision was taken to move our field programs to Miles City in 1981. In order to define such an integrated program, an initial planning meeting in March was attended by CSD and HIPLEX staff, as well as scientists from the University of Wyoming and the South Dakota School of Mines & Technology, two groups which have played major roles in CSD and HIPLEX field programs over a period of several years. Subcomittees were appointed to plan studies of a number of specific scientific issues; these plans will be incorporated into a program prospectus to be prepared this summer, which will describe the basic structure of the program as well as possible at this stage, so that scientists elsewhere can determine whether their research in cloud physics or related areas can profit from participation in it. Plans are to organize a meeting in the fall of 1979 to provide an opportunity for all interested scientists to make inputs into the planning of the program and to clarify their own plans for participation.

In the following sections, brief discussions are presented of findings which have emerged during the past year, mostly from case study analyses of data obtained in the 1976 field season. More complete documentation of several such case studies has been published in NCAR Technical Notes TN/130+STR (1978), TN/132+STR (1978), and TN/134+STR (1979).

Ice Particle Economy of Cumuli

Ever since the first attempts at seeding clouds to increase ice concentrations and precipitation, one of the major tasks of cloud physics has been to characterize and explain the ice contents of clouds. The early observations, made with airborne replicators, revealed a great deal of variability and sometimes indicated very much higher ice concentrations than measurements of the ice nuclei could explain. Much work has been done on possible mechanisms of ice crystal "multiplication," whereby ice crystals may somehow induce the formation of more crystals without new, primary nucleation events occurring.

The discrepancy between ice concentrations and nucleus concentrations could, of course, result from other factors than ice multiplication; perhaps the ice nucleus measurements are unrealistic or are not made in the right places. The problem of being sure the nucleus measurements are appropriate is especially acute in convective clouds, in which air from different sources is mixed in complicated ways and the time available for ice formation is often very poorly known.

Over the last few years, new and improved instruments have become available for measuring ice crystal concentrations from aircraft; however, methods for measuring ice nuclei have not made comparable advances. Nevertheless, the discovery by Andrew Heymsfield, Peter Johnson, and James Dye that vigorous cumulus congestus in northeastern Colorado often have undiluted cores of significant size raised the possibility of obtaining more easily interpretable comparisons between ice crystals and ice nuclei.

An extensive program of ice nucleus measurements was carried out in 1976 by the University of Wyoming and NCAR, at three ground sites and from aircraft, using two different measurement techniques. The surface measurements were found to be representative of the cloud base inflow, as expected. The NCAR/NOAA sailplane made several vertical ascents within vigorous cumulus, covering a range of temperatures and including reliable temperature measurements which could be used to determine when the cloud air was unmixed. Measurements were also made of ice concentrations using a photographic system. Measured updrafts in the unmixed regions ranged from about the value predicted from simple parcel calculations down to about half that value. Liquid water contents were usually found to be adiabatic within the rather wide limits of accuracy of the instrument used (Heymsfield, Johnson, and Dye, 1978).

The lower detection limit of the camera was 100 μm in diameter for ice particles, and so very recently formed ice particles could not be detected. Moreover, model calculations using experimental ice growth rates showed that in no case would ice nucleated in updrafts have time to grow larger than 200 μm in diameter. The measured ice concentrations in this size "window" were therefore compared with concentrations of ice crystals in this size range, as predicted for unmixed regions from the measured nucleus spectra and the model updraft profiles.

Figure 1 is a summary of the results, for nine days' data. The shaded area is the region of predicted ice concentrations, the variation at one temperature being caused both by different ice nucleus spectra and different updraft strengths on the various days. The ice concentrations and air volumes sampled, for both unmixed and mixed regions, are listed at the left. Concentrations are also plotted. At any one temperature, the concentrations in mixed regions tend to be higher than those found in, or predicted for, unmixed regions. Only mixed regions were encountered in ascents above the -21°C level, and ice concentrations increased to over 100 ℓ^{-1} in the -27 to -30°C layer.

Heymsfield, Charles Knight, and Dye concluded that no meaningful discrepancy between nuclei and crystals exists in the unmixed regions. Downward mixing from higher and colder regions is the primary candidate to explain the higher ice contents in the mixed regions. Entrainment studies by Ilga Paluch support this downward mixing. Ice particles larger than 200 μm (graupel) were sometimes found in unmixed regions also. Their presence has been ascribed to sedimentation, since they were usually so big as to preclude any possibility of their having grown within the strong updrafts in the time available.

This technique shows promise of helping to delineate the conditions in which ice nucleus measurements can be used to predict ice particle concentrations in clouds and of leading to a more detailed understanding of the ice economy of natural cumuli. Further observations of this kind were made during the 1978 field season, when a special effort was made to record the visual history of cloud tops in order to place time and temperature limits on potential ice crystal sources. (These data have not yet been analyzed, pending completion of the NHRE Final Report.) In future work, more sensitive methods will be used to detect ice crystals at sizes below 100 μm; this will improve the results, making them less dependent on the model used to predict the concentration of observable features in unmixed updrafts.

Simultaneous measurements of temperature, liquid water content, vertical velocity, and ice crystal concentrations within cumulus clouds, of an accuracy and reliability sufficient to permit detailed conclusions about entrainment and ice crystal origins, are only now becoming possible. The NCAR/NOAA sailplane "Explorer II" is preeminent in these areas; indeed, this sailplane system represents a notable instrumental achievement in its own right, which has resulted from a long-continued effort started in the cloud physics group at NCAR some ten years ago. Development has continued at a low but relatively stable level in NHRE and CSD. Continuing

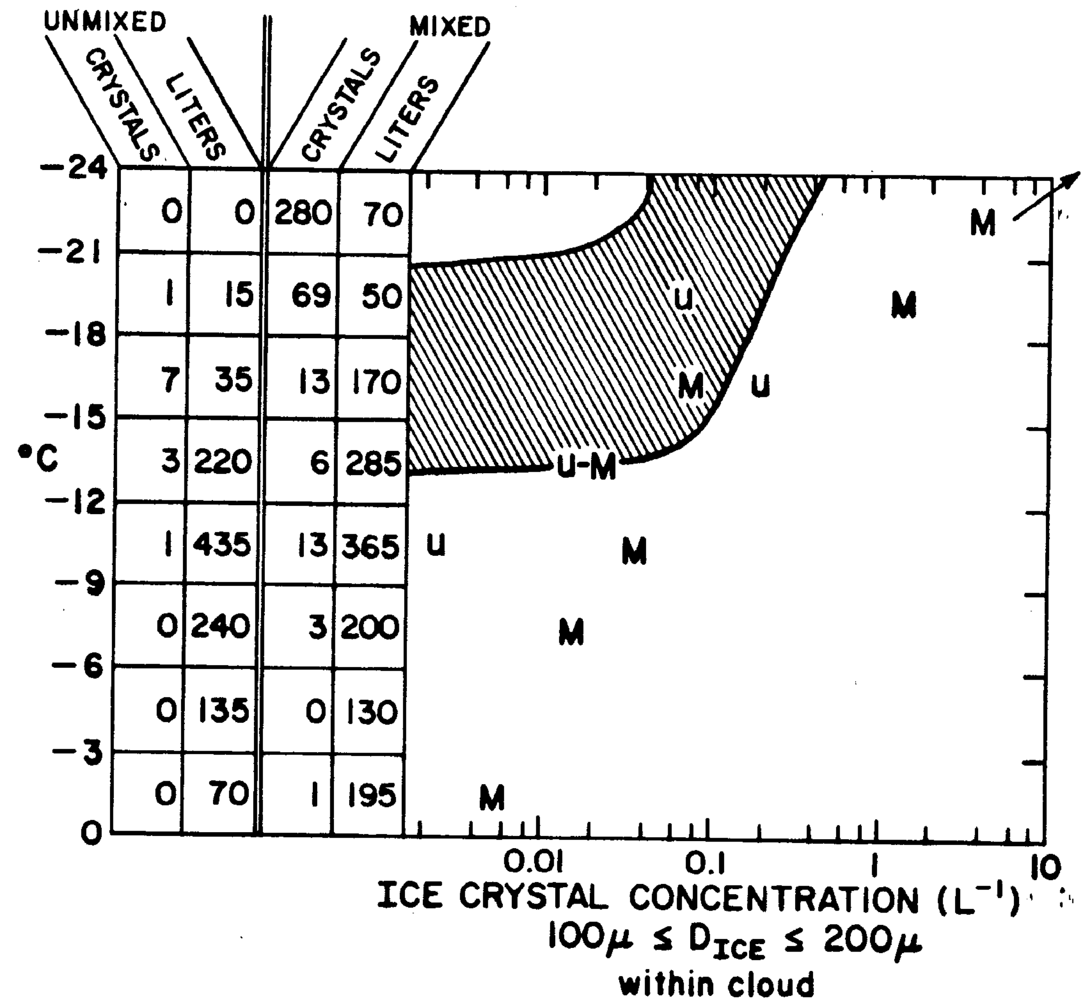


Figure 1. The concentrations of small ice crystals within active cumulus congestus clouds, measured from the NCAR/NOAA "Explorer" sailplane, are separated into two categories. Unmixed (U) represents portions of the updraft not diluted by mixing with environmental air. The mixed portions are designated by M. The data are from all nine applicable ascents during 1976, lumped together. The shaded region represents the range of predicted ice crystal concentrations, calculated using measured ice nucleus spectra and modeled updraft profile for each of the nine days.

work to improve our ability to measure fundamental cloud properties forms an important part of CSD's objectives and is being coordinated with the Research Aviation Facility.

Ice Nucleus Storms

A group composed of Gerhard Langer, Griffith Morgan, Clarence Nagamoto, Mark Solak, and Jan Rosinski has analyzed 1976 field observations of ice nuclei in northeastern Colorado and documented numerous examples of "ice nucleus storms." Such storms are large jumps, sometimes brief and sometimes of many hours' duration, in the concentration of natural ice-forming nuclei observed at the ground. Meteorological analyses show that their onset often corresponds with the passage of thunderstorm "gust fronts." Indications are that everywhere in the cold air outflow of thunderstorms, the ice nucleus concentration is as much as 10 to 100 times the normal values, at least at ground level.

On 22 June 1976, measurements were carried out at two ground stations and on board an NCAR Queen Air which was sampling the boundary layer. Figure 2 shows a striking example of an ice nucleus storm, observed at the surface. The Queen Air flew in the vicinity of the turbulent interface between the cold outflow (downdraft) and the warm inflow (updraft) of a large hailstorm system and recorded indications that blobs of ice-nucleus-rich air were being mixed across this interface and into the inflow. This raises the possibility that these ice nucleus storms, generated within the thunderstorm, might play some role in precipitation formation process.

Langer and his colleagues can only speculate on the origin of these particles, but they believe that some process of activation in the hail and rain fallout zone of the thunderstorm may be responsible for their ice nucleation activity.

A Storm Case Study

In a case study, all data relevant to a particular storm are assembled and studied with the objective of producing as complete a description as possible of its evolution. Such studies provide a baseline for modeling efforts and also permit a critical evaluation of the obervational procedures, indicating what important features are not reliably depicted by the data collected. Obviously, the full discussion and reasoned presentation of each study is voluminous; the example given here represents a bare outline, for the purpose of indicating what kinds of analysis have been carried out, and what conclusions appear to be emerging.

The long process of analysis and interpretation of the data taken on the storm near Grover, Colorado, on 22 June 1976 was nearly completed this year. The storm produced hailstones 3 cm in diameter and up to 10 cm

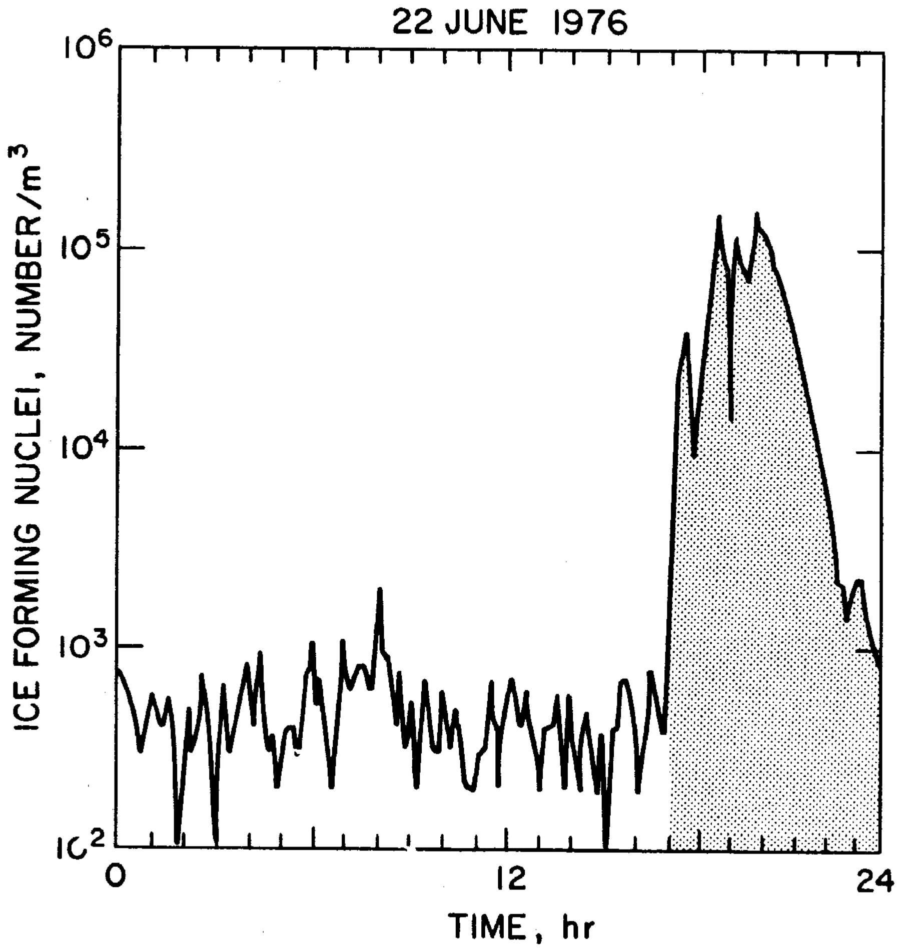


Figure 2. Concentrations of -16°C ice nuclei recorded at the Chapel Ranch field station on 22 June 1976. The shading on the right begins at the time (MDT) of passage of the thunderstorm gust front.

of precipitation at single gages. At its maximum development, it had an area of 160 km^2 of radar reflectivity factor greater than 50 dBZ_e at 7.5 km MSL, i.e., at about -20°C. It was one of the largest and severest storms encountered in the NHRE study area over the five years of NHRE field work, and the observations represent one of the most complete data sets available in terms of precipitation, surface, radar, and external aircraft data. These data document the modulation of the storm's behavior by the interaction of its own outflow with the environment and illustrate how the complex storm structure relates to hail and rain formation in a storm of this type. The data collection was a joint effort with collaboration between NHRE staff, NCAR/ATD, and the National Oceanic Atmospheric Administration/Wave Propagation Laboratory (NOAA/WPL; two 3 cm Doppler radars), the University of Wyoming (Queen Air 10UW), and the South Dakota School of Mines and Technology (armored T-28).

The convective activity started about 1400 local time in the form of a north-south line of cells just east of Grover, along a poorly developed dry line. As the surface outflows from these cells formed, merged and moved south and east, the southern end of the line of activity developed into a stationary, severe storm that maintained a relatively steady configuration from about 1600 to 1700. The study concentrated on this period of time, and included a detailed documentation of the outflow characteristics as well as the thermodynamic and wind structure of the inflow sector.

The storm remained essentially stationary over a dense network of hail and precipitation gages during its "steady" phase, while the outflow at the surface moved southeastward, against the inflow, at 4 to 6 m sec^{-1}. Figure 3 shows a detailed surface wind field across the inflow-outflow boundary for one time, with its associated divergence field. Conversions used at each surface mesonet station to transform time series data to the space domain are also indicated. Three time-to-space conversion principles were used: displacement was according to (a) the surface wind velocity in the environment southeast of the outflow boundary, (b) the motion of the boundary itself for sites near or along the boundary, and (c) the radar echo cell motion at points behind (i.e., northwest of) the boundary.

The general features of the radar reflectivity and air velocity structure of the storm are shown in Figs. 4 and 5. Figure 4 is a composite horizontal representation of several features of the data at about 1630. It shows the outflow boundary position as a front, with the broad arrows to the southeast representing surface inflow, and the dashed, broad arrows to the northwest representing storm outflow at the surface. Also shown are the mid-level radar reflectivity factor (shaded areas represent 10 dBZ steps starting at 20 dBZ_e), the area of cloud base updraft as determined by the NCAR/RAF and University of Wyoming Queen Airs (northwest-to-southeast hatching), and surface convergence area along the outflow

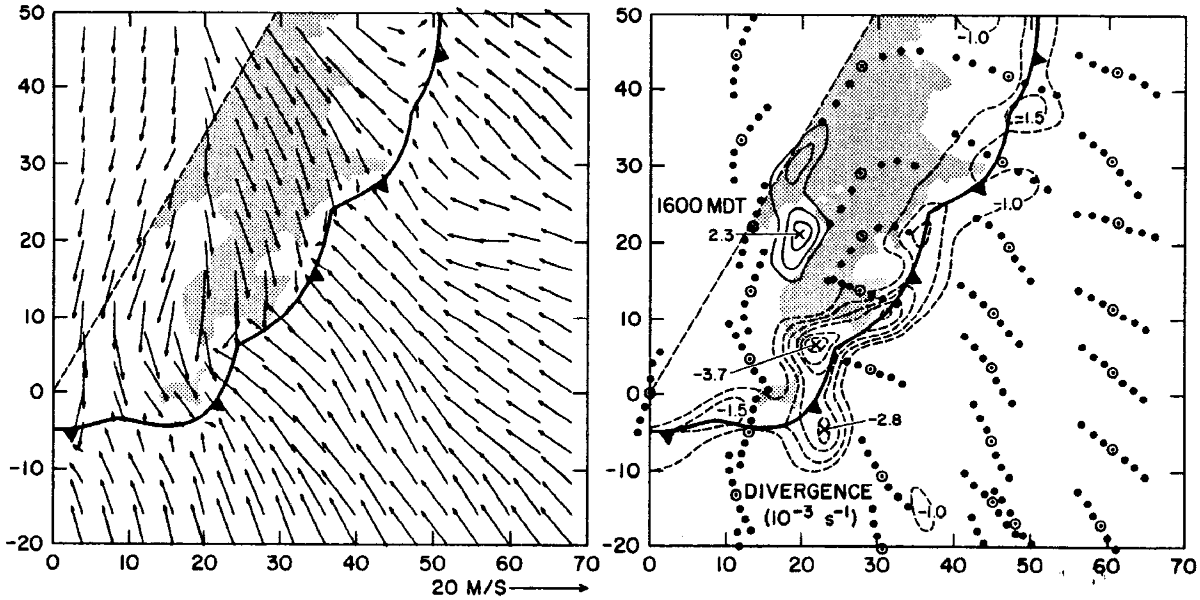


Figure 3. Surface wind vectors (left) at 1600 MDT, 22 June 1976, interpolated numerically from data observed at mesonetwork sites designated as open circles on the right. The series of dots distributed about the station locations demonstrates how time series data were incorporated in the spatial interpolations. Contours on the right represent associated fields of horizontal mass divergence (solid) and convergence (dashed) in units of 10^{-3} s^{-1}. Heavy barbed line shows leading edge of the thunderstorm's advancing cold air outflow. The stippled region indicates low level radar echoes, ≥ 35 dBZ. Borders of the grids are labeled in 10's of kilometers relative to the Grover, Colorado field headquarters.

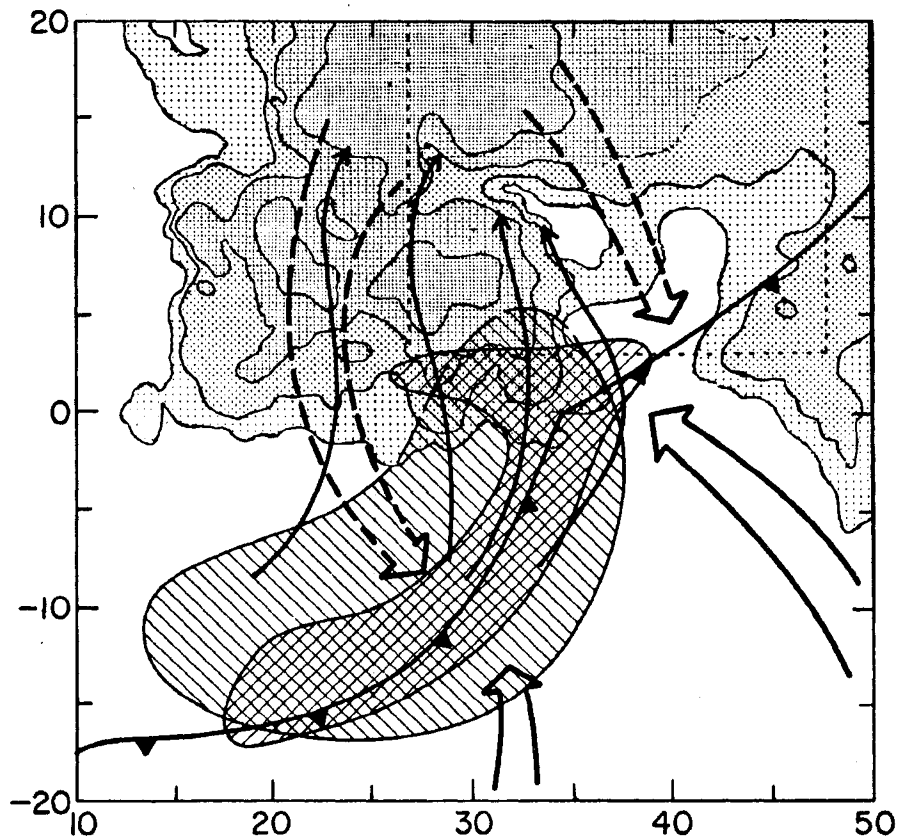


Figure 4. Synthesis of radar, surface mesonetwork, and aircraft observations in the inflow region to the storm of 22 June 1976. The heavy barbed line shows interface between ambient south-southeasterly surface airflow (broad solid arrows) and branches of the storm's outflow (broad dashed arrows) originating beneath zones of highest radar reflectivity factor (shown at 7.5 km MSL in increments of 10 dBZ beginning at 20 dBZ). Cross-hatching oriented from lower left to upper right identifies region of maximum surface convergence ($\geq 2 \times 10^3\ s^{-1}$). Opposite hatching is the area of significant vertical velocity ($w \geq 1$ or $2\ m\ s^{-1}$) observed by aircraft near cloud base altitude beneath shelf cloud along the southern flank of the storm. Curved single-lined arrows illustrate the horizontal tracks of the most intense radar echo cells which have the greatest influence on the storm's stationarity and longevity. The border gives distance in kilometers east and north of the Grover, Colorado field site and conditions as shown relate best to a period near 1630 MDT.

boundary (northeast-to-southwest hatching; shown in Fig. 3 for an earlier time). The storm had an extensive radar echo overhang to the south, and updrafts throughout most of its upper portion, as illustrated by the south-to-north cross section in Fig. 5. The vertical velocities were derived from data from three Doppler radars. The four single-line arrows on Fig. 4 show typical tracks of radar echo "cells," one of which can be seen as the reflectivity maximum in the southward overhang in Fig. 5.

The 22 June storm displayed a prominent bounded vault in the radar reflectivity from about 1600 until about 1630. It also displayed a marked cellular development in the radar reflectivity structure for its entire lifetime. The cells formed far south of the vault (Fig. 5) and moved to the north, remaining aloft for most of their lifetimes. Most of the cells moved around the vault, but a few moved directly into it. They moved with the local winds in the lower 2 km above cloud base, as determined by Ian Harris from an analysis of data from three Doppler radars (two NOAA/WPL, one NCAR/FOF). The cell motion analysis, done by James Fankhauser, was made as objective as possible by imposing strict duration, height, and reflectivity factor criteria. The storm's radar echo structure displayed two scales of organization: a gross scale of 20-40 km, which, from the standpoint of radar reflectivity factor, observed at the lower levels, remained stationary and fairly steady, and a smaller scale of a few kilometers, associated with cells that formed out over the inflow to the south and moved through the larger scale at an average speed of about 15 m sec^{-1}, represented schematically by the tracks in Fig. 4.

Fankhauser defined cell "origin" as the first appearance of 20 dBZ_e for a cell. Using this and the somewhat arbitrary definition of a cell, he found that there was a strong correlation between the location of the cell origin and the later cell intensity (reflectivity). Cells that originated near the surface outflow boundary were strongly favored to achieve maximum reflectivity above 60 dBZ_e (Fig. 6). Mechanical forcing provided by the outflow spreading toward the south is clearly a very important factor both to the details of the storm organization and to its stationarity, and this was maintained in spite of the strong northward component exhibited both by the airflow within the storm and the storm cell motion.

It has become common to think of severe storms in terms of a simple dichotomy developed by Browning, Chisholm, Marwitz and others, but presented most succinctly by Browning (1977)[1]. In this idealization, one

---

[1]Browning, K.A., 1977: The structure and mechanism of hailstorms. Meteor. Monogr., No. 38, 1-43.

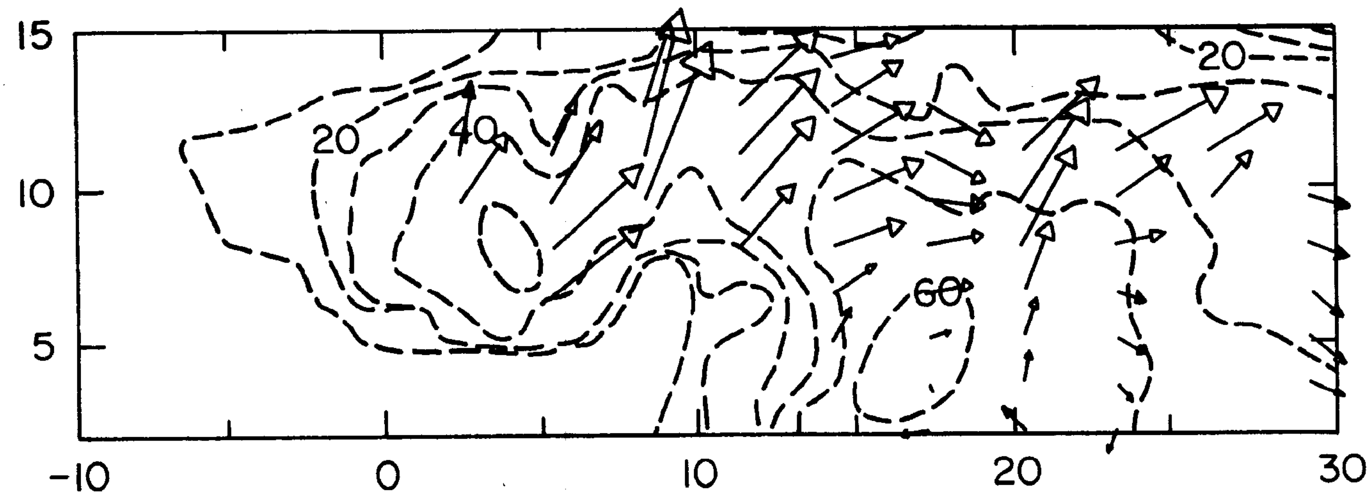


Figure 5. A vertical south to north cross section along x = 28 (Fig. 4), through the weak echo region at 1625 for the 22 June 1976 storm. Countours are radar reflectivity factor at 10 dBZ intervals, with the minimum contour at 10 dBZ. Vectors are depictions of velocities in this plane and are scaled at 7.5 m s $^{-1}$ km^{-1}.

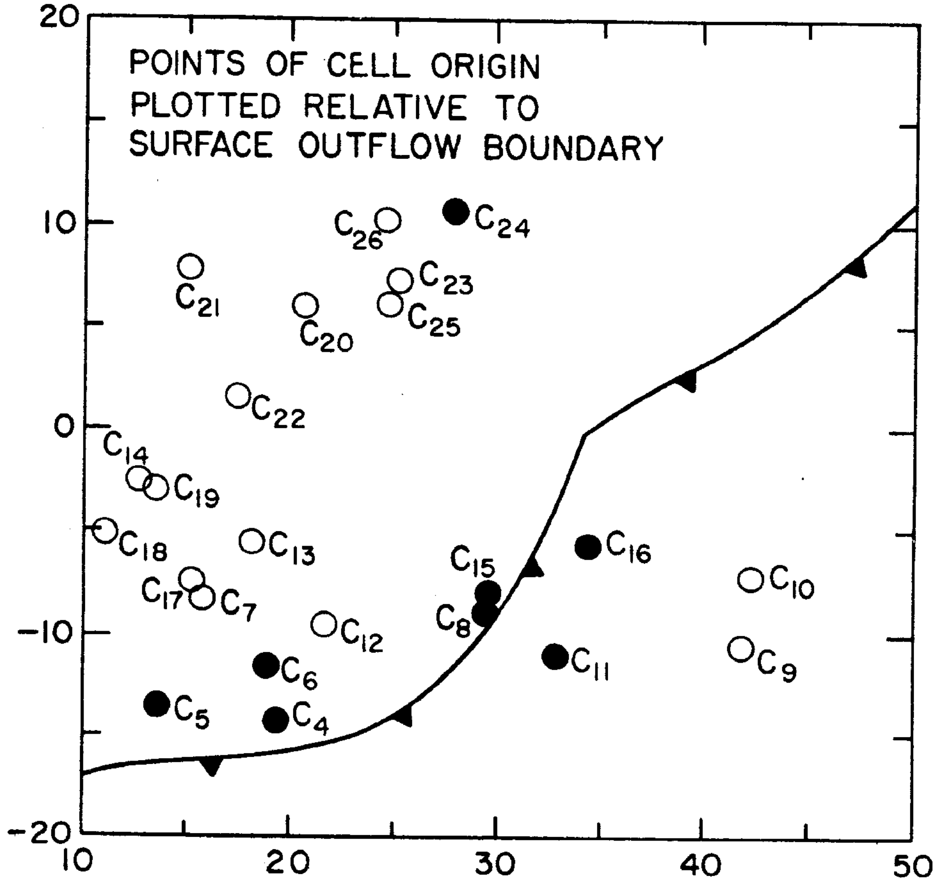


Figure 6. Points of origin for radar echo cells (designated by the subscripted letter C) plotted relative to the position of the surface outflow boundary at the time when the cell first achieved an echo intensity of 20 dBZ. Filled circles designate cells that eventually produce a radar reflectivity factor of ≥ 60 dBZ.

type of storm, the supercell, is characterized by a large, vigorous, steady updraft that is so wide and strong that the flow is relatively laminar and does not provide time for precipitation to grow in its core or allow turbulence to mix it in from the outside. Therefore one of its distinctive features is a region of weak radar echo that is bounded on its top and all sides by radar echo of greater intensity. Organized circulation in this type of storm is thought to provide for an extreme size sorting of hail such that the largest hail grows the fastest, and supercell storms in general are thought to produce exceptionally large hail. At the same time they are proposed to be inefficient as total precipitation producers, because of the updraft strength and its isolation from particles of the size that can effectively collect the cloud droplets and bring the water substance down to earth. Browning and Foote (1976)[2] argued convincingly that the extreme size sorting in supercells would make hail suppression by seeding difficult, if not impossible, and that seeding such storms might even produce more hail.

The other conceptual severe storm type is the multicell, which is envisioned to be composed of an organized series of simple convective cells, as first described in The Thunderstorm.[3] Each cell has a 30-45 minute life cycle, starting with vigorous updrafts and no precipitation and ending with downdrafts and the fallout of the precipitation that has formed. The multicell storm consists at any one time of several cells in different stages of development. In terms of precipitation development, each cell has been supposed to be independent, acting as if it were isolated. Hail embryos are postulated to grow in an early stage of cell development, when the updraft is relatively weak, and complete their growth during the mature phase of the cell when the stronger updraft can support them. Multicell storms are thought to be potentially susceptible to hail suppression by seeding of individual cells very early in their lifetimes, inducing competition between embyros and reducing ultimate hail size.

Severe storms are large, complicated, and confusing phenomena, and either of these two concepts presents a very useful simplification for the purpose of deciding what is important in hail and rain formation. The supercell concept postulates a steady state and relatively laminar flow, so that reasoning about and modeling growth trajectories become tractable. The multicell concept simplifies the problem by reducing

---

[2]Browning, K.A., and G.B. Foote, 1976: Airflow and hail growth in a supercell storm and some implications for hail suppression. Quart. J. Roy. Meteor. Soc., 102, 499-533.

[3]Byers, H.R., and R.R. Braham, Jr., 1949: The Thunderstorm. Washington, D.C., U.S. Govt. Printing Ofc., 287 pp.

its scale and treating the storm as a simple combination of smaller (and presumably simpler) elements that can be understood independently.

The problem is not whether either of these idealizations is right or wrong. As idealizations, everyone would acknowledge that both are always more or less wrong. The problem that is addressed by means of case study analysis, as exemplified by the 22 June study, is whether either is applicable enough to be a useful aid in understanding precipitation formation in a storm and so make it possible to understand the precipitation efficiency, the hail-to-rain ratio, the maximum hail size, and the potential effects of seeding.

The organization of the 22 June storm had aspects of both the supercell and the multicell models: it had a cellular reflectivity structure, but superimposed upon a fairly steady, larger scale organization, and a bounded weak-echo region, but neither were long-lasting enough to be convincingly steady nor associated with a sharp enough reflectivity gradient to indicate the size sorting of the prototype supercell. The surface data also showed little size sorting. The emphasis of the analysis just completed has been to try to decide whether the rain and hail formation in this storm conforms to the idealization of precipitation formation in either of these ideal storm types, whether it partakes of both at once in some sense, or whether it is importantly different from either.

To this end, two of the objectives of Harris' analysis of the Doppler radar-derived wind fields have been to determine the dynamic counterparts to the reflectivity cells and to the reflectivity vault. In conformity with the supercell model, one might anticipate on the one hand a very exceptionally strong updraft above the echo vault, with much weaker updraft or downdraft in the surrounding, more intense echo. On the other hand, the radar echo cells might be expected (ideally) to be loci of intense dynamic activity surrounded by more quiescent air. In fact, both of these expectations are about half true. The vault is the location of strong updraft, but the strong updraft region is in fact much larger than the vault and extends tens of kilometers to the south and, to a degree, in other directions as well. The cells are regions of dynamic activity, and at times updraft maxima are associated with cells, but the entire storm is active and there generally is no indication that the cells are either very distinctly defined dynamic entities or, indeed, very much more important than the large volumes of radar echo not assigned to cells.

Some of the other important, testable implications of the storm type upon precipitation formation, according to Browning and previous researchers, are as follows:

(1) The overall precipitation efficiency of supercells is likely to be low (of the order of 20%) because of the high updraft velocity, as evidenced by the low reflectivity within the updraft core, whereas multicell storms are more likely to have precipitation efficiencies of 50% or more because the relatively short duration of the updraft, its comparatively lower velocity, and its smaller size allow precipitation to enter the updraft and scavenge the cloud droplets more effectively. Fankhauser's analysis shows the 22 June storm to have a precipitation efficiency of 50% or greater during its severe phase.

(2) An implication of the supercell organization drawn by Browning is that the back side of the reflectivity vault is defined by the largest hail with the highest fall velocity. This extreme size sorting should produce a very sharp reflectivity gradient. Size sorting may occur in multicells, but it is likely to be much less marked because precipitation is able to fall through the updraft, and the greater turbulence promoted by the smaller updraft extent leads to more mixing. The biggest vault formed in the 22 June storm was not bounded by a very sharp reflectivity gradient, and both the aircraft data and the time-resolved surface data show little size sorting. The echo vault, while large and the site of strong updraft, was evidently a transitory feature pushed up into the base of the reflectivity overhang by a temporary updraft impulse superimposed upon a broad, continuing updraft region.

(3) In this connection, Harris performed approximate trajectory calculations of growing hailstones in the vicinity of the vault, using the most appropriate Doppler scan and assuming steady state, and found that hail of the sizes observed could not follow trajectories over the north side of the vault. They would be projected to the northeast by the strong horizontal wind component relative to the vault.

These three lines of evidence establish that the rain and hail formation in the 22 June storm were not importantly affected by the size sorting and "unfair competition" mechanisms that Browning and Foote described in relation to supercells.

The important simplifications of the multicell concept also do not survive careful scrutiny of this data set. Local wind hodographs constructed by Harris with respect to the motion of individual reflectivity cells, using the horizontal flow fields derived from the Doppler data, show ample opportunity--likelihood, in fact--for graupel and hail to have trajectories involving residence in more than one cell. Hail trajectories deduced from the structures of hailstones from accurately time-resolved hailstone collections by Nancy Knight from two of the cells show a great variety of vertical histories, even in a short time. Furthermore, several of the cells form within pre-existing radar echo regions, and the hail embryo formation may not have been associated with the cell at all. Thus the simplified multicell concept, at least as far as hail formation is concerned, does not apply.

Charles Knight showed that the time required for the growth of the largest hailstones was reasonably available, by considering the lifetime within the storm to be limited by the horizontal winds relative to the storm in the hail growth layer. Adiabatic or lower liquid water contents in the form of cloud droplets could supply adequate supercooled water to grow the hailstones within reasonable times. Using the facts that (1) the hail and rain were always mixed together, (2) the precipitation efficiency was high, (3) the hail was only about 3% of the total precipitation, (4) the hail growth trajectories were nonuniform, and (5) the radar reflectivity and airflow within the storm had rather large variations at small ($\sim$ 1 km) scales, a more probabilistic concept of hail formation appears more appropriate than either of the former idealizations, for this storm. The bigger hailstones must have nucleated out near the farthest reaches of the overhang to have had time to grow, but they must also have been lucky enough to encounter favorable growth environments for much of their residence time within the storm. They could not have spent too much time above the -40°C level, where growth is not possible, or too much time in regions with substantially depleted liquid water. However, the relatively high precipitation efficiency implies considerable liquid water depletion on the average, and the high rain-to-hail ratio ($\sim$ 30:1 in terms of mass) implies that most of the real depletion was accomplished by the relatively small precipitation particles, not by the hail.

Thus any seeding near the outer (southern) edge of the overhang might not materially have increased competition, resulting in smaller hail, since the natural depletion is accomplished by relatively small precipitation particles that originate over the entire, broad inflow region. Increasing the population of potential embryos only at the southern end of the overhang, as the currently popular suppression concept advocates, would be expected to have a relatively small influence on the total precipitation and the total depletion. However, it might increase the population of the largest hailstones by increasing the population of just those embryos that have the longest lifetimes within the storm and therefore the best chance to grow large.

The analysis of this storm represents one step along the way towards defining a set of conceptual models which will help to classify and describe storm behavior. It also tends to confirm the view that we are not as yet in a position to specify a generally applicable seeding technique for hail suppression. Other case studies in progress point in the same direction.

Modeling Studies

A three-dimensional numerical cloud model is being developed to study the sensitivity of severe storm evolution to various physical processes. Terry Clark recently simulated the multicellular storm of 22 June 1976 that occurred in the NHRE area and was chosen for intensive case study. The simulations are encouraging in that the model is capable of reproducing features of storm evolution. For example, propagation resulting from the formation of new cells--a fundamental aspect of storm behavior--was simulated with reasonable time and space scales. (In addition, the evolving flow fields derived from such simulations are proving to be valuable as proxy data for developing improved methods of handling multiple-Doppler radar observations.)

However, it is clear that there is still much to be learned about the properties of the model itself before we can proceed confidently to detailed comparison of its behavior with that of a real storm. One aspect needing further clarification is the sensitivity of the results to the type of initialization typically used by modelers. For cases with strong low-level wind shear, the commonly used initialization with a radially symmetric buoyant bubble results in the bending of the horizontal vortex lines such that a vortex doublet develops in the updraft. This vortex doublet causes dry environmental air to be entrained between the vortex centers, producing a region of strong negative buoyancy which results in the splitting of the original cell. Such instabilities are interesting in themselves, but the research indicates that such splitting may be only an artifact of the design of the numerical experiment; one should be cautious in drawing parallels between this type of cell splitting and that observed to occur in nature.

Two other aspects investigated recently were the sensitivity of the multicellular storm simulation to lateral boundary conditions and to domain size. It was shown that the boundary conditions, if not controlled, can lead to a runaway situation with respect to low-level convergence and upper-level divergence. Two types of boundary conditions described in the current literature were tested with two different domain sizes. Figure 7 shows the solutions for vertical velocity at a height of 7 km above the surface for the four cases mentioned. A fairly high degree of sensitivity of the results is shown, particularly with respect to the lateral boundary conditions. These types of results suggest a strong need for further sensitivity tests to boundary conditions, domain size, and resolution.

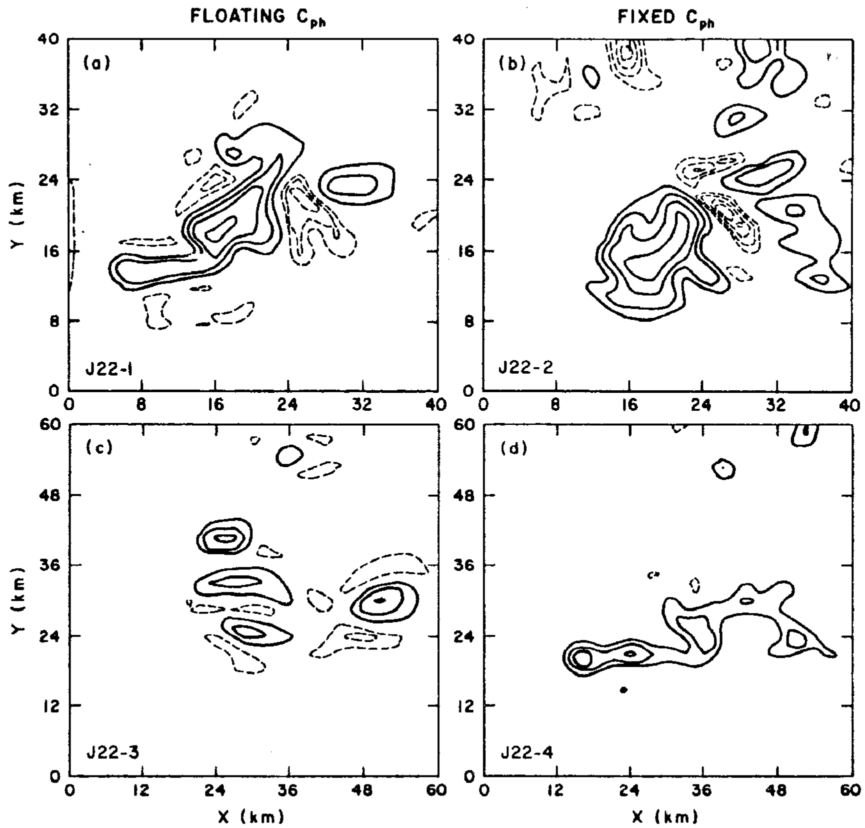


Figure 7. Plots of vertical velocity, w, at a constant altitude of z = 7 km above the ground or 8.25 km MSL. The solid contours indicate positive values using a contour interval of 6 m s $^{-1}$ and the dashed contours indicate negative values using a contour interval of 2 m s^{-1}. The four experiments shown are designated (a), (b), (c), and (d). Experiments (a) and (b) used a horizontal grid size of 1.0 km resulting in a 40 by 40 km domain size whereas (c) and (d) used a horizontal grid size of 1.5 km, resulting in a 60 by 60 km domain size. The floating or fixed Cph refers to the type of extrapolation used at the lateral boundaries to estimate the future normal velocities. The floating Cph allows variable characteristic slopes whereas the fixed Cph assumes a fixed characteristic slope. The times shown are 80 min for plates (a) and (b) and 93.3 min for plates (c) and (d).

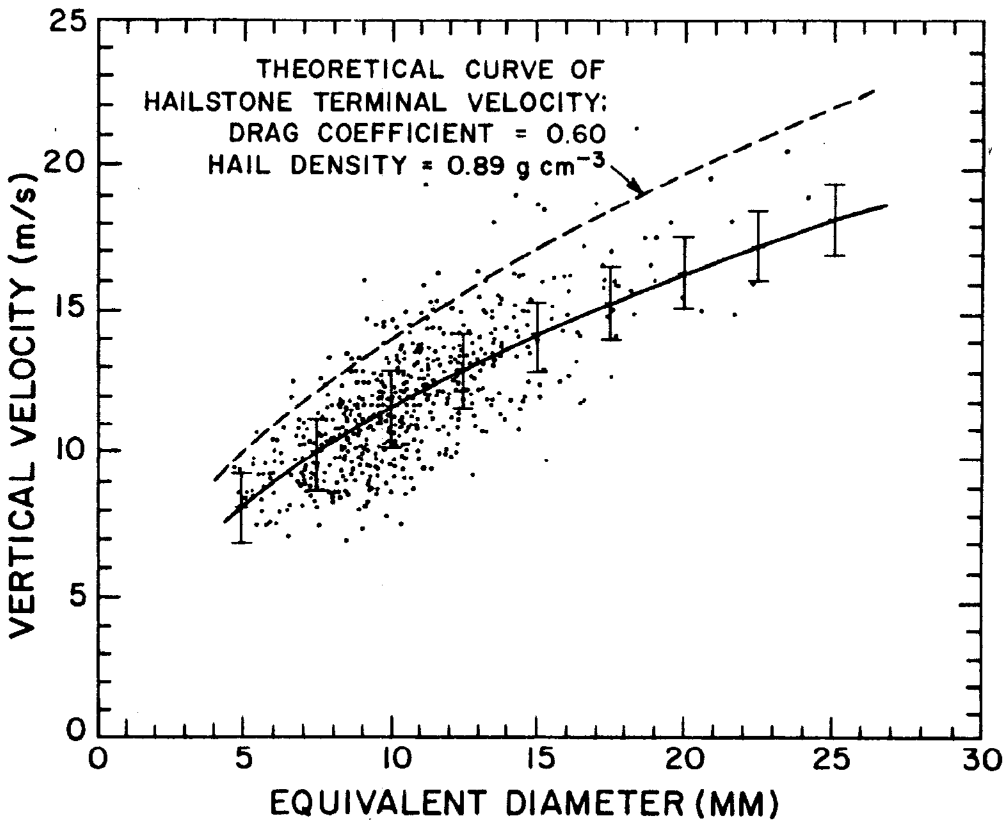


Figure 8. Experimental measurements of hailstone fall speed versus volume equivalent diameter. The dashed curve is the previously accepted theoretical relation. The solid curve is the result of a linear least-squares fit to the logarithms of the data. The vertical bars indicate one standard deviation of the residuals. An air density of 0.99 x 10^{-3} g cm^{-3} applies to both curves.

Photographic Observations of Hailstones Falling Under Natural Conditions

The kinematic behavior of hailstones falling in their natural environment near the surface was studied by Rick Matson and Arlen Huggins using stroboscopic photography in a mobile van. The experimental results permitted determination of the shape, dimensions, and fall velocity of hailstones falling into the van. Velocity data were obtained for more than 600 hailstones in the diameter range 5 to 25 mm sample in southeast Wyoming, southwest Nebraska, and northeast Colorado.

Very little data previously existed for the most commonly occurring hailstones in the range of Reynolds numbers 10^3 to 2×10^4. Matson and Huggins' study provided data in the gap between small graupel particles and large hailstones.

The vertical velocity measurements revealed that hail falls significantly slower than theoretical calculations for spherical particles would predict, even with enhanced drag coefficients of 0.60 to allow for surface roughness (Fig. 8). Thus Matson and Huggins found empirically that the fall speed (V_T m sec^{-1}) of hailstones was related to their volume equivalent diameter ($D_e$cm) by $V_T = 11{\cdot}45\ D_e^{0.50}$. Assuming a drag coefficient of 0.60, the theoretical expression for summertime conditions in northeastern Colorado is: $V_T = 13.96\ D^{0.50}$

The drag coefficients, inferred from velocity measurements, naturally reflect the relatively slow terminal velocities. The median experimental value of 0.87 is 45% higher than the value of 0.60 assumed in the above theoretical fall velocity expression. None of the experimental uncertainties could account for such a difference.

A very obvious feature of the measured terminal velocities and computed drag coefficients is their great natural variability. The regression curve for velocity can only predict V_T for hailstones of a given diameter to within ± 3 m s^{-1} ($\pm$ 26% for D_e = 1 cm). This variability must be due mostly to the great variety of shapes a hailstone of given mass (and therefore D_e) can assume. Some of this variability would have been due to variations in hailstone density ($\pm$ 2%), variations in air density ($\pm$ 4%), possible small-scale turbulence in the wind field near the surface, and error ($\leq$ 10%) in measuring stone dimensions.

The majority of hailstone shapes photographed were oblate spheroids, but more than 40% of these were considered fair to poor fits to the spheroid model. With another 16% of the hail being classified as conical, it is clear, at least for this sample, that a significant number of hailstones were not spherical as is usually assumed.

The data give an indication that fall speed decreases with increasing oblateness. In general, for hailstones classified as spheroidal, fall speed decreased about 20% as axis ratio decreased from 1.0 to 0.5.

An important implication of slower fall speeds is that a hailstone may spend significantly more time in the updraft of a storm. The observed fall speeds are also useful for the calibration of hail instruments such as hailpads. A common calibration technique involves dropping steel spheres onto pads from heights such that the impact kinetic energy of the sphere equals that of a spherical hailstone of the same diameter and drag coefficient 0.60 falling at terminal velocity. The sizes of the dents produced in the pads are then related to the sphere sizes. But according to the present study, use of this drag coefficient overestimates V_T and, therefore, kinetic energy as well. Present calibrations of hailpads may thus lead to underestimates of hailstone diameter by about 15%.

STAFF

ADMINISTRATION

Elmore Bartow
Helen Bartow
Sharon Blackmon
Jeffrey Callander
Toni Chapman
Kenneth Hite
Carole Pearce
Richard Sanborn
Laurence Sorensen
Rita Sorensen
Patrick Squires (Director)

EMPIRICAL STUDIES GROUP

Janice Baird
Cleon Biter
Gerald Cooper
Edwin Crow
Arlen Huggins
Gerhard Langer (to 9/29/78)
Alexis Long
Dennis Martin
Griffith Morgan, Jr.
Clarence Nagamoto
Jan Rosinski
Mark Solak
Barbara Strand
Peter Summers (to 7/28/78)
Peter Weickmann

MACROPHYSICS GROUP

Terry Clark
James Fankhauser
G. Brant Foote
Harold Frank
Eleanor Garvey
William Hall (long term visitor)
F. Ian Harris
Barbara Horner
Karen Miller
Carl Mohr
Michael Morse
Joanne Parrish
Ronald Rinehart
Barbara Toland
Quang Vu
Charles Wade
Barry Weiss
N. Joan Wilkerson

MICROPHYSICS GROUP

Daniel Breed
Carol Brown
Theodore Cannon
Steven Chapel
William Devine
James Dye
Kenneth Evans
Jack Fink
Vincent Glover
Walter Grotewold
Dewitt Harrison, Jr.

MICROPHYSICS GROUP continued

Andrew Heymsfield
Wayne Howie
Hans Jensen
Peter Johnson
Katherine Kime
Charles Knight
Nancy Knight
Philip Kuhn
Alice Lecinski
John Murino
Ilga Paluch
Debra Plastrik
Philip Roskowski
Vim Toutenhoofd
Robin Vaughan
James Weber

VISITORS

Ronald Biondini, University of Virginia Empirical Studies Group, 1 July 1978 - present.

Arthur R. Jameson, Illinois State Water Survey; Microphysics Group, 12 February - 11 March 1979.

John Thomas Marrs, Texas A&M University; Microphysics Group, 12 June - 20 July 1978.

William J. Megaw, York University; Microphysics Group, 16 January - 31 July 1978.

Timothy Miller, University of Arizona; Macrophysics Group, 5 June - 20 August 1978.

Mario Schaffner, unaffiliated; Macrophysics Group, 1 June - 31 December 1978.

Kenneth Young, University of Arizona; Macrophysics Group, 5 June - 20 August 1978.

ADVANCED STUDY PROGRAM

INTRODUCTION

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

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

ASP regular full-time Ph.D. staff members (outside of ESIG) are those responsible for running the ASP visiting and educational programs. These staff members also conduct research on problems of their own choosing.

POSTDOCTORAL AND SENIOR POSTDOCTORAL FELLOWSHIP PROGRAM

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

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

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

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

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

(4) continued use of its facilities;

(5) bringing word of the talents and facilities of NCAR to their home institution, encouraging their colleagues to take more advantage of the opportunities that NCAR provides, and generally identifying positively with NCAR goals and activities.

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

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

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

Included at the edn of this section are lists of the ASP Fellows for the academic years 1977/78 and 1978/79. Each group contains scientists from a wide range of disciplines and the disciplines represented vary widely from one year to the next depending on the nature of the applicant pool.

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

Peter Hildebrand, Senior Postdoctoral Fellow (1978/79), has directed the planetary boundary layer (PBL) experiment called Phoenix. This multipurpose, joint NCAR/National Oceanic and Atmospheric Administration (NOAA)/university experiment was conducted at the Boulder Atmospheric Observatory (BAO) tower east of Boulder. The Phoenix included: PBL growth and structure in the complex Boulder terrain; experimental verification of theoretical and empirical descriptions of the PBL; Eulerian-Lagrangian turbulence statistics; comparisons of various methods of measurement; and an evaluation of multiple Doppler radar air-motion measurements. Facilities used included two NCAR Queen Air aircraft, one NCAR and two NOAA radars, an NCAR portable automated mesonet (PAM) system, and an NCAR rawinsonde, as well as the tower.

Data from this experiment have been put into archival format and several further analyses have begun. Comparisons have been made of inversion height measurements from different sensors. A comparison of aircraft and multiple Doppler radar measurements of air motions is being conducted. A case study of the growth of the PBL is underway. Preliminary calculations show obvious effects of local hills and the mountains to the west. Further study will continue after Hildebrand returns to the Illinois State Water Survey.

Paul Dusenbury (1978/79) has investigated various properties of streaming plasmas including their dissipation to find when the linear approximation breaks down. He has also completed a comprehensive analysis of streaming instabilities in a cold plasma and has begun to detail the differences between warm and cold streaming plasmas. Dusenbury is applying his results to the solar wind in order to explain heat flux instabilities, which are an important link in understanding solar-terrestrial interactions.

Dusenbury has also collaborated with Larry Lyons (NOAA) in a study of plasma wave turbulence associated with auroral arcs in the presence of parallel electric fields. The onset of turbulence is of special interest. Dusenbury has also worked with Joseph Hollweg, High Altitude Observatory (HAO), on developing a theory for the quasilinear acceleration and heating of the He^{2+} particle distribution function by Alvén turbulence generated near the sun.

Two other Fellows, Val Veirs (1977/78) and Robin Dennis (1978/79), have developed the Denver Brown Cloud study, which is discussed in the section on ESIG.

UCAR FELLOWSHIP PROGRAM

UCAR provides a limited number of graduate fellowships for study in the atmospheric sciences leading to the Ph.D. During the academic year, these Fellows attend the graduate school of their choice, spending their summers only in ASP. As Fellows they receive a stipend and their tuition is paid by UCAR. We attempt to support the best students, whether or not they have had previous training in the atmospheric sciences. Our primary concern is that the student be interested in pursuing a graduate career in the atmospheric sciences (broadly defined) and that he or she have the ability and motivation to attain the Ph.D.

The principal ASP and NCAR objective in participating in the UCAR Fellowship Program is to expose scientists at an early stage in their professional careers to the facilities and programs of NCAR with the expectation that, just as with the Postdoctoral Fellows, many of these students will form longer-term association with NCAR through use of its facilities for their dissertation research and beyond, by participation in NCAR projects when appropriate, and even by subsequently being hired by NCAR. The Fellows also form an informal bridge between their advisors and NCAR.

UCAR Fellows learn about NCAR through seminars from NCAR project leaders, by taking special courses (such as the Computing Facility summer course), and through working with individual NCAR staff members on projects of mutual interest. Often these activities lead to dissertation work that, on occasion is supervised by an NCAR staff member.

Also included at the end of this section are lists of the UCAR Fellows for the years 1977/78 and 1978/79. Fellows come from a wide variety of backgrounds. Of the eleven Fellows listed, four had undergraduate training in the atmospheric sciences, the other 5 had undergraduate degrees in physics, chemistry, and mathematics. The Fellows were interested in diverse topics for their graduate work. Climate and dynamic meteorology however were of interest to the largest number; others were interested in tropical meteorology, atmospheric chemistry, cloud physics, and air pollution and public policy.

NCAR GRADUATE ASSISTANTSHIPS

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

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

SUMMER FELLOWSHIPS FOR WOMEN AND MINORITY STUDENTS

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

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

Each year we also ask one or two minority educators to visit NCAR in the summer. In a few cases, the educator has experience in some aspect of atmospheric science research. In general, however, these educators are physics or physical science teachers who are interested in the atmospheric sciences. Some are planning to develop an introductory course for their colleges; others just desire the experience of being affiliated with a major scientific center. We have found that these educators believe their visit to NCAR to be personally rewarding, and we find that they are quite helpful in recruiting students for our program in subsequent years.

Listed at the end of this section are the participants in our program for the summer of 1978.

The success of the ASP summer program for women and minority students led to the establishment of a new summer internship program. Four universities received grants to develop introductory courses designed to encourage members of ethnic minority groups and women to enter the atmospheric sciences. The program is being sponsored by UCAR and the American Meteorological Society. The Max C. Fleischmann Foundation of Reno, Nevada, and NOAA each provided $50,000 to help finance the independent university programs for the summers of 1977 and 1978. The universities that participated in 1978 were the University of Missouri, State University of New York at Albany, the University of Washington, and the University of Wisconsin. There has been strong interaction among the five programs, with students referred from one program to another and with ideas exchanged among the various program leaders. We hope that some university programs will soon be established permanently.

SUMMER COLLOQUIUM

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

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

In 1978 the colloquium was entitled "The General Circulation: Theory, Observations, and Modeling." Six scientists and fourteen graduate students were full-term colloquium participants. Many short-term visitors gave one or two lectures and/or interacted with the colloquium participants for part of the summer. Each of the faculty participants guided two of the graduate students in research projects on general circulation. ASP Chairman Maurice Blackmon, who organized the colloquium, also guided two students. The research projects were designed so that the student could make some progress on the subject. Students reported on their work at the end of the colloquium.

There were usually four lectures or seminars per week. Most speakers gave only one to two talks, generally on their recent research. John M. Wallace and Ngar-Cheung Lau (Geophysical Fluid Dynamics Laboratory [GFDL]) however, opened the colloquium with a two-week series of lectures on observational studies of the general circulation. These lectures included summaries of the classic papers of Starr, Palmén, and others as well as summaries of the more recent work by Blackmon, Wallace, and Lau. A volume containing written lectures and reports of the students' research projects will be available in the fall of 1979.

ENVIRONMENTAL AND SOCIETAL IMPACTS GROUP

The members of the Environmental and Societal Impacts Group (ESIG) have been active in many areas. Only part of their research will be discussed here.

Denver Air Pollution Study

Last year a pilot study was carried out by Val Veirs, a Senior Postdoctoral Fellow, in collaboration with ESIG long-term visitor Jeryl Mumpower (permanently affiliated with Institute of Behavioral Science, University of Colorado), to test the feasibility of developing an air pollution model of Denver for use in the development of public policy. Veirs' model was purely statistical and used traffic data, auto emissions data, projections of traffic and emissions, and meteorological data to predict CO concentration, visibility, and energy consumption, along with other variables. This model was linked to one that relates values to policies. Judgement/value modeling is the speciality of Prof. Kenneth Hammond, IBS, and his coworkers. Veirs and Mumpower developed a reasonable set of scenarios for the Denver air pollution problem for the next twenty years. These scenarios were evaulated and ranked by a limited number of interested citizens.

Several interesting results were obtained. On the physical side, the most important variable turned out to be the total number of vehicle-miles traveled per day. Changes in the number of people riding public transportation by even a factor of two were ineffective in controlling pollution. Auto emissions control technology was effective in reducing concentrations, allowing sizeable population growth, if the total vehicle-miles traveled was held within bounds. Vehicle-miles traveled can be limited by reducing trip length, which probably requires land-use restrictions, and by increasing the average occupancy of cars, which could be accomplished by car-pooling.

The citizens who examined the scenarios were fairly uniform in their judgments that health effects be minimized, federal air pollution standards be met, and aesthetic values (haze reduction, for example) be maintained. However, there was no agreement concerning what policies should be implemented to achieve the desired results. The pilot project was a success in that it demonstrated that the mass of available scientific information can be put in a form that citizens and policy-makers can use. The pilot study had obvious inadequacies which are now being remedied.

Robin Dennis, another Senior Postdoctoral Fellow, has been adapting a dispersion model for use in this study. Dennis' model uses as data a comprehensive emissions inventory, provided by the Colorado Health Division, and meteorological data to predict CO concentrations. Paulette Middleton has begun work on including chemistry in the dispersion model so that the effects of NO_x, O_3, and emitted hydrocarbons can be considered. Dennis has also been developing economic and lang-use components for the study. Mumpower and Dennis have developed a plan for a three-year comprehensive study that will provide decision-makers with the best information on causes and effects of Denver's air pollution and on policies for its control, including the costs and effects of implementing these policies.

Value of a Reliable El Niño Forecast

Michael Glantz has undertaken a survey of experts -- scientists, social scientists, and administrators -- concerned with fisheries exploitation in general and with the Peruvian fisheries in particular.

The purpose of the study was to evaluate how a reliable El Niño forecast two to four months in advance might be used to minimize its impact on Peru. (El Niño is an oceanographic-meteorological event that occurs in the eastern equatorial Pacific.) It has consistently been assumed that such a forecast would be of great social and economic value to the Peruvians.

The study's findings suggest that, while such assumptions may be valid in theory, there is little evidence to suggest how valuable such a forecast would be in practice. The study also suggests that, while such information could in theory be useful for improved management of the anchoveta, the real value to society of the forecast will be determined in large part by the political, economic, and social contexts in which that information exists.

Another important conclusion of the study is that there is a pressing need, for society as well as for science, for more research on the Peruvian upwelling ecosystem (including El Niño). Such a research effort would be extremely valuable not only for the Peruvian fishery industry but also as a well-documented case study of the combination of human and physical impacts on a living marine resource. This would provide useful information for those developing countries that are planning to or are in the process of developing their coastal fisheries potential as an integral part of their economic development plans and who wish to exploit those resources in such a way as to have them available for exploitation by future generations.

A result of the El Niño study is that Glantz and J. Dana Thompson (a 1974 ASP Postdoctoral Fellow) are in the process of editing and contributing to a book entitled The Science, Politics, and Economics of the Peruvian Fisheries and El Niño. This is to be published by John Wiley and Sons in mid-1980.

Two additional current projects are on the impact of streamflow forecasts for Yakima Valley, Washington and on the impact of a hypothetical CO_2-induced global warming on society. Both of these topics represent areas of national concern and awareness about climate-society interactions.

The Yakima study is based on the reaction of farmers and others to a streamflow forecast of 6-20% of the long term average. Five months later the forecast was revised upward to 80-120% of "normal," but it was too late to reverse many of the responses such as the drilling of wells or the selling of water rights. This provides an interesting case study of the impact (economic, social, political, and legal) of a forecast that was incorrect. Such a case study could be useful as an analogue to those who wish to assess the impact of an incorrect forecast related to energy activities, for example.

The hypothetical global CO_2-induced warming research efforst are in the preliminary stages, but members of ESIG are involved in the early stages of preparation for the AAAS/DOE Workshop on "Environmental and Societal Consequences of a Possible CO_2-induced Climate Change."

Value of Frost Forecasts to Orchardists

Richard Katz and Allan Murphy have developed a decision-analysis approach for assessing the value of frost forecasts to orchardists in the Yakima Valley of Washington. In this model, the orchardists have two possible actions: to protect or not to protect their crop. Their action is influenced by the available minimum temperature forecast and the accuracy of the forecast. Protective measures cost money, but successful protection increases income so there is a non-trivial economic decision to be made.

Katz and Murphy found that the forecasts do in fact have value. The present forecasts have already captured a large fraction of the maximum potential value of forecast (from a perfect forecast).

Improvements in current forecasts are not likely to be as significant in terms of dollars as have been past improvements.

Katz and Murphy are presently formulating a more comprehensive model that will take into account the history of the minimum temperature over the fruit growing season. This will allow for more complex decision making based on decisions and losses earlier in the season.

STAFF RESEARCH - MAURICE BLACKMON

Blackmon, in collaboration with Roland Madden (NCAR) and John M. Wallace and David Gutzler (University of Washington) completed a study of the vertical structure of fluctuations in the geopotential height.

Temporal (but nonseasonal) fluctuations in the geopotential height field exhibit large regional contrasts in vertical structure, as manifested in the geographical distributions of the correlation between 100 and 500 mb height and in the ratio of the amplitudes of the fluctuations at those levels. This geographical variability was investigated in order to ascertain its seasonal, frequency, and zonal wavenumber dependence and its relation to other indicators of vertical structure, such as statistics involving the 100-500 mb thickness and the structure of the dominant mode in an eigenvector analysis expansion of geopotential height in the vertical.

Particularly striking is the contrast between transient fluctuations over the eastern oceans, which exhibit a highly barotropic structure with strong vertical coherence in the geopotential height field and small temperature variability, and those over the interior of the continents, whose structure is much more baroclinic, with low or negative temporal correlations between 1000 and 500 mb height. Such contrasts show up clearly in station data; they are observed during both winter and summer and for temporal frequencies ranging from synoptic to interannual time scales. They are largely a reflection of the vertical structure of planetary=scale fluctuations. There is also evidence of smaller scale regional contrasts in vertical sturcture, some of which appear to be associated with synoptic=scale disturbances.

On the basis of 1000 and 500 mb height data alone it is possible to represent, with a high degree of accuracy, the geographical distribution of the shape of the dominant eigenvector in the expansion of the vertical profile of geopotential height in transient disturbances.

The implications of these results on the design of observing networks and objective analysis procedures were discussed.

Blackmon, in collaboration with Ngar-Cheung Lau (GFDL) is completing a study of seasonally averaged statistics of a general circulation model developed at GFDL. Using previous observational work for comparison, model statistics are calculated for mean, variance, and covariance quantities. The model does not simulate the low-frequency statistics well. The model does simulate realistically the position of the baroclinic disturbances, however. Although the variances and covariances associated with baroclinic disturbances are approximately of the correct magnitude in the lower troposphere, the fluctuations in the upper troposphere are too weak.

STAFF

Maurice Blackmon, Chairman
Bernhard Haurwitz, NCAR Research Associate
Jackson Herring (to 1 October 1978)
Verlene Leeburg
Jane Mayberry
Ursula Rosner
Betty Wilson

Environmental and Societal Impacts Group (ESIG):

Mary Bartels (to 5 February 1979)
Robin Dennis (long-term visitor, previous affiliation: International Institute for Applied Systems Analysis, Austria, September 1978-present)
Michael Glantz
Richard Katz
Maria Krenz
Jeryl Mumpower (long-term visitor, permanent affiliation, University of Colorado, June 1978-present)
Allan Murphy
Suzanne Parker
Gregg Scott (Western Interstate Commission for Higher Education [WICHE] intern, December 1978-present)

VISITORS

Postdoctoral and Senior Postdoctoral Fellows, 1977/78:

Geirmundur Árnason, permanent affiliation: State University of New York, Albany, August 1977-August 1978.

Steven Ashe, present affiliation: Harvard University, November 1977-November 1978.

Thomas Bell, present affiliation: Goddard Space Flight Center, September 1977-September 1978.

Walter Berg, present affiliation: AQD, NCAR, September 1977-September 1978.

Richard Bogart, present affiliation: HAO, NCAR, February 1978-February 1979.

James Curry, present affiliation: Massachusetts Institute of Technology, June 1977-June 1978.

Michael Davey, present affiliation: University of Washington, January 1978-January 1979.

Alan Fried, present affiliation: Bureau of Standards, October 1977-October 1978.

Shadia Habbal, present affiliation: Harvard University, September 1977-September 1978.

William Hall, present affiliation: CSD, NCAR, August 1977-August 1978.

James Hill, permanent affiliation: Iowa State University, September 1977-July 1978.

Barry Huebert, permanent affiliation: Colorado College, September 1977-September 1978.

Warren Knapp, permanent affiliation: Cornell University, August 1977-August 1978.

John Middleton, present affiliation: Colorado State University, September 1977-September 1978.

Mario Schaffner, present affiliation: FOF, NCAR, June 1977-June 1978.

Richard Skaggs, permanent affiliation: University of Minnesota, September 1977-August 1978.

Robert Street, permanent affiliation: Stanford University, March-September 1978.

Val Veirs, permanent affiliation: Colorado College, June 1977-June 1978.

Stephen Warren, present affiliation: AAP, NCAR, January 1978-January 1979.

John Whitehead, Jr., permanent affiliation: Woods Hole Oceanographic Institution, September 1977-June 1978.

Postdoctoral and Senior Postdoctoral Fellows, 1978/79:

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

Robert Cahalan, previous affiliation: University of Missouri, St. Louis, September 1978-present.

John Corbett, previous affiliation: Instituto de Estudios Administrativos y Sociales, Mexico, August 1978-present.

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

John Grant, previous affiliation: University of Colorado, November 1978-present.

Gary Greenhut, permanent affiliation: Seton Hall University, July 1978-present.

Peter Hildebrand, permanent affiliation: Illinois State Water Survey, August 1978-present.

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

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

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

Richard Siquig, previous affiliation: Hamburger Sternwarte, Federal Republic of Germany, June 1978-present.

Joseph Tribbia, previous affiliation: Purdue University, August 1978-present.

Philip Wilksch, previous affiliation: National Oceanic and Atmospheric Administration (NOAA), July 1978-present.

Ad-Hoc Faculty:

Stella Coakley, University of Denver, February 1977-present.

Short-term Faculty:

Eric Kraus, University of Miami, July-August 1978.

Arthur Loesch, State University of New York, Albany, July-August 1978.

Edward Lorenz, Massachusetts Institute of Technology, July-August 1978.

Thomas Lundgren, University of Minnesota, June-August 1978.

Michael McIntyre, University of Cambridge, England, July 1978.

Paulette Middleton, AQD, NCAR, December 1978-March 1979.

Rachel Pinker, University of Maryland, July-August 1978.

Eric Siggia, Cornell University, June-August 1978.

Eiichi Suzuki, Aoyama Gukin University, Japan, August-September 1978.

John Tukey (AAP/ASP), Princeton University and Bell Laboratories, November-December 1978.

Val Veirs, Colorado College, June-August 1978 and January 1979.

Short-term Students:

Shi-hung Chou, State University of New York, Albany, May-August 1978.

Timothy Kittel, University of California, Davis, June-August 1978.

Thomas Parish, University of Wisconsin, June-August 1978.

Michael Samuel, University of California, Davis, June-August 1978.

Glenn White, University of Washington, November 1978-present.

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

Mary Anne Carroll, Massachusetts Institute of Technology.

Richard Deininger, Massachusetts Institute of Technology.

Leo Donner, University of Chicago.

Dale Durran, Massachusetts Institute of Technology.

Matthew Hitchman, University of Washington.

Former UCAR Graduate Fellows on Summer Appointment with ASP, 1978:

Robert Chen, Massachusetts Institute of Technology.

Geoffrey Domm, Massachusetts Institute of Technology.

William Gutowski, Massachusetts Institute of Technology.

Lynn Hubbard, University of California, Riverside.

George Huffman, Massachusetts Institute of Technology.

Susan Solomon, University of California, Berkeley.

Summer Fellowship Program for Women and Minority Students, 1978:

Keith Bibbins, Howard University, Washington, D.C.

Denise Brandon, Ohio Wesleyan University, Delaware, OH.

Robert Estes, Bishop College, Dallas, TX.

Monique Gamache, LeMoyne College, Syracuse, NY.

Lloyd Gavin, present affiliation: Xavier University of Louisiana, New Orleans, LA (educator).

Benjamin Gottlieb, permanent affiliation: Bishop College, Dallas, TX (educator).

Peter Green, University of Colorado, Boulder, CO.

Ronald Green, Metropolitan State College, Denver, CO.

Caryl James, Talladega College, AL.

Charles Linnear, Bishop College, Dallas, TX.

Daphne Smith, Spelman College, Atlanta, GA.

Michelle Vidal, Linfield College, McMinnville, OR.

Bryan Weare, permanent affiliation: University of California, Davis, CA (lecturer).

Graduate Assistantships, 1978/79:

Alan Bohne, University of Chicago (to 1 January 1979).

Russell Dickerson, University of Michigan.

Ronald Ferek, Florida State University.

Laurence Goldberg, University of Colorado.

William Kohri, Drexel University.

Robert Rasmussen, Drexel University.

Bruce Wielicki, University of California, San Diego.

Summer Colloquium, 1978:

Richard Blakeslee, University of Arizona.

Stephen Colucci, State University of New York, Albany.

Randy Dole, Massachusetts Institute of Technology.

Timothy Dunkerton, University of Washington.

Brian Farrell, Harvard University.

Robert Gall, permanent affiliation: University of Arizona (lecturer).

David Gutzler, University of Washington.

William Heckley, University of Reading, England.

Isaac Held, permanent affiliation: Harvard University (lecturer).

Brian Hoskins, permanent affiliation: University of Reading, England (lecturer).

Arthur Hou, Harvard University.

Petros Ioannou, Harvard University.

Claudia Johnson, University of Illinois, Urbana.

David Karoly, University of Reading, England.

Ngar-Cheung Lau, Princeton University.

Richard Lindzen, permanent affiliation: Harvard University (lecturer).

Kevin Trenberth, permanent affiliation: University of Illinois, Urbana (lecturer).

David Venne, Iowa State University.

Robert Walko, University of Arizona.

John Wallace, permanent affiliation: University of Washington (lecturer).

Glenn White, University of Washington.

NCAR Annual Scientific Report April 1978 - March 1979 - Link Page

Next PART0002

ATMOSPHERIC TECHNOLOGY DIVISION

INTRODUCTION

Of the two missions of NCAR, the one specifically accomplished through the Atmospheric Technology Division (ATD) is to provide research services and facilities of the outstanding quality required for effective progress in atmospheric science and to assure the optimum use of these services and facilities by scientists in the universities and NCAR.

Through the six[1/] facility groups comprising ATD, the division makes available to large and small research programs, to individual scientists, and to multi-institution field programs the advanced, complex observational systems and high-speed computing power essential to investigate atmospheric processes. The operational and development strategies guiding the accomplishment of the ATD mission are necessarily varied, as is appropriate to the diversity of services provided.

Over the past two years, the demand for ATD services has become intense, with a much greater need for quantity of service, quality of measurements, and additional measurement capabilities than can be fulfilled. This increasing demand stems from the needs of individual investigators as well as from those of the many multi-investigator programs and the major international field programs. While we expect to see a gradual shift of funding support for university and NCAR research from the traditional NSF sources to mission agencies, we do not expect a diminution in the demands placed upon us. If anything, the contrary is true.

The provision of sophisticated research-facility support to NCAR and to the academic atmospheric research community is expensive. Over 40% of NCAR's budget goes to such support, nearly half of this to computing. During the year, there has been much interest in the balance between the funding for ATD facilities and the funding for the atmospheric research programs the facilities serve. Principal attention has focused

---

1/ Five of these facilities are formally within NCAR: the Computing Facility (CF); the Field Observing Facility (FOF); the Research Aviation Facility (RAF); the Research Systems Facility (RSF); and the Global Atmospheric Measurements Program (GAMP). The sixth, the National Scientific Balloon Facility (NSBF), is located in Palestine, Texas.

on the ratio of ATD to NCAR-science funding, a ratio that has been growing in recent years. This has been a matter of concern to those who recognize the importance of a strong and healthy science program at NCAR. Recently, there has been a growing awareness that the focus ought to be on the ratio of ATD funding to the remainder of the NSF funding going for research, both NCAR and university research. The demand placed upon ATD depends upon the total funding for these two components, not the NCAR part alone. At present, more than 70% of ATD support is to programs outside of NCAR. The ratio of ATD to total NSF atmospheric research funding has grown only slightly over the past five years. There is increasing evidence that the ratio remains too low, that is, that the number of research facilities presently available is inadequate to meet the essential demands produced by the current rate of investment in research.

There are other aspects to the issue of ATD's ability to meet present and future demand, such as the aging of ATD's entire inventory of advanced research facilities without adequate provisions for replacing these systems as they become obsolete. For the past four or five years the bulk of ATD has been living off of earlier capital investments and this is likely to continue. Even in computing, where a truly generous infusion of new money has occurred during this period, the fact that the CDC 7600 and the Ampex mass storage system have been prepaid means that current CF budget levels are well below the funding required to maintain the NCAR computing capacity by the early 1980s when these systems will reach the end of their useful lives. Another equally pressing example is the fleet of RAF research aircraft, most of which are already obsolete to the science they are trying to serve.

A second aspect has to do with expansion and upgrading of existing facilities. We recognize that it is unreasonable to expect that ATD's capacity could or should be expanded to meet all of the demand described earlier. However, some expansion *is* necessary and justified. Even more important are ATD's efforts to upgrade facilities. ATD's *future* resides in its current development program. Yet ATD's carefully considered multi-year plans have failed to generate any new dollars for ATD's development activities, except for computing. Virtually *all* of the NCAR/ATD recent developments -- some of which have opened new horizons for scientific investigation -- including the color doppler radar displays, PAM, Safesonde, RDSS, ARIS IV, etc., have been accomplished, not on planned incremental funding, but rather in the catch-as-catch-can environment of reprogrammed reserves. Without adequate funds, we see no opportunity to maintain a *coherent* development program, and at the same time a level of service dictated by community needs. It will soon become necessary to scale down services to reprogram for development.

The ATD facilities have, however, continued to score a record of quality research support for which we are proud. The facility reports which follow detail an impressive list of accomplishments in computing, research aviation, ballooning, field observing and instrument development.

RESEARCH AVIATION FACILITY

Mission and Goals of RAF

The Research Aviation Facility (RAF) provides atmospheric scientists with a state-of-the-art research capability consisting of instrumented aircraft and associated ground support, and undertakes technical developments to maintain and update this capability.

The aircraft platforms are applied to research activities by university and NCAR scientists in a wide variety of research areas, principally in the areas of the boundary layer, cloud physics, mesoscale and severe storms, air chemistry, and radiation studies. RAF presently operates four NSF-owned instrumented research aircraft: a four-engine turboprop Electra (N308D), a twin-jet Sabreliner (N307D) and two twin-engine Queen Airs (N304D and N306D). The programs supported by these aircraft are often national or international in scope.

Strategies and Highlights

The strategy of RAF over the past year has been to hold flight support at as high a level as possible while working to improve data quality and to add to the RAF measurement capabilities. Concerted efforts have been made to improve technical staff and staff assignment, and to set priorities for the purchase of urgently needed sensor equipments, test and calibration equipment, and instrumentation spares. These efforts have been only partially successful and are now being re-initiated with new dedication--with present funding outlooks, each RAF staff position and each dollar budgeted for flight hours or instrumentation must be critically examined to insure the best RAF performance for both the short and long term.

In the past year, flight and project operations have been continued at a high level of both quantity and quality. The Queen Airs and the Sabreliner have each supported nearly a full schedule of operations. The Electra has been a workhorse in truly worldwide programs (JASIN, GAMETAG, CYCLES, Winter and Summer MONEX), in support of investigator programs in chemistry, air-sea interaction, cloud physics, and large- and small-scale dynamics. In these programs the Electra has flown over 500 research flight hours, nearly two times the normally scheduled hours. This commitment to Electra research programs while maintaining nearly a full schedule on the other aircraft has been possible only because of dedication, hard work, long hours, time away from family, etc. of the RAF staff.

Data processing continues to be of high quality and timely processing schedules are maintained. Present attrition of data processing support staff (principally provided by the Computing Facility) is causing minor delays in some data processing and more than minor delays in software development. Field project operations have been well supported during the year, in terms of both aircraft (pilots and maintenance) and flight operational control (project scientists and engineers), despite the strains associated with the heavy flight schedules. RAF recognizes a weakness in the area of instrumentation and development which has persisted; this must be rectified if we are to maintain the sophisticated instrumentation and data systems being flown by the Facility and to develop the sensor systems needed in the decade ahead. Additionally, RAF has been short of scientific expertise needed to interact with investigators for improving aircraft research applications and techniques, and for assisting the investigators in data interpretation and analysis.

RAF strategy for the near future is based on the recognition that during the early 1980s, progress in the atmospheric sciences depends to a substantial degree upon progress toward improved RAF capabilities centered in three top priority areas:

1. Replacement of existing limited-performance small aircraft with aircraft of increased range, altitude, and load-carrying performance which are capable of meeting a larger fraction of the scientific program need. Presently, the acquisition of a first replacement aircraft is not scheduled until 1982. For the benefit of the scientific community, every effort must be made to accelerate this schedule.

2. Improvement of the airborne measurement systems and support services. The immediate need is to improve the reliability and capability of the on-board data systems, to improve data quality through better system design and data management, and to improve sensor instrumentation in cloud physics, in air chemistry, and in atmospheric dynamics monitoring. Accomplishing these tasks will require a competent and dedicated engineering staff and sufficient funding. Efforts to improve in these areas over the past two years have been only partially successful--a renewed effort has been initiated in the last months of this reporting period.

3. Maintaining a high enough number of research hours flown to support a steady fraction of the increasing demand for research aircraft. At present RAF has tried to maximize the number of research flight hours consistent with quality support of university and NCAR research demands despite

superinflationary fuel and other costs.

Exciting developments and uses of research aircraft measurement systems must and will occur within the field of environmental science. Research aircraft platforms will have to be equipped with in-situ and remote probes as well as with expendable (droppable) probes to provide scientists with the vast amount of data they need. These are the requirements of ongoing programs in weather understanding, interpretation, forecast, and warning; in oceanography and air-sea interaction; in the coming climate program; in studies of arctic ice and cloud systems; in radiation and radiation-energy flow studies; in the study of pollution sources and sinks, of chemical transition and decay processes, of the transport processes of chemical particulate and gaseous contaminants; in monitoring and analyzing the carbon dioxide problem; in providing ground-truth continental and oceanic measurements for interpreting satellite observations. The 1980s will challenge our abilities and our resourcefulness.

Recent Accomplishments

In the past year, significant improvements in aircraft instrumentation systems have been made.

1. A major development project in air motion sensing on the Queen Air (N304D) was accomplished with the installation of a de-iced, four-fixed-vane gust probe on a new shock-mounted noseboom. The boom assembly on N304D is similar to that on the Electra, with the Inertial Navigation Unit (INU) located rigidly on the rear of the shock-mounted central boom structure in the nose. This provides more cabin space in the Queen Air, as well as more accurate air motion measurements. The system performed excellently in Connell's Mountain Air Flow project. A second heated (de-iced) gust probe assembly has been installed on the Electra and will be used in the Summer Monsoon Experiment (MONEX). For the earlier CYCLES project, which also was flown in icing conditions, an alternate Rosemount de-iced five-port pressure gust probe system was installed on the Electra noseboom. This system provided lower frequency turbulence data for turbulent flux and mass flow analysis. Hot-wire anemometers were flown on the Queen Airs in support of Project Phoenix, a boundary layer experiment at the newly created Boulder Atmospheric Observatory (BAO), and on the Electra during the Joint Air-Sea Interaction Experiment (JASIN). These anemometers are capable of producing turbulence data to scales of a few centimeters. Thus it is evident that air motion sensing is at the state of the art on the Queen Air and Electra aircraft. For the Sabreliner, RAF plans to improve a pressure-transducer system to provide more accurate and reliable measurements of low-frequency turbulence (a few Hz), mass flux, and winds.

2. A new Lyman-alpha humidiometer was developed in cooperation with RSF. This unit is designed to operate exposed to the air stream and mounted at the tip of the nose booms on either the Queen Air or Electra. The sensor is de-iced; the entire system has been specifically designed for an aircraft environment and for ease of flight operations and servicing. Previous models were mounted on the fuselage or had a ducted air flow probe. The new device has been installed on the Electra for Summer MONEX. Performance tests of the instrument look extremely good.

3. A high-altitude (0-100,000 ft) precision radar altimeter has been installed on the Sabreliner and used for the Shapiro Jet Stream project. This unit worked successfully and provided Shapiro with the additional data needed to determine the pressure gradients within the jet stream. A second radar altimeter unit has been installed on the Electra for the Summer MONEX project. These radar altimeter units are of an older design and have been obtained in used condition at low initial cost. The units are an important addition to RAF's instrumentation; however, their reliability and precision must be evaluated in an operational mode.

4. A surplus Research Systems Facility minicomputer (NOVA) data processing system, with components similar to those of the Electra Data Management System (EDMS), was acquired by RAF to provide a ground station for program development of the Electra on-board NOVA EDMS computer system. This has enabled software programs to be written while the Electra was in the field. This system may provide the essential components necessary for the development of a mobile quick-look ground data processing system as well. However, cost and performance comparisons must be made with more modern, readily available systems.

5. Two Acid Precipitation Experiments (APEX) were supported this year. For these air chemistry studies, additional venturies were added to Queen Air N306D to provide increased sampling flows.

6. In the coming year, RAF will continue to concentrate on improving the RAF capability in cloud physics measurements. Improvement or redesign of the particle probe data buffer linking the PMS probes to the ARIS IV data systems is required to accept the high data rates of FSSP and ASAS probes. This need became clear during Braham's Lake Michigan cloud physics program when the existing buffer failed to pass the data properly during high concentrations of particles (i.e., for the higher data rates). Reliability of the Cannon camera system has to be improved for operation with full magazines of film in cold temperatures. Responsibility for this system has been passed to RAF during the past year. Presently, RAF has only

one-dimensional PMS hydrometeor cloud and precipitation probes, but is pursuing (jointly with NCAR's Convective Storms Division) the acquisition and data interfacing of a two-dimensional particle probe.

7. The ARIS IV data system, developed jointly with the Research Systems Facility, has been installed on the Sabreliner during the year. This system is now undergoing a shakedown test of field operation on all the twin-engine aircraft. Some problems have been isolated and minor design changes are anticipated to increase reliability and to improve the "human-engineering" of the system for operation under turbulent flight conditions.

Support Operations

During the period 1 April 1978 through 31 March 1979, RAF flew missions in support of 25 field experiments. Of these, eight were flown by Queen Air N304D, seven by Queen Air N306D, five by the Sabreliner, and five by the Electra.

In brief review, Queen Air N304D flew a total of 259 hours in support of research, all within the continental United States. Queen Air N306D flew in support of one less project; however, those projects were of somewhat longer duration, for a total of 330 research flight hours. The Sabreliner flew 209 research hours; two of the five programs in which it participated, both air chemistry programs, were outside the continental United States (Greenland and Panama). The Electra was heavily committed during the year in support of four major research programs and one engineering test program for a total of 515 hours. GAMETAG (Global Atmospheric Measurements Experiment on Tropospheric Aerosols and Gases), an atmospheric chemistry project, required Electra continental and oceanic flight routes from the Canadian Arctic to south of New Zealand. JASIN (Joint Air-Sea Interaction Experiment), an extensive boundary layer project, was flown over the North Atlantic Ocean northwest of Scotland. The Electra aircraft participated in the Winter Monsoon Experiment (Winter MONEX) with the primary base at Kuala Lumpur, Malaysia, and will support Summer MONEX extensively from Bombay and Calcutta, India, in summer 1979. Additionally, the Electra supported the University of Washington CYCLES program (Cyclonic Extratropical Storms), a Pacific storm structure and dynamics study off the coast of Washington in March 1979. The small amount of time the Electra was available and the paucity of storms for study somewhat limited the value of the Electra support on this program. The number of large-scale international programs in which the Electra participated resulted in its flying approximately double the number of hours normally programmed for this aircraft.

To aid in analyzing aircraft usage, we can define four broad categories of science that require aircraft support. The four categories--air chemistry, boundary layer turbulence, cloud physics, and mesoscale storms--are chosen to best identify the types of research in which the RAF aircraft participated during the past twelve months. Frequently the categories overlap in a given project. Of the 25 research projects supported, eight were air chemistry programs and eight were boundary layer turbulence programs. In addition, at least four other projects carried air chemists as adjunct investigators. Five programs were supported in cloud physics and two mesoscale storm programs were supported. The air chemistry projects (407 flying hours) and boundary layer turbulence projects (406.5 flying hours) accounted for well over one half (62%) of the total number of flying hours flown in support of research during the past twelve months.

The Data Management Group (DMG) of RAF provided data processing support for 32 different projects during the past twelve months, including production runs, quick-look processing for projects in the field, and spectral analysis for engineering tests. The large volume of data throughput left few resources available for the development of new software. Some effort was put into development of a third-generation digital data processor, General Processor 2 (GENPRO 2). This processor, when complete, will greatly improve the efficiency of the data processing effort of the DMG. Unfortunately, at current staffing levels this software program will not be operational before 1981.

The list of users at the end of the ATD report summarizes the 25 research projects flown during the reporting period. The following is a short summary of various research programs supported by RAF during the past twelve months.

1. Dr. Marvin Wilkening of the New Mexico Institute of Mining and Technology at Socorro, New Mexico, used Queen Air N304D in his study of dry mountain-induced convection in New Mexico. The aircraft was equipped with standard state parameter sensors plus a gust probe and inertial platform, since vertical air motion and turbulent flux measurements were required. The program was quite successful, with no significant problems encountered.

2. The Convective Storms Division of NCAR, in its continuing investigation of the formation of severe hail-producing thunderstorms, used both Queen Air aircraft during the summer of 1978. National Hail Research Experiment measurements in the past have suggested that recirculation is important in precipitation and hail growth in convective clouds. The 1978 project, under the direction of Charles Knight of NCAR's Convective Storms Division, sought to resolve existing

uncertainties of growth during recirculation or in weak or pre-existing turrets. The experimental program and accompanying analysis of data from the aircraft and ground instruments is leading to an understanding of precipitation growth mechanisms in convective storms.

3. The Phoenix program was conducted at the Boulder Atmospheric Observatory with lead scientist Peter Hildebrand of Illinois State Water Survey (FOF Scientific Visitor) in conjunction with FOF and NOAA. A large array of instruments, remote and in-situ, were used to make the most complete field observations ever of the local boundary layer. The gust probe-equipped Queen Air was used, providing the three components of motion, mean flow, and the turbulent fluxes of heat, moisture, and momentum.

4. Dr. Peter Lester of California State University at San Jose used the Queen Air N306D in his study of mass and energy transport by internal gravity waves. The research focused on quantifying the transport of mass and energy through hydrostatically stable atmospheric layers. The aircraft was used to measure state parameters through vertical cross sections, and carried instruments to measure particulate concentrations and ozone content. Although problems occurred which degraded the quality of the mean winds somewhat, computation of turbulent flux data, which was the most important portion of the experiment, was unaffected.

5. Dr. Herman Sievering of Governor's State University in Illinois, continuing a study of the loading of Lake Michigan from airborne particulate deposition, employed Queen Air N306D to measure state parameters, air motion, and aerosol concentration through flights over the lake. Several ARIS IV data system problems were encountered and repaired in the field. Dr. Sievering, in a letter to the RAF Manager, gave special praise to the outstanding support he received from RAF in making the project a success.

6. Drs. Heidt and Mankin of NCAR's Atmospheric Quality Division used the Sabreliner with great success to obtain measurements of stratospheric trace gases using both gas chromatography and infrared spectroscopy techniques. The two methods yielded measurements on thirteen different species and resulted in a unique data set. The experiment flights extended from northern Canada to Panama. All systems operated as planned.

7. The Electra participated in Project JASIN (Joint Air-Sea Interaction Experiment), an extensive boundary layer project flown off the west coast of Scotland during the summer of 1978. This project, originally proposed by the British in 1966, involved research aircraft from three nations and surface vessels from four nations.

The lead scientist for the U.S. aircraft participation was Joost Businger of the University of Washington. The aircraft data were necessary for a study of the vertical heat and moisture fluxes and their role in creating and maintaining the thermodynamic structure of the atmospheric boundary layer. A better understanding of the dynamic structure of the oceanic boundary layer, including the momentum balance, has evolved. An undetected glitch in the EDMS data recording during the program was found during data processing following the field phase. This at first made the experimental results questionable; however, through almost heroic efforts the RAF data management team determined the nature of the glitch and recovered the proper data format.

8. The most extensive air chemistry program of the period was flown on the Electra. This program, planned to last for seven years, was titled Global Atmospheric Measurements Experiment on Tropospheric Aerosols and Gases (GAMETAG). Douglas Davis of the Georgia Institute of Technology served as chairman of a committee of scientists. Some 23 investigators participated in the NSF-sponsored program. The flight tracks for GAMETAG covered the latitudes lying between the Canadian Arctic (70°N) and a leg south of New Zealand to sample polar tropical and transition air masses.

9. The Acid Precipitation Experiment (APEX) is designed to explore the air chemistry involved in the formation of acid precipitation on a regional basis. Allan Lazrus of the NCAR Air Quality Division is the lead scientist on the experiment. APEX represents the first concerted effort to make simultaneous measurements of atmospheric acids and bases, their precursors, products, and reactants responsible for their conversions. The 1978 APEX mission yielded vertical profiles of sulfuric acid aerosol and nitric acid vapor. It was found that H_2SO_4 tends to form at greater distances from source areas than does HNO_3. Of great interest was the fact that nitrogen dioxide, which can be rapidly oxidized to HNO_3, was found to be five to 50 times more concentrated than HNO_3 vapor. Ammonia vapor, of which there are very few measurements, was found in equal concentrations in both the Great Plains region and the Northwest. The aircraft measurement program is expected to continue through 1979 and 1980 and perhaps longer.

10. The Severe Environmental Storm and Mesoscale Experiment (Little SESAME), the aircraft program under John McCarthy of the University of Oklahoma, investigated the kinematic and thermodynamic structure of the thunderstorm environment at low and mid-levels in central Oklahoma. This major study employs multiple ground doppler

radar, surface networks, etc. in addition to aircraft for the analysis of gust fronts and tornado cyclone structure, mid-level mixing properties, and the structure of the drylines. RAF's Queen Air and Sabreliner are used in this field program, which began in Spring 1979.

11. Dr. James Connell of the Battelle Pacific Northwest Laboratories used Queen Air N304D for measurements within his Mesoscale Mountain Airflow and Boundary Layer Dynamics experiment. This was the first program to use the new gust probe on this aircraft. All instrumentation worked very well during the project. The ARIS IV performed perfectly during test flights and throughout the program.

12. Dr. Josef Podzimek's Sea Salt Nuclei project employed a Queen Air to study the evolution and transformation of the condensation nuclei spectrum in the boundary layer above the seashore where maritime and continental aerosols interact. Weather conditions were marginal for the type of data Dr. Podzimek wished to acquire. A major instrumentation problem was that the RAF-designed particle spectrometer data buffer could not accept the data rates supplied by the Active Scattering Aerosol Spectrometer (ASAS). This problem must be rectified prior to future programs requiring high-rate particle spectrometer data input.

13. Dr. Roscoe Braham of the University of Chicago continued his study of the physics and dynamics of winter snowstorms over the Lake Michigan area. Among his interests are the physics of nucleation and snow growth in winter clouds, and the lake-air heat, moisture, and momentum diffusion and transport. While the instrumentation in general performed well, a serious problem was identified in the NCAR-designed particle spectrometer buffer system. While the system would accept slow-rate data, it did not accept high data rates from sensors such as the Forward Scattering Spectrometer Probe (FSSP). This problem has cast doubt on the validity of high-rate data buffered through this system to date.

14. The Sabreliner was used twice during the past twelve months by Dr. Melvyn Shapiro of NCAR's Atmospheric Quality Division to continue his research into the jetstream structure, associated frontal systems, and stratosphere-troposphere exchange. A high-altitude (0-100,000 ft) radar altimeter was installed on the aircraft for the second of the two projects, and worked very well. Dr. Shapiro, in a letter to RAF, was very pleased with the support provided.

15. Drs. Leroy Heidt and William Mankin of NCAR's Air Quality Division developed a long-path absorption cell for use in observing local concentrations of trace gases by spectroscopic means. The temporal resolution of the system was approximately ten seconds. The Sabreliner, with its high altitude capability, was particularly well

suited as an airborne platform from which to test this system. The flight tests were conducted on schedule with no problems encountered.

16. The Sabreliner was employed by Dr. Gerald Grams of the Georgia Institute of Technology in his Stratospheric Aerosol Validation Experiment (SAVE) to obtain data on the optical properties of stratospheric aerosol particles. The data were used in "ground truth" measurements to verify the Stratospheric Aerosol Measurement (SAM II) sensor on the NIMBUS-G satellite. The program operated very successfully, and in a letter to the ATD Director, Dr. M. P. McCormick, NASA SAM II Science Team Leader, praised the exceptional research support provided by RAF.

17. The Electra participated in the Winter Monsoon Experiment (MONEX) in Malaysia, providing excellent instrumentation support to all on-board scientists. The lead scientists on the Electra were Drs. Robert and Joanne Simpson and Dr. Charles Wagner of the University of Virginia and Drs. Chang and Webster of the Naval Postgraduate School. Any problems encountered were due primarily to inadequate communication between the scientists and the Electra crew. This will be resolved prior to the Summer MONEX field project.

18. Dr. Peter Hobbs of the University of Washington continued his study of extra-tropical cyclonic storms, this year using the Electra aircraft. The program seeks to gain knowledge concerning the mesoscale organization of precipitation and the microphysic processes by which precipitation particles are produced in these storms. The Electra was used because of its long endurance and its ability to fly in known icing conditions. Although data system problems forced the aircraft to return to Jeffco for repair, it was back on station within 72 hours and provided excellent support to Dr. Hobb's program.

Summary

This report has given some indication of the tremendous scope of scientific research supported by the Research Aviation Facility. 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 scientific program needs because of limits on the number of flight hours and on its instrumentation capabilities. The needs of the 1980 decade for research observations are enormous. 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 have to make significant changes in aircraft types, instrumentation, and staff ability to support university and NCAR investigations. These are needs which somehow must be met despite limiting factors of budget and personnel.

Aircraft	Principal Investigator	Institution	Experiment Location	Hours Flown
Queen Air	Wilkening	New Mexico Institute of Mining & Technology	New Mexico	37.5
Queen Air	Knight	NCAR	Colorado	55.4
Queen Air	Hildebrand	Illinois State Water Survey	Colorado	44.7
Queen Air	Lester	California State	California	47.3
Queen Air	Sievering	Governors State University	Illinois	51.0
Queen Air	Knight	NCAR	Colorado	38.7
Queen Air	Hildebrand	Illinois State Water Survey	Colorado	54.3
Sabreliner	Shapiro/Cadle	NCAR	Western U.S.	46.7
Sabreliner	Mankin/Heidt	NCAR	Northern U.S. Panama	84.8
Electra	Businger	University of Washington	Scotland	130.3
Electra	Davis	Georgia Institute of Technology	South Pacific, Canada	131.3
Queen Air	Hildebrand	Illinois State Water Survey	Colorado	0.5
Queen Air	Lazrus	NCAR	Central & Eastern U.S.	74.0
Queen Air	McCarthy	University of Oklahoma	Oklahoma	4.5
Queen Air	RAF(Noseboom)	NCAR	Colorado	1.0
Queen Air	Connell	Battelle Pacific Northwest Labs.	Idaho	40.9
Queen Air	Lazrus	NCAR	Central & Eastern U.S.	10.9
Queen Air	Podzimek	Univ.of Missouri	Texas	37.6

Aircraft	Principal Investigator	Institution	Experiment Location	Hours Flown
Queen Air	Braham	University of Chicago	Michigan	89.7
Sabreliner	Shapiro	NCAR	Western & Eastern U.S.	35.1
Sabreliner	Mankin	NCAR	Colorado	4.6
Sabreliner	Grams	Georgia Institute of Technology	Greenland	37.3
Electra	Simpson	University of Virginia	Malaysia	186.5
Electra	Saum	NCAR	Colorado & Florida	19.3
Electra	Hobbs	University of Washington	Washington	47.7

COMPUTING FACILITY

Mission and Goals of the Computing Facility

The mission of the NCAR Computing Facility (CF) is to provide computing services to the national atmospheric research community. This includes computing support to large national and international programs involving university and NCAR scientists, joint projects between NCAR and university scientists, and independent research projects by NCAR or university scientists. The computing service emphasizes the capability of running large simulation models and processing very large data sets generated by data collection systems or numerical models. It also provides significant archiving capabilities for these data sets and graphical display facilities to aid the scientist in his comprehension and presentation of scientific results.

To meet these goals, the community requires very high-speed computers, software designed to efficiently run large models, high-speed transmission of large data sets, and large storage capacities for these data sets. It also needs remote job entry facilities for off-site users, tools and methods for the development of large programs, sophisticated consulting support for the users, and a variety of services to help a large number of users with diverse requirements.

The CF is organized into four sections and various staff functions reporting to the CF Manager. The User Services Section is responsible for offering consulting services for users, providing information on all services, policies, and operational procedures of the facility, providing software libraries of numerical and utility tools, and supporting special software products including ATD software support.

The Data Support Section has the goal of establishing, maintaining, and distributing high-quality meteorological and climate data sets to the atmospheric science community. It is also NCAR's interface to national and international groups planning the archiving of climate data.

The Systems Section maintains all operating systems and language compilers within the central CF. It develops the necessary interface (network) software between elements of the NCAR system. Where essential for maximum utilization, the section designs, develops, tests, and documents the appropriate system software.

The Operations Section is responsible for efficient and effective operation and maintenance of the central CF. It also provides digital data library services, use statistics, microfilm/microfiche and movie capabilities, and unit record and digitizer services.

Because efficient use of the very high-speed CRAY-1 and CDC 7600 computers is so important, the Advanced Methods Group is responsible for informing users and CF programming staff about advanced techniques in numerical analysis, data management, and other areas of computer science. Particular emphasis has been placed upon Poisson solvers, spectral methods, and elliptic partial differential equation solvers.

The administrator is responsible for managing the CF budget and its management reporting system, engaging in short- and long-term functions. The Clerical Support Group provides clerical services to the approximately 100 members of the CF.

Strategies

The atmospheric sciences have entered a period in which cooperative field experiments, designed and conducted by several agencies, are returning huge quantities of data that cover every scale from a single convective cloud system to the entire globe. To handle this increasing flow of observational data, as well as the complex computations of modern numerical models of atmospheric and oceanographic processes, powerful high-speed computers are essential.

For the past several years, the NCAR CF has acquired and implemented computer hardware and software that are responsive to the needs of scientific researchers in accomplishing these larger computing tasks. The CF's recognized mission is to provide effective computing power for developing and running large numerical models, and to enable the processing of very large data sets. The facility provides these capabilities through its system of large computers and through a remote job entry (RJE) system. Also, as computational research tools have grown more complex, the CF has provided the more sophisticated consulting support needed by its users. The facility now represents a unique resource for researchers in the atmospheric science community.

Major components of the CF system are a CRAY-1 computer, a Control Data 7600 computer, an Ampex TeraBit Memory System (TMS-4) with a 40 billion byte on-line storage capacity, a MODCOMP computer (used for RJE), and a "front end" system consisting of smaller interactive computers at various NCAR locations. A network control computer has been acquired recently to handle communications between the computers in the NCAR system.

The CRAY-1 computer, acquired last year, is well suited to run large numerical models; in its first year of operation it has proved to be extremely reliable. Substantial advances in modeling have been made possible in several scientific areas using the CRAY-1.

An example of the modeling efforts is the development of severe storm models. Cumulonimbus or severe storm models have been developed by groups at Colorado State University (William Cotton), the University of Hawaii (Tsutomu Takahashi), the University of Illinois (Robert Wilhelmson), and at NCAR by Joseph Klemp (Mesoscale Research Section) and by Terry Clark and William Hall (Convective Storms Divison). Many of these models are built from the same basic software modules using an advanced language called FLOTRAN. A set of supporting routines called FLOW has been developed to manage the data flow and simplify the "bookkeeping" required of the scientist.

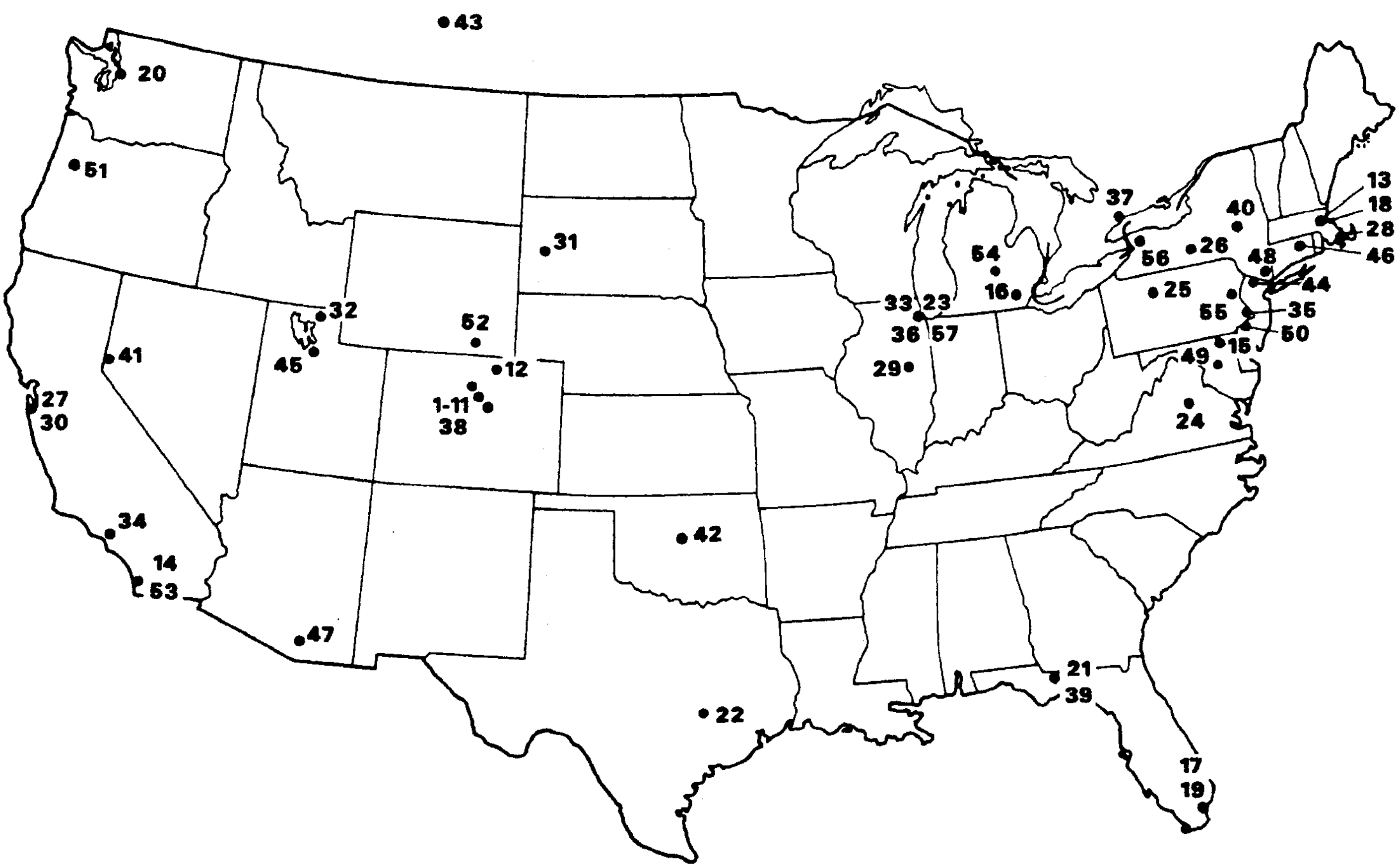
In addition to performing high-speed calculations (sometimes called "number crunching") on large-scale models on the CRAY-1, the CF system has also serviced large data-processing jobs using the Control Data 7600 and the TMS-4. For example, this year Julius London of the University of Colorado processed approximately 1,200 magnetic tapes from an Orbiting Geophysical Observatory satellite (OGO-4). The 7600 was also used for processing most of the data from an Orbiting Solar Observatory satellite (OSO-8); project scientists included Oran White of the High Altitude Observatory and Charles Barth of the Laboratory for Atmospheric and Space Physics at the University of Colorado. The CF prepared a subset of information collected by a Stationary Meteorological Satellite (SMS-1) during the Atlantic Tropical Experiment of the Global Atmospheric Research Program (GATE). The 84 GATE data tapes (which were culled from nearly 2,400 tapes in all) are being examined by Thomas Vonder Haar and Eric Smith of Colorado State University. Considerable amounts of data from the NCAR aircraft were processed.

Accomplishments of the Past Year

During FY 1978, the CF served 500 users; half of these were university users working on individual projects or engaged in joint projects with NCAR scientists. Some 450,000 jobs were run on the Control Data 7600 computer and nearly 60,000 jobs were run on the CRAY-1 computer which became operational in December 1977. Sixty-two universities accessed the NCAR computers from remote locations using remote job entry (RJE) terminals (see accompanying map). This RJE system for university and remote users has been a key element in the growth of university usage of the NCAR CF over the past year. Such use now makes up 40 percent of the job load. By the end of FY 1978, there were approximately 200 remote users of the CRAY-1.

As part of a multi-year augmentation program, NCAR is gradually acquiring a distributed front end system of interactive computers and peripheral equipment. When combined with the larger computers and the RJE computer, it will form what is called the NCAR network. The NCAR network is aimed at facilitating both local and remote use. The front end computers will provide an interface between the user and the large CRAY-1 and Control Data 7600 computers.

NCAR REMOTE BATCH TERMINAL NETWORK



1 Boulder, CO – # 1
2 Boulder, CO – # 2
3 Boulder, CO – # 3
4 Boulder, CO – # 4
5 Boulder, CO – # 5
6 Boulder, CO – # 6
7 Boulder, CO – # 8
8 Boulder, CO – # 9
9 Boulder, CO – # 10
10 Boulder, CO – # 11
11 Boulder, CO – # 12
12 Ft. Collins, CO – CSU (2)
13 Cambridge, MA – MIT
14 La Jolla, CA – Scripps Institute of Oceanography
15 Baltimore, MD, – Johns Hopkins
16 Ann Arbor, MI – Univ. of Michigan
17 Miami, FL – Univ. of Miami
18 Cambridge, MA – Harvard Univ.
19 Dania, FL – Univ. of Miami
20 Seattle, WA – Univ. of Washington
21 Tallahassee, FL – Florida State Univ.
22 College Station, TX – Texas A&M Univ. (2)
23 Chicago, IL – Univ. of Chicago
24 Charlottesville, VA – Univ. of Virginia
25 University Park, PA – Penn State
26 Ithaca, NY – Cornell Univ.
27 Stanford, CA – Stanford Univ.
28 Woods Hole, MA – Woods Hole Institute (2)
29 Urbana, IL – Univ. of Illinois (2)
30 Moffet Field, CA – NASA Ames Research Center
31 Rapid City, SD – S.D. School of Mines
32 Logan, UT – Utah State Univ.
33 Argonne, IL – Argonne National Lab
34 Pasadena, CA – Jet Propulsion Lab
35 Philadelphia, PA,– Drexel Univ.
36 Evanston, IL – Northwestern Univ.
37 Toronto, Ontario – Univ. of Toronto
38 Boulder, CO – Univ. of Colorado (4)
39 Tallahassee, FL – Florida A&M Univ.
40 Albany, NY – SUNY
41 Reno, NV – Desert Research Institute
42 Norman, OK – Univ. of Oklahoma
43 Saskatoon, Saskatchewan – Univ. of Saskatchewan
44 New Brunswick, NJ – Rutgers Univ.
45 Salt Lake City, UT – Univ. of Utah
46 Hartford, CT – Center for Environment & Man
47 Tucson, AZ – Univ. of Arizona
48 New York, NY – SUNY
49 College Park, MD – Univ. of Maryland
50 Newark, DE – Univ. of Delaware
51 Corvallis, OR – Oregon State Univ.
52 Laramie, WY –Univ. of Wyoming
53 La Jolla, CA – Univ. of California at San Diego
54 East Lansing, MI – Michigan State Univ.
55 Bethlehem, PA – Lehigh Univ.
56 Niagara University, NY – Niagara Univ.
57 Park Forest South, IL – Govenors State Univ.

INACTIVE SITES

Atlanta University
Bureau of Reclamation
UCLA # 1
UCLA # 2
Univ. of Colorado Medical Center
Columbia University
Harvard # 2
Nation Meteorological Center
Tentime
Univ. of Texas (Austin)
Univ. of Wisconsin

One of the front end devices acquired last year was a new computer output microfilm (COM) graphic device (manufactured by Dicomed Corp. of Minneapolis) to improve the quality of graphics produced at NCAR. The Dicomed produces text, graphics, and CRAY-scale pictures. It has a resolution approximately ten times finer than is available on the graphics plotters it is replacing. The COM device will be especially useful to scientists for presenting visual images of digital data and for storing (archiving) these data in compact form for retrieval at a later time (as will be done, for example, for satellite images from the Solar Maximum Mission in 1979).

Another component on the network is a UNIX system accepted in March 1979. CF programmers, administrators, and clerical staff will start to use these interactive computers for program preparation, debugging, word processing, and management reporting for the facility. Other components on the NCAR network will include a Systems Engineering Laboratories 32/35 computer to be used by the Atmospheric Quality Division for processing data from the Limb Infrared Monitor of the Stratosphere (LIMS) aboard Nimbus 7 and a Digital Equipment Corporation PDP 11/70 that will handle local computing chores for the High Altitude Observatory.

In summary, the nature of large-scale computing has been changing rapidly. In order to serve the research needs of users, it has become necessary to build a system architecture constituting a system network from a variety of specialized subsystems. Planning for the CF has emphasized the special needs of large-scale modeling research and of data processing jobs of increasing magnitude together with the need to broaden computer access through RJE and front end systems.

NAME	AFFILIATION	START VISIT	END VISIT	PROJECT
ABBOTT, RICHARD	INDEPENDENT - BOULDER			36341001
ACKERMAN, BERNICE	ILLINOIS WATER SURVEY			35481005
ADAMS, JEANNE	SUMMER FELLOWSHIP			36410000
ADAMS, JEANNE	SUMMER FELLOWSHIP			36410001
ADAMS, JEANNE	SUMMER FELLOWSHIP			36410002
ADAMS, JEANNE	SUMMER FELLOWSHIP			36410003
ADAMS, JEANNE	SUMMER FELLOWSHIP			36410004
ADAMS, JEANNE	SUMMER FELLOWSHIP			36410005
ADAMS, JEANNE	SUMMER FELLOWSHIP			36410006
ADAMS, JEANNE	SUMMER FELLOWSHIP			36410007
ALEKSANDROV, V.V.	SUMMER FELLOWSHIP			36411000
ALPERT, JORDAN	UNIVERSITY OF MICHIGAN			5013600
ALPERT, JORDAN	UNIVERSITY OF MIAMI-MIAMI			35191002
AMES, WILLIAM	UNIVERSITY OF MICHIGAN			35201023
ASTLING, ELFORD	UNIVERSITY OF UTAH	780517	780519	35351005
AYAD, SAMIR	COLORADO STATE UNIVERSITY			35081050
AYRES, THOMAS	UNIVERSITY OF COLORADO			35071058
BABOOLAL, LAL	UCLA	781031	781130	35681002
BAER, F.	UNIVERSITY OF MICHIGAN			35201006
BAKER, GARY	FLORIDA UNIVERSITY	790122	790131	35931001
BANNON, PETER	UNIVERSITY OF COLORADO			35071052
BARTLEIN, DICK	UNIVERSITY OF VIRGINIA	790226	790301	35691005
BASRI, GIBOR S.	UNIVERSITY OF COLORADO			35071044
BEARDSLEY, ROBERT C.	MASSACHUSETTS INST. OF TECH.			35171011
BELL, DENNIS	UNIVERSITY OF WASHINGTON			35371013
BENTON, NED	UNIVERSITY OF COLORADO			35071054
BERG, LOREN	UNIVERSITY OF WYOMING			35711013
BERNARDO, WILLIAM	UNIVERSITY OF MICHIGAN			35201025
BERNHADT, PAUL	STANFORD	780623	780715	35661008
BERNHARDT, PAUL A.	STANFORD			35661014
BESSEY, R.J.	UNIVERSITY OF WYOMING	780721	780721	35711010
BESSEY, ROBERT	UNIVERSITY OF WYOMING	781227	781229	35711010
BLAKE, DONNA	FLORIDA STATE UNIVERSITY			35111025
BLANCHAR, DAVID	COLORADO STATE UNIVERSITY			35081042
BLANCHAR, DAVID	COLORADO STATE UNIVERSITY			35081045
BOHNE, ALAN R.	UNIVERSITY OF CHICAGO			35061017
BOUDRA, DOUG	UNIVERSITY OF MIAMI-MIAMI	780731	780915	35191003
BOUDRA, DOUGLAS	UNIVERSITY OF MIAMI-MIAMI			35191005
BOVILLE, BYRON	UNIVERSITY OF WASHINGTON			35371007
BOWSER, RON	HARVARD UNIVERSITY			35121013
BOYD, JOHN P.	UNIVERSITY OF MICHIGAN			35201018
BRAHAM, JR., ROSCOE	UNIVERSITY OF CHICAGO			35061000
BRANTSTATOR, GRANT	PURDUE UNIVERSITY			5013532
BRIGGS, PAUL	COLORADO STATE UNIVERSITY	781204	791231	35081048
BRINCKO, ALEX	NOVA UNIVERSITY	780828	780915	35571001
BRINCKO, ALEX	NOVA UNIVERSITY	780701	780708	35571001
BRINGI, V.N.	OHIO STATE UNIVERSITY	780621	780710	36091000
BROWNING, GERALD	NEW YORK UNIVERSITY			43613019
BUCY, RICHARD	UNIV OF SOUTHERN CALIF.			36381000
BUILTA,ARTHUR	SCIENCE APPLICATIONS, INC.			36481000

BURTON, GRANT	COLORADO STATE UNIVERSITY			35081051
BURTON, GRANT	COLORADO STATE UNIVERSITY			35081052
BUZZELL, EDWIN	COLORADO STATE UNIVERSITY			35081057
CANFIELD, R.	UNIV. OF CALIFORNIA-SAN DIEGO			36011003
CHALLA, MALAKONDAYYA	FLORIDA STATE UNIVERSITY			35111030
CHEN, MIKE	IOWA STATE UNIVERSITY	790223	790306	35461003
CHEN, TSING-CHANG	IOWA STATE UNIVERSITY			35461004
CHIPMAN, ERIC	UNIVERSITY OF COLORADO			35071000
CHOU, SHIH-HUNG	STATE UNIVERSITY OF NEW YORK	780602	780828	35251002
CHU, JAN-HWA	UNIVERSITY OF WISCONSIN			35381006
CICERONI, RALPH J.	UNIVERSITY OF MICHIGAN			35201010
COAKLEY, STELLA	DENVER UNIVERSITY			35101015
COLINI, STELLA	UNIVERSITY OF UTAH	781218	781223	35351002
CONTI, PETER S.	UNIVERSITY OF COLORADO			35071025
COOK, GARY	DENVER UNIVERSITY			35101011
CORONA, THOMAS	COLORADO STATE UNIVERSITY			35081056
COTTON, WILLIAM R.	COLORADO STATE UNIVERSITY			71213003
COWLEY, ANN	PURDUE UNIVERSITY			35291003
COX, STEPHEN	COLORADO STATE UNIVERSITY			35081030
CRAVENS, THOMAS	UNIVERSITY OF MICHIGAN	780806	780810	35201021
CRYSTAL, THOMAS	STANFORD			35661006
CURRY, JAMES	MASSACHUSETTS INST. OF TECH.	781208	781216	35171018
DANIELSEN, EDWIN	OREGON STATE UNIVERSITY			35271006
DAS, P.	TEXAS A+M UNIVERSITY	780821	780828	35311024
DAVIS, JOHN	COLORADO STATE UNIVERSITY			35081039
DAVIS, JOHN	COLORADO STATE UNIVERSITY			35081044
DEAVEN, DENNIS G.	DENVER UNIVERSITY			12053039
DEININGER, RICHARD	STATE UNIVERSITY OF NEW YORK	780424	780515	35251004
DELUISI, JOHN	NOAA			35561000
DENAVIT, J.	NORTHWESTERN UNIVERSITY			36101000
DENAVIT, J.	NORTHWESTERN UNIVERSITY			36101001
DERICKSON, RUSS	COLORADO STATE UNIVERSITY			35081005
DICKINSON, ROBERT				3013016
DODD, GREGORY	UNIVERSITY OF UTAH	780906	780908	35351006
DOLSKE, DON	GOVERNORS STATE COLLEGE			36401000
DOOLEN, GARY	TEXAS A+M UNIVERSITY			35311013
DWIVIDI, PARMESH	DENVER UNIVERSITY			35101016
DWIVIDI, PARMESH	DENVER UNIVERSITY			35101018
DWIVIDI, PARMESH	DENVER UNIVERSITY			35101020
ECCLES, MARGARET	METEOROLOGY TECHNOLOGY ENTER.			33223000
ECCLES, MARGARET	UNIVERSITY OF COLORADO			35071074
ECCLES, MARGARET	UNIVERSITY OF COLORADO			35071076
EDDY, AMOS	UNIVERSITY OF OKLAHOMA	780922	780925	35261001
EDMON, HAROLD, JR.	UNIVERSITY OF WASHINGTON			35371012
EMSLIE, GORDON	HARVARD UNIVERSITY			82233023
ESBENSEN, STEVEN	OREGON STATE UNIVERSITY	790324	790327	35271009
ESPOSITO, LARRY	UNIVERSITY OF COLORADO			35071059
ESTOQUE, M.	UNIVERSITY OF MIAMI-C. GABLES			35501011
ESTOQUE, MARIANO	UNIVERSITY OF MIAMI-C. GABLES	780703	780731	35501008
EVERHART, EDGAR	DENVER UNIVERSITY			35101010
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	781102	781106	35641008
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	780407	780417	35641008

FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	790201	790208	35641009
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	780706	780711	35641009
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	790307	790315	35641011
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES	780905	780908	35641011
FARLEY, RICHARD	SOUTH DAKOTA SCHOOL OF MINES			35641012
FINDIKAKIS, ANGELOS	STANFORD	780327	780403	35661012
FIORINO, MICHAEL	PENNSYLVANIA STATE UNIVERSITY	781108	781110	35281008
FLEISCH, DAN	RICE UNIVERSITY	780629	780710	36431000
FOO, E-CHIEN	UNIVERSITY OF MIAMI-MIAMI			35191009
FOOTE, BRANT	SOUTH DAKOTA SCHOOL OF MINES			71213005
FRITTS,DAVE	UNIVERSITY OF COLORADO			35071079
GAL-CHEN, TZVI	UNIVERSITY OF TORONTO			35341002
GARY, JOHN	UNIVERSITY OF COLORADO			35071042
GASSMANT, FRITZ	CTR FOR ENVIRONMENT AND MAN	780414	780419	36121001
GATES, LAWRENCE	OREGON STATE UNIVERSITY			35271008
GAYTON, ANN	UNIVERSITY OF WISCONSIN			35381007
GEBBIE, K.				28403023
GELTMAN, SYDNEY	UNIVERSITY OF COLORADO			35071002
GOLDMAN, AHARON	DENVER UNIVERSITY			35101019
GORDON, ROBERT	UNIVERSITY OF MICHIGAN			35201020
GRAY, WILLIAM M.	COLORADO STATE UNIVERSITY			35081014
GROSS, JIM	UNIVERSITY OF MIAMI-C. GABLES	780713	780730	35501012
GUBBINS, DAVID	UCLA			35681001
GUTZLER, DAVID	UNIVERSITY OF WASHINGTON			35371008
HAAGENSON, PHILLIP	GEORGIA TECH			36511000
HAAR, PATRICK	COLORADO STATE UNIVERSITY			35081038
HAFITIZI, BAHMAN	UNIVERSITY OF COLORADO			35071045
HAGAN, DENISE	TEXAS A+M UNIVERSITY	790102	790110	35311006
HAGAN, DENISE	TEXAS A+M UNIVERSITY	780511	780522	35311006
HAGAN, DENISE	TEXAS A+M UNIVERSITY	780413	780415	35311006
HAGAN, DENISE	TEXAS A+M UNIVERSITY	780623	780831	35311006
HAIDVOGEL, DALE	WOODS HOLE OCEANOGRAPHIC INST.			35781010
HAIDVOGEL, DALE	HARVARD UNIVERSITY	790301	790320	35121011
HAIDVOGEL, DALE	HARVARD UNIVERSITY	780624	780703	35121011
HALE, BARBARA	UNIVERSITY OF MISSOURI-ROLLA			33173000
HALE, BARBARA	UNIVERSITY OF MISSOURI-ROLLA			35531000
HANEY, JAMES	ST. LOUIS UNIVERSITY	790203	790208	35301003
HART, JOHN	MASSACHUSETTS INST. OF TECH.			35171012
HASCHKE, DIETER	CTR FOR ENVIRONMENT AND MAN	780414	780419	36121001
HELD, ISAAC M.	HARVARD UNIVERSITY			35121014
HELSDON, JOHN	SOUTH DAKOTA SCHOOL OF MINES	790312	790315	35641011
HENDERSHOTT, M. C.	SCRIPPS INST. OF OCEANOGRAPHY			35631003
HENDERSON, HARRY W.	PENNSYLVANIA STATE UNIVERSITY			35281009
HENOUX, JEAN CLAUDE	OBSERVATOIRE DE PARIS			36421000
HERBERT, FLOYD	UNIVERSITY OF ARIZONA	780525	780531	35021001
HEYMSFIELD, ANDREW	UNIVERSITY OF WYOMING			35711015
HEYMSFIELD, GERALD	UNIVERSITY OF CHICAGO			35061028
HILDEBRAND, PETER	ILLINOIS WATER SURVEY			35481004
HILDEBRAND, PETER	ILLINOIS WATER SURVEY			35481007
HILL, JIM	IOWA STATE UNIVERSITY			35461000
HIPSKIND, STEVE	OREGON STATE UNIVERSITY	780710	780715	35271005
HIRSCH, JOEL	HARVARD UNIVERSITY			35121001

HJELMFELT, MARK	UNIVERSITY OF CHICAGO			35061025
HOBBS, MAURINE	STATE UNIVERSITY OF NEW YORK			35251003
HOBBS, PETER V.	UNIVERSITY OF WASHINGTON			35371002
HOLLAND, BILL	USSR ACAD OF SCIENCES			9013013
HOLLOWAY, GREG	WOODS HOLE OCEANOGRAPHIC INST.			35781005
HOLLOWAY, GREG	SCRIPPS INST. OF OCEANOGRAPHY			35631006
HOU, ARTHUR	HARVARD UNIVERSITY			35121017
HOUSE, FRED	DREXEL UNIVERSITY			35431002
HSIE, E.Y.	SOUTH DAKOTA SCHOOL OF MINES	780623	780630	35641008
HSIE, EIRH-YU	SOUTH DAKOTA SCHOOL OF MINES	780519	780531	35641009
HSU, CHIH-PING FLOSS	UNIVERSITY OF WASHINGTON			35371004
HUBBARD, LYNN	UNIVERSITY OF CALIFORNIA AT RIVERSIDE	790312	790401	36571000
HUMMER, D. G.	UNIVERSITY OF COLORADO			35071006
INAN, UMRAN	STANFORD	780322	780403	35661007
INAN, UMRAN	STANFORD	781106	781109	35661013
INAN, UMRAN	STANFORD	790323	790405	35661015
JACOBS, CLIFFORD	CTR FOR ENVIRONMENT AND MAN	780414	780419	36121001
JAMART, BRUNO	UNIVERSITY OF WASHINGTON	780508	780515	35371006
JAMESON, ARTHUR	ILLINOIS WATER SURVEY			35481008
JENSEN, CARL	LOS ALAMOS SCIENTIFIC LABORATO			43113014
JOHNSEN, PETER	IOWA STATE UNIVERSITY	790223	790306	35461003
JOHNSON, CLAUDIA	UNIVERSITY OF ILLINOIS	781107	781114	35141011
JOHNSTON, ANDY	NOAA			71413008
JOYCE, GLENN R.	UNIVERSITY OF IOWA			35471000
JULIAN, PAUL R.	UNIVERSITY OF COLORADO			6013703
KAHN, PHILIP	UNIVERSITY OF WASHINGTON	790105	790125	44093025
KAO, S.K.	UNIVERSITY OF UTAH			9033701
KAPLAN, LEWIS	UNIVERSITY OF CHICAGO			9033702
KARWEIT, MICHAEL	JOHNS HOPKINS UNIVERSITY	780814	780820	35151006
KASAHARA, AKIRA	COMMONWEALTH SCI & IND RES ORG			9013005
KASTING, JAMES	UNIVERSITY OF MICHIGAN			35201019
KATTAWAR, GEORGE W.	TEXAS A+M UNIVERSITY			35311027
KEEN, RICHARD	UNIVERSITY OF COLORADO	780317	780417	35071050
KELCH, WALTER	UNIVERSITY OF COLORADO			35071048
KELLEY, MICHAEL	CORNELL UNIVERSITY			35091004
KELLY, GENE	UNIVERSITY OF MIAMI-MIAMI			5013040
KELLY, GRAEME	UNIVERSITY OF WISCONSIN	790212	790216	35381008
KERR, ROBERT	CORNELL UNIVERSITY			35091005
KIDDER, STANLEY	COLORADO STATE UNIVERSITY			35081015
KIERNAN, JAMES	UNIVERSITY OF WYOMING			35711014
KITADA, TOSHIHIRO	UNIVERSITY OF KENTUCKY	780919	781020	35971001
KITTEL, TIMOTHY	UNIV OF CALIFORNIA AT DAVIS	780623	780831	36131001
KITTERMAN, TOM	FLORIDA STATE UNIVERSITY	780531	780831	35111011
KLEIN, RICHARD I.	UNIVERSITY OF COLORADO			35071039
KNOX, STEVE	COLORADO STATE UNIVERSITY			35081025
KNYSH, VASILIY	USSR ACAD OF SCIENCES			36581000
KOPP, FRED	SOUTH DAKOTA SCHOOL OF MINES	781102	781106	35641008
KOPP, FRED	SOUTH DAKOTA SCHOOL OF MINES	780823	780827	35641008
KOPP, FRED	SOUTH DAKOTA SCHOOL OF MINES	790201	790208	35641009
KREISS, OTTO	NEW YORK UNIVERSITY			9013001
KUNASZ, C.V.	UNIVERSITY OF COLORADO			35071053
KURUCZ, ROBERT	SMITHSONIAN	780918	781001	35651000
KURUCZ, ROBERT	SMITHSONIAN	780427	780430	35651000

LABITZKE, KARIN	FREE UNIV. OF BERLIN			36491000
LALAS, DEMETRIUS	WAYNE STATE UNIVERSITY	780710	780831	36311000
LANGER, STEVE	STANFORD	780403	780412	35661005
LANGER, STEVEN	STANFORD	780814	780822	35661005
LEHR, TIMOTHY	UNIVERSITY OF COLORADO			35071056
LEITH, C.	MASSACHUSETTS INST. OF TECH.			9013002
LEVINE, RANDOLPH	HARVARD UNIVERSITY	790220	790222	35121015
LEWIS, FRED	UNIVERSITY OF UTAH	780724	780808	35351006
LEWIS, FRED	UNIVERSITY OF UTAH			35351010
LIN, YUH-LANG	SOUTH DAKOTA SCHOOL OF MINES	790307	790309	35641011
LINDBERG, WILLIAM R.	UNIVERSITY OF WYOMING			35711006
LIOU, KUO-NAN	UNIVERSITY OF UTAH			35351004
LIOU, KUO-NAN	UNIVERSITY OF UTAH			35351008
LITES, BRUCE	UNIVERSITY OF COLORADO			35071061
LIU, M.L.	UNIVERSITY OF UTAH	781204	781220	35351009
LIU, SHAW C.	UNIVERSITY OF MICHIGAN			35201014
LIU, SHAW C.	UNIVERSITY OF COLORADO			35071073
LOESCH, ARTHUR	STATE UNIVERSITY OF NEW YORK	780424	780501	35251004
LONDON, J.	UNIVERSITY OF COLORADO			35071012
LONDON, J.	UNIVERSITY OF COLORADO			35071062
LONGNEEKER, DAVID	DENVER UNIVERSITY	781208	781213	35101008
LUTHER, MARK EDWARD	UNIVERSITY OF NORTH CAROLINA			36461000
MALO, JANE	SOUTH DAKOTA SCHOOL OF MINES	780706	780711	35641009
MARCUS, PHILIP	CORNELL UNIVERSITY			35091008
MARMORINO, GEORGE	FLORIDA STATE UNIVERSITY	790219	790226	35111039
MARTIN, JON	UCLA			35681003
MARTIN, NANCY	SYRACUSE UNIVERSITY			36541000
MARWITZ,JOHN	UNIVERSITY OF WYOMING			35711011
MASON, STEVE	UNIVERSITY OF WYOMING	780428	780430	35711010
MASS, CLIFFORD	UNIVERSITY OF WASHINGTON			35371009
MASSIE, STEVEN T.	UNIVERSITY OF COLORADO			35071078
MCCOMAS, CHARLES HEN	WOODS HOLE OCEANOGRAPHIC INST.	790216	790415	35781008
MCCRAY, RICHARD	UNIVERSITY OF COLORADO			35071034
MCCUMBER, MIKE	UNIVERSITY OF VIRGINIA	781204	781208	35691005
MCKAE, BILL	OREGON STATE UNIVERSITY	780627	780706	35271007
MCKART, TOM	OREGON STATE UNIVERSITY	790324	790327	35271009
MCKEE, THOMAS B.	COLORADO STATE UNIVERSITY			35081029
MCKEEN, STAN	STATE UNIVERSITY OF NEW YORK			35251005
MCLAUGHLIN, JOHN B.	HARVARD UNIVERSITY			35121009
MCNAB, ALAN	PENNSYLVANIA STATE UNIVERSITY			35281011
MCNIDER, RICHARD	UNIVERSITY OF VIRGINIA			35691004
MEDER, H.	UNIVERSITY OF TORONTO			35341003
MEILKE, PAUL	COLORADO STATE UNIVERSITY			71133000
MELVILLE, KEN	UNIV. OF CALIFORNIA-SAN DIEGO	781005	781012	36011004
MERRILL, J. T.	UNIVERSITY OF MIAMI-MIAMI			35191004
MIHALAS, BARBARA	COLORADO STATE UNIVERSITY			35081037
MIHALAS, DIMITRI	UNIVERSITY OF COLORADO			28103024
MILLER, JAY	NOAA			71413007
MILLER, TIM	UNIVERSITY OF ARIZONA	780605	780820	35021005
MOBLEY, ROBERT	OREGON STATE UNIVERSITY			35271010
MOE, KENNETH	NORTHROP UNIVERSITY			36441000
MOORE, DENNIS	NOVA UNIVERSITY	780828	780915	35571001
MOORE, DENNIS	NOVA UNIVERSITY	780701	780708	35571001

MORGAN, JR., GRIFFIT	ILLINOIS WATER SURVEY			35481000
MULDER, PAUL	UNIVERSITY OF WISCONSIN			6013014
NAMIAS, JEROME	SCRIPPS INST. OF OCEANOGRAPHY			35631004
NELSON, CRAIG	UNIV. OF CALIFORNIA-SAN DIEGO	780919	780930	36011002
NELSON, CRAIG	UNIV. OF CALIFORNIA-SAN DIEGO	780616	780630	36011002
NELSON, GEORGE	SAC PEAK			35611000
NEWKIRK, G. A.				82233010
NEWKIRK, G. A.	HARVARD UNIVERSITY			82233013
NGHIEM-PHU, LAN	UNIVERSITY OF MIAMI-MIAMI			35191006
NOERDLINGER, PETER D	CORNELL UNIVERSITY			35091003
NOERDLINGER, PETER D	CORNELL UNIVERSITY			35091007
NOERDLINGER, PETER D	MICHIGAN STATE UNIV.			36331000
OH, Y.	UNIVERSITY OF HAWAII-HONOLULU	781113	781213	35131003
OLSON, DON	TEXAS A+M UNIVERSITY	780623	780831	35311006
ONEIL, STEVE	UNIVERSITY OF COLORADO			35071064
ORSZAG, S. A.	MASSACHUSETTS INST. OF TECH.			35171017
OTT, EDWARD	CORNELL UNIVERSITY			35091002
OTT, EDWARD	CORNELL UNIVERSITY			35091006
OTTO-BLEISNER, BETTE	UNIVERSITY OF WISCONSIN	790203	790302	35381005
OTTO-BLIESNER, BETTE	UNIVERSITY OF WISCONSIN	780818	780827	35381005
OTTO-BLIESNER, BETTE	UNIVERSITY OF WISCONSIN	780610	780617	35381005
OWENS, W. BRECHNER	WOODS HOLE OCEANOGRAPHIC INST.			35781003
OWENS, W. BRECHNER	WOODS HOLE OCEANOGRAPHIC INST.			35781007
PAEGLE, JAN	UNIVERSITY OF UTAH			35351007
PAN, HUA-LU	FLORIDA STATE UNIVERSITY	781208	781231	35111034
PAN, HUA-LU	FLORIDA STATE UNIVERSITY			35111035
PANDOLFO, JOE	CTR FOR ENVIRONMENT AND MAN	780414	780419	36121001
PARK, CHUNG	STANFORD	780703	780710	35661011
PASCH, RICHARD	FLORIDA STATE UNIVERSITY	781215	781231	35111034
PASSARELLI, RICHARD	UNIVERSITY OF CHICAGO			35061024
PAZAN, STEPHEN	SCRIPPS INST. OF OCEANOGRAPHY			35631008
PEFFLEY, MONTY	FLORIDA STATE UNIVERSITY	790219	790226	35111029
PELTIER, W. R.	UNIVERSITY OF TORONTO			35341000
PESKIN, RICHARD	RUTGERS UNIVERSITY			
PESKIN, RICHARD	RUTGERS UNIVERSITY			6013015
PFEFFER, RICHARD	FLORIDA STATE UNIVERSITY			35111037
PITCHFORD, LEANNE	UNIVERSITY OF COLORADO			35071063
PLOOSTER, MYRON	DENVER UNIVERSITY	780607	780610	35101012
PRELLER, RUTH	FLORIDA STATE UNIVERSITY	790219	790226	35111029
PRZYBYLOWICZ, JOHN	STATE UNIVERSITY OF NEW YORK	780705	780831	35251004
RAITT, W. J.	UTAH STATE UNIVERSITY			35361005
RANDALL, JOAN MARY	UNIVERSITY OF TORONTO			35341004
RANDALL, JOAN MARY	UNIVERSITY OF TORONTO			35341005
RAO, G. V.	ST. LOUIS UNIVERSITY			4013016
RAO, G.V.	ST. LOUIS UNIVERSITY	790203	790208	35301003
RASMUSSEN, GARY	DREXEL UNIVERSITY			35431003
RAUCH, HARRY E.	CITY UNIVERSITY OF NEW YORK			36321000
REDDY, J.N.	UNIVERSITY OF OKLAHOMA	780806	780810	35261002
REED, RICHARD	UNIVERSITY OF WASHINGTON			35371005
REES, DAVID	UNIVERSITY OF SYDNEY			28403048
REES, M.H.	UNIVERSITY OF ALASKA	780605	780630	35011000
REINHARDT, WILLIAM	UNIVERSITY OF COLORADO			35071023

REITER, ELMAR R.	COLORADO STATE UNIVERSITY			35081035
REITER, ELMAR R.	COLORADO STATE UNIVERSITY			35081047
RHINES, PETER	WOODS HOLE OCEANOGRAPHIC INST.			35781006
ROADS, JOHN	SCRIPPS INST. OF OCEANOGRAPHY			35631007
ROBLE, R.	UNIVERSITY OF COLORADO			14013002
ROBLE, R.	UNIVERSITY OF ALASKA			14013004
ROBLE, R.	STANFORD			14013005
ROBLE, R.	UNIVERSITY OF MICHIGAN			14013006
ROBLE, R.	STANFORD			13013033
ROBLE, RAY	NATIONAL ASTRONOMY & IONOSPHER			36551000
ROLENS, DARWIN	DENVER UNIVERSITY			35101017
ROTUNNO, RICHARD	UNIVERSITY OF COLORADO			35071051
ROUSSEL-DUPRE, DIANE	UNIVERSITY OF COLORADO			35071069
RUBENSTEIN, DAVID	UNIVERSITY OF COLORADO			35071065
RUDSINSKI, LAWRENCE	ARGONNE NATIONAL LAB	780402	780405	43113012
RUDSINSKI, LAWRENCE	ARGONNE NATIONAL LAB			43513023
RUSCH, DAVE	UNIVERSITY OF MICHIGAN			35201022
RUSTAN, PEDRO	FLORIDA UNIVERSITY	790122	790131	35931001
SAENZ, RICHARD	COLORADO COLLEGE			36351000
SAMIR, URI	UNIVERSITY OF MICHIGAN			35201017
SAMUEL, MIKE	UNIV OF CALIFORNIA AT DAVIS	780620	780831	36131001
SATAKE, AKIO	UNIVERSITY OF OKLAHOMA	780806	780810	35261002
SCHENDEL, MARK	FLORIDA STATE UNIVERSITY			35111038
SCHERRER, PHILIP	STANFORD	781129	781130	35661010
SCHLESINGER, ROBERT	UNIVERSITY OF WISCONSIN	780905	780916	35381004
SCHLESINGER, ROBERT	UNIVERSITY OF WISCONSIN	790212	790216	35381008
SCHMITZ, JOYCE	TEXAS A+M UNIVERSITY	780623	780831	35311006
SCHNEIDER, STEVE	TEXAS A+M UNIVERSITY			3013023
SCHUBERT, WAYNE H.	COLORADO STATE UNIVERSITY			35081026
SEKORSKI, JOE	CTR FOR ENVIRONMENT AND MAN	780414	780419	36121001
SEKORSKI, JOSEPH	CTR FOR ENVIRONMENT AND MAN			36121004
SHEN, COLIN	UNIVERSITY OF WASHINGTON			7013014
SHKOLLER, BORIS	UNIVERSITY OF COLORADO			35071067
SHORT, DAVID	UNIVERSITY OF WASHINGTON			35371010
SHOUB, EDWARD C.	UNIVERSITY OF COLORADO			35071040
SHOUB, EDWARD C.	UNIVERSITY OF COLORADO			35071055
SIGGIA,ERIC	CORNELL UNIVERSITY			35091009
SILVA DIAS, MARIA F.	COLORADO STATE UNIVERSITY			35081054
SMITH, JR., PAUL L.	SOUTH DAKOTA SCHOOL OF MINES			35641013
SMITH, PHIL	PURDUE UNIVERSITY			5013526
SMITH, ZDENKA	UNIVERSITY OF ALABAMA			36471000
SMYTH, WILLIAM H.	IOWA STATE UNIVERSITY			35461002
SMYTHE, WILLIAM H.	HARVARD UNIVERSITY			35121012
SMYTHE, WILLIAM H.	HARVARD UNIVERSITY			35121016
SNOW, TIMOTHY	UNIVERSITY OF VIRGINIA			35691003
SNYDER, RUSSELL L.	NOVA UNIVERSITY			35571000
SOLL, DAVID	UNIV OF SOUTHERN CALIF.			36381001
SOONG, SU-TZAI	UNIVERSITY OF ILLINOIS	781027	781103	35141013
SRIVASTAVA, R. C.	UNIVERSITY OF CHICAGO			35061012
STAMNES, KNUT	UNIVERSITY OF ALASKA	780605	780630	35011000
STEINOLFSON, RICH	UNIVERSITY OF ALABAMA	790128	790228	36471001
STEINOLFSON, RICH	TEL AVIV UNIVERSITY	781218	790110	35881000
STEINOLFSON, RICH	TEL AVIV UNIVERSITY	780705	780731	35881000

STEPHENS, MARK	COLORADO STATE UNIVERSITY	781028	781029	35081013
STEWART, A. I.	UNIVERSITY OF COLORADO			35071046
SWARZTRAUBER, PAUL	UNIVERSITY OF COLORADO			43513022
SWEETON, EDWARD	CTR FOR ENVIRONMENT AND MAN			36121002
SWEETON, EDWARD	CTR FOR ENVIRONMENT AND MAN			36121006
TAKAHASHI, TSUTOMU	UNIVERSITY OF HAWAII-HILO			35451005
TAKAHASHI, TSUTOMU	UNIVERSITY OF HAWAII-HONOLULU			35131001
TAKAHASHI, TSUTOMU	UNIVERSITY OF HAWAII-HONOLULU	781113	781213	35131003
TAO, WEI-KUO	UNIVERSITY OF ILLINOIS	780531	780602	35141012
TARBELL, TERRY C.	PENNSYLVANIA STATE UNIVERSITY			35281010
TECSON, JAIME	UNIVERSITY OF CHICAGO			35061029
TENCH, ALAN H.	COLORADO SCHOOL OF MINES			35801001
TENCH, ALAN H.	INDEPENDENT - BOULDER			36341002
THOMAS, GARY	UNIVERSITY OF MICHIGAN			14013000
THOMAS, GARY	UNIVERSITY OF COLORADO			35071066
TRENBERTH, KEVIN	UNIVERSITY OF ILLINOIS			35141014
TRUHLAR, DONALD	UNIVERSITY OF MINNESOTA	780710	780724	35211000
VAN HELVOIRT	UNIVERSITY OF VIRGINIA			35691006
VARONA, ERIBERTO	UNIVERSITY OF VIRGINIA			35691002
VASTANO, ANDREW	TEXAS A+M UNIVERSITY	790102	790110	35311006
VASTANO, ANDREW	TEXAS A+M UNIVERSITY	780511	780522	35311006
VASTANO, ANDREW	TEXAS A+M UNIVERSITY	780413	780415	35311006
VASTANO, ANDREW	TEXAS A+M UNIVERSITY			35311018
VASTANO, ANDREW	TEXAS A+M UNIVERSITY	790202	790216	35311025
VASTANO, ANDREW	TEXAS A+M UNIVERSITY			35311026
VASTANO, DREW	TEXAS A+M UNIVERSITY	780623	780831	35311006
VASTANO, JOHN	TEXAS A+M UNIVERSITY	780623	780831	35311006
VAZIRI, ARSALAN	UNIVERSITY OF DELAWARE			35751001
VAZIRI, ARSALAN	UNIVERSITY OF NEVADA	780410	780419	35231000
VOLMER, JOHN	FRENCH MET. OFFICE			5013716
VONDER HAAR, ET AL	COLORADO STATE UNIVERSITY			35081046
VONDER HAAR, ET AL	COLORADO STATE UNIVERSITY			35081049
WAGNER, JOHN	DENVER UNIVERSITY	781208	781213	35101008
WAITE, J. HUNTER	UNIVERSITY OF MICHIGAN			35201024
WALSH, JOHN	UNIVERSITY OF ILLINOIS	780615	780707	35141011
WASHINGTON, W. M.	COMMONWEALTH SCI & IND RES ORG			3013605
WEATHERFORD, CHARLES	FLORIDA A+M UNIVERSITY	780820	780824	36061000
WEIL, JOYCE	UNIVERSITY OF CHICAGO			35061027
WELCH, RONALD	COLORADO STATE UNIVERSITY			35081031
WELCH, RONALD	COLORADO STATE UNIVERSITY			35081040
WELCH, RONALD	COLORADO STATE UNIVERSITY			35081041
WESSEL, WILLIAM R.	FLORIDA STATE UNIVERSITY			35111013
WESTHOFF, DANIEL	COLORADO STATE UNIVERSITY			35081024
WESTHOFF, DANIEL	COLORADO STATE UNIVERSITY			35081034
WHITBY, KENNETH	UNIVERSITY OF MINNESOTA			35211001
WHITE, DICK	UNIVERSITY OF COLORADO			28403017
WHITE, DICK	UNIVERSITY OF COLORADO			28403047
WHITE, GLENN	UNIVERSITY OF WASHINGTON			31103014
WOFSY, STEVEN	HARVARD UNIVERSITY			35121008
WROBLEWSKI, JOSEPH S	FLORIDA STATE UNIVERSITY			35111024
YOUNG, KEN	UNIVERSITY OF ARIZONA	780605	780820	35021005
YOUNG, KENNETH	UNIVERSITY OF ARIZONA	781218	781222	35021008
YOUNG, RICHARD	UNIVERSITY OF CALIFORNIA-NASA			35031000
YOUNG,DAVID PAUL	UNIVERSITY OF COLORADO			35071080
ZEMAN, OTTO	UNIVERSITY OF COLORADO			35071057
ZUREK, RICHARD W.	UNIVERSITY OF COLORADO			35071038

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

FOF's near-term strategies are virtually unchanged as demand for services continues to be the major driving force in dictating how FOF must operate. Some modifications are necessary to accommodate to the FY 1980 budget and to permit a fuller involvement with the Boulder Atmospheric Observatory (BAO). In this regard, FOF's services will change somewhat.

FOF will continue to fully staff its major systems, the radars and PAM. Users of these systems will receive the equipment, an operational staff, and scientific program management. Rawinsonde users will receive training assistance but operators cannot be provided.

Despite severe budget pressures in FY 1980, NCAR management will fully support the BAO. FOF will absorb certain BAO costs from its base budgets beginning in 1980. These costs include programming support for the BAO data acquisition system and partial maintenance of the system. BAO management will be provided from existing scientific staff and FOF will be able to contribute a limited number of rawinsonde and boundary layer balloon measurements from the BAO, at no cost to users.

In order to accommodate BAO needs, other activities considered to be less important will be eliminated. Minor meteorological equipment loans, recorders, cameras, boundary profile systems, etc., will be discontinued. The environmental chamber will be taken out of service and FOF will no longer operate the ruby lidar system unless external funds are made available for its maintenance. These moves and other economies will result in a more consolidated facility, with fewer activities, but with those performed better.

Accomplishments of the Past Year (April 1978 - March 1979)

Field Program Support. During April 1978, the PAM system was used by Professor Businger, University of Washington, for his study of airflow over non-uniform terrain in the vicinity of the BAO tower. Thirty PAM remote stations were deployed in an 8 x 10 km grid centered at the tower.

Following Businger's study the PAM system was moved to Illinois along with two FOF Doppler radars, as well as rawinsonde and radio communication support, to engage in the Northern Illinois Meteorological Research on Downdrafts (NIMROD). The NIMROD project, conducted during May and June, was headed by Professors Fujita and Srivastava of the University of Chicago and was perhaps the most ambitious program thus far supported by the Facility. NIMROD focused on damaging thunderstorm winds and particularly the intense downdrafts referred to by Fujita as downbursts. In addition to the PAM, a triple Doppler array (with CHILL), and rawinsondes, Fujita used high-altitude aircraft photography, satellite photos at three-minute intervals, conventional time lapse photography, and ground damage analysis to better document the cases observed.

In July, FOF personnel operated the CP-2 radar and provided rawinsonde support for the NCAR Convective Storms Division (CSD) early-echo cloud growth studies conducted at Grover, Colorado. The CSD effort was directed at understanding better the early microphysical and dynamical processes in convective clouds.

The Thunderstorm Research International Program (TRIP) also conducted a field experiment in Florida during July, 1978, and FOF provided one Doppler radar in support of Professor Roger Lhermitte, University of Miami. The NCAR radar was positioned near the Kennedy Space Flight Center. TRIP is a cooperative program involving about twenty scientists whose fundamental interest is the study of convective storms with emphasis on atmospheric electricity. Principal scientists other than Lhermitte included Professors Marx Brook and Charles Moore, New Mexico Institute of Mining and Technology; Drs. Bernard Vonnegut and Richard Orville, State University of New York; and Dr. Philip Krider, University of Arizona.

The first major boundary layer experiment at the Boulder Atmospheric Observatory took place in September. This was also a cooperative experiment which included participation from NOAA, NCAR, and university scientists. A wide variety of instruments were deployed, with FOF contributing a Doppler radar, the PAM system, and rawinsonde support and RAF contributing two Queen Air aircraft. The principal focus of this program was the turbulent structure and growth of the convective boundary layer over the complex terrain of the BAO. An outstanding feature of this study (termed PHOENIX) was the regular occurrence of unusually strong clear air echoes to ranges as great as 40 km. Although chaff was used to provide artificial tracers, it was found that on many occasions the natural tracers in the air were sufficiently dense to obviate the need for chaff. Dr. Peter Hildebrand, a scientific visitor to FOF from the Illinois State Water Survey directed the PHOENIX research with Drs. William Hooke and Robert Kropfli, NOAA/WPL. Prof. Joost Businger, University of Washington, continued his terrain-related research at BAO during this period.

Since 1974 the Field Observing Facility has each year supported the University of Washington CYCLES program headed by Professor Peter Hobbs. Again in 1979, during February and March, the CP-3 Doppler radar was located at Ocean Shores, south of the Olympic Peninsula of Washington. The CYCLES program emphasizes the study of wintertime extratropical cyclones, their kinematic fields, and precipitation structure. The coastal location for the radar was selected in order to observe storms as they make the transition from sea to land.

In addition to major experiment support, the facility during the past year provided boundary layer systems, rawinsonde, lidar observations, and numerous loans of small meteorological recorders, cameras, theodolites, etc., for use by the scientific community.

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

1. Radar Video Recorder. For example, with the cooperation of the Research Systems Facility a video recorder for coherent Doppler radar has been developed. A Sony VO-1800 video cassette is used as the recorder and storage medium. This technique preserves significantly more of the information in the radar signal than has heretofore been practical. The recorder was used with the CP-2 radar during the 1978 summer CSD field program and will be assigned to the CP-4 radar during the 1979 SESAME in Oklahoma.

2. PAM Calibration. During this reporting period the PAM system has been augmented with a portable mini-base station. This is a suitcase size, self-powered station which can interrogate a remote station and display the received data message on an interval printer. The objective is to verify correct operation of a remote station during set-up and to monitor the operation of a remote station for calibration and maintenance. In addition, the mini-base station plus a special set of sensors constitutes a portable reference remote station which will be used for sensor intercomparison.

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

4. Airborne Doppler Radar. FOF worked with NOAA/ERL in conducting preliminary tests of an airborne Doppler radar aboard the NOAA P-3 aircraft. NOAA engineers in Boulder developed the radar assisted by FOF engineer Charles Frush. Frush also interfaced the lidar data acquisition system to the radar and supervised the data taking. The results were quite encouraging, indicating that coherence was maintained aboard the aircraft. A few comparisons between the airborne Doppler data and the ground-based NSSL radars indicated good agreement.

5. Radar Calibration. During the Phoenix experiment FOF used the BAO tower for siting a radar signal generator, thus permitting excellent antenna beamwidth and gain measurements. Out of these and other tests, solar gain calibration is emerging as our basic procedure for antenna gain measurements.

6. Software Development and Data Processing. FOF has continued to provide large quantities of archived radar data and further development of the Doppler radar software library has taken place. Much of this work has been accomplished by Computing Facility applications programmers with the help of FOF student assistants. All data which have been requested for analysis during the past year have been archived on a timely (1 month) basis. This effort represents about 300 tapes and 200 radar hours of data. The software library (for higher levels of processing) has experienced substantial growth during the past year. New capabilities such as single radar filtering to Cartesian space, dual-Doppler filtering to cylindrical space, power spectral analysis of radial velocity and reflectivity fields, and major streamlining of the data archive and access software have been realized during this period.

7. Technique Development. FOF staff scientists have been involved with two major cooperative efforts. Collaboration with the University of Chicago in connection with Project NIMROD has revealed exciting applications of the RDSS for data analysis. Fujita and Wilson have demonstrated the value of color time-lapse motion pictures of Doppler radar data for studying severe storm development, downburst propagation and tornado genesis. One joint publication is in progress and more are likely to follow. Collaboration with the University of Wyoming, Bureau of Reclamation and NOAA/WPL in connection with the Sierra Cooperative Pilot Project has resulted in some unique triple Doppler radar findings. These findings bear heavily on the techniques for future Doppler data acquisition and the kinematic structure of cold fronts in California. Two publications are currently in progress.

Long-Range Development Plans

Part of FOF's effort is directed toward the development of long-range plans for the facility based upon the needs of atmospheric science. Long-range planning is a continuous evolutionary process that uses inputs from the FOF Advisory Panel, university and NCAR users, the National Science Foundation, larger scientific planning groups such as those organized by SESAME and TRIP, workshop groups such as that which reviewed PAM, and the Scientific Programs Evaluation Committee panel. FOF's assessments of future needs are described below.

Vertically Pointing Radar. FOF's radars and PAM have been responsible in part for major new scientific advances; yet there remain many deficiencies in FOF's ability to provide fully comprehensive observing, processing, and analysis systems for boundary layer and mesoscale research. For example, high-resolution observations of vertical particle motion are required for several applications. Results from the recent Northern Illinois Meteorological Research on Downdrafts (NIMROD) experiment have shown that a scanning Doppler radar can detect strong thunderstorm downbursts and provide warnings of their occurrence that would be important in aircraft operations. However, further understanding of the downburst phenomenon is necessary before development of a fully reliable detection technique can be realized. An important tool for this purpose is the vertically pointing Doppler radar. A vertically pointing Doppler would be of great value to all thunderstorm research efforts for determining better the structure and magnitude of the vertical component of air velocity. Such measurements are critical in understanding how thunderstorms develop and decay, how environmental mixing occurs, and how precipitation embryos are recirculated. These are fundamental questions which will be probed in the next decade for the benefit of weather modification, severe storm prediction, and real-time warning.

PAM. It is an undeniable fact that PAM has reduced the data reduction effort associated with surface meteorological data by an order of magnitude compared to mechanical stations and has produced data of uniformly higher quality as well. Yet PAM's current number of 30 remote stations is insufficient to satisfy the needs of most programs. CSD used approximately 50 stations in its 1976 field program and SESAME will deploy approximately 85 stations in 1979. In addition to the need for more remote stations, the demand for PAM is great enough that two systems are necessary.

FOF has repeatedly stated its case for expanding PAM to 60 stations and adding a second base station, thus permitting service to two programs simultaneously. While the need for PAM expansion remains as pressing as ever, recent developments in satellite communications hardware have led FOF to consider new approaches to the PAM concept. Despite its success and enthusiastic reception from the community, PAM does have a "weak link" and this is its radio communication network. Communications range is limited by terrain, heavily forested areas will attenuate the signal, and multipath in mountainous terrain can seriously reduce the system's effectiveness. A radio repeater, which was added to the system in 1977, mitigates these problems somewhat, but the basic problems of communicating over long distances at UHF remain. Moreover, the need for installing tall towers in the network presents logistical problems.

FOF and RSF have recently conducted a preliminary design study on the use of the GOES communications channels for relaying PAM data. The results of this study are most promising. A single base station in Boulder could collect and archive data from several experiments throughout the country. Each scientist would have real-time access to data displays with a simple, low-cost graphics terminal at his or her field site location. Terrain would have little, if any, effect on communications. Installation of remote stations would be simplified because of shorter mast height and it would no longer be necessary to transport the base station to the field site. Operational costs would be reduced substantially and reliability would be improved. In addition, this concept will reduce the number of new staff required from four to two persons as compared to earlier plans for PAM expansion. Overall, this second generation PAM system is very exciting and represents the next step forward in automatic surface weather data gathering.

Rapid Scanning Radar. The demand and need for Doppler radar remains great. Many advances have been made in understanding the air flow in convective storms through the use of multiple Doppler radars. Yet many questions regarding fine-scale features remain unresolved due to the temporal and spatial scale limitations imposed by antenna scan rates. Contemporary wisdom suggests that convective storms should be scanned in less than three minutes. However, present radars often require at least five minutes to scan the entire volume occupied by the storm. Given a 10 m/s propagation velocity, a storm will have moved 2-3 km in the period typically used for one volume scan of a severe storm, and many Oklahoma storms move at 20-30 m/s. Research at NCAR has shown that spatial scales of 1-2 km are important and work underway in the TRIP program indicates that even smaller scales must be resolved in examining the fine-scale structure of precipitation. It appears hopeless to try to get true "snapshots" of storms which reveal scales of the order of 1 km or less without more rapidly scanning antennas.

FOF has been examining this problem in some detail and has had several discussions with Lhermitte at Miami, and Brook and Krehbiel at New Mexico Institute of Mining and Technology. We believe that through the use of broader bandwidth signal transmissions, electronic antenna scanning techniques, and somewhat more sophisticated processing than is now employed, it will be possible to increase antenna scan rates by an order of magnitude or more without compromising data quality. This capability would lead to quantum jumps in our understanding of the growth and structure of convective storms.

Safesonde. Frequent and accurate soundings are among the more basic and necessary requirements of virtually all experimental field programs. Yet the operational and research communities rely on the antiquated GMD rawinsondes, which have become increasingly difficult and expensive to operate and maintain, and few of which are transportable for general use. The advancement of atmospheric science at a reasonable rate demands that an improved rawinsonde system be developed. High time and space resolution are necessary for convective storms research on the storm scale. The system must be transportable, employ solid state electronics for reliability, and be easy to deploy; moreover, its balloon-borne packages must be nonhazardous to aircraft. The Safesonde system being developed jointly by GAMP and RSF satisfied these requirements.

Data Processing. FOF supports all of its systems with data processing services and analytical software and makes use of interactive computing as available on the Research Data Support System. In the 1980s there will be increased emphasis on interactive computing that can be provided by merging a powerful minicomputer with the display capabilities that are now available. Although fundamentally slower than large computers such as the CDC 7600 and the CRAY-1, interactive features often permit scientists to complete their objectives more quickly than through the use of batch processing techniques. We are convinced that a well-designed interactive system can satisfy virtually all of FOF's data processing needs in the 1980s and remove this large burden from the central computing facility. The FOF staff must have access to such a system to operate effectively at the BAO.

Other Developments. Finally, there are a host of other exciting new capabilities that can be envisioned. These include radiometric remote sounding techniques for temperature and humidity profiles and VHF Doppler radar for profiles of all three components of air velocity in the troposphere and stratosphere. Doppler lidar development has been slow but steady and small scanning incoherent lidars are available for mapping particulate loading in the boundary layer. FOF cannot hope to develop all of these or even to take advantage of new capabilities after they are established. We will try to keep abreast of important new developments and to incorporate the more promising of these into FOF's plans.

Long-Range Strategies

In recent years, FOF's strategy for the long term has been to plan annually for new system developments and for associated orderly growth. These plans have always been favorably received, but budget limitations have tended to preclude the undertaking of any major new initiatives. The FY 1980 budget situation is severely limiting and prospects for the future do not appear to be bright. How then can FOF hope to provide new observing systems for atmospheric science and avoid technical and scientific obsolescence?

We recall that FOF arrived at its current status by totally reprogramming its effort in 1973. For a period of two years, almost no support was provided to the scientific community while major new developments took place. Thus, in times of fixed budgets and staff, new capabilities can be added by reducing the levels of support provided. However, development of an additional new system alone will not provide the continuing long-range funds for its operation and maintenance. In a level budget situation new systems that come on line can be staffed and supported only by phasing out older hardware.

Our long-range strategy is based on the assumption that FOF cannot grow indefinitely without limit. We assume further that, after a steady state has been reached, it will be possible to interweave periods of intense field work (and reduced development) with periods of concentrated development (and reduced field work). Such a strategy should work very well in the long run although it may meet with some resistance from a user community unless adequate notice is provided. Long-range planning, such as was initiated at the NCAR mesoscale workshop and the Norman, Oklahoma, workshop in March, can assist in scheduling new developments, particularly if these workshops clearly identify their observational needs several years in advance of the field programs.

A cyclic mode of operation as described above requires, however, that the steady state or critical mass has been reached and this is simply not the case for FOF's current variety and levels of services. A triple Doppler radar capability, a mobile, vertically pointing Doppler radar, a satellite-based PAM system with 60 remote stations, three to five next-generation rawinsonde systems, and an interactive computing system are all necessary. To reach these objectives, the FOF staff must be increased by approximately four radar persons, three persons for the PAM and rawinsondes, one scientist for technique development and program management, one programmer-engineer, and one full-time person for data processing to replace student assistants. In addition, FOF must continue to receive its current allocation of applications programming support. A period of rapid growth is needed now.

The methods for proceeding with the development of any new system will be similar to those employed in the past. FOF and RSF staff will undertake feasibility studies and these will be submitted to the FOF Advisory Panel and the user community at large for comments. Detailed design phases will follow and only after careful internal scrutiny and further external advice will the major hardware development begin. It is possible that university groups, with special expertise, will be included in one or more of the development programs. In some cases, the feasibility phase will require expenditures for special-purpose new hardware. We believe that it is possible to make major strides in improving and advancing the state of the art in surface-based observing systems in the 1980s and we look forward to the challenge. If we can, by 1985, reach the goals stated, a new era of mesoscale research will be possible.

ATD/FOF

Field Observing Facility - Users

Ronald Alberty	National Severe Storms Laboratory
Stanley Barnes	NOAA
Joost Businger	University of Washington
William Clayton	Texas A & M
James Connell	Battelle Institute
Ted Fujita	University of Chicago
M. E. Harward	Oregon State University
Peter Hildebrand	Illinois State Water Survey
Peter Hobbs	University of Washington
Raymond Jordan	Colorado School of Mines
Chandran Kaimal	NOAA
Thomas Kitterman	Lyndon State College
Warren Knapp	Cornell University
Carl Kreitzberg	Drexel University
Roger Lhermitte	University of Miami
Norman Markworth	Steven F. Austin University
Thomas McKee	Colorado State University
Maynard Miller	Foundation for Glacier and Envir. Res.
Robert Rader	Solar Energy Research Institute
Peter Ray	National Severe Storms Laboratory
Mario Schaffner	Unaffiliated
W. L. Somervill, Jr.	Colorado State University
Ramesh Srivastava	University of Chicago
Donald Stedman	University of Michigan
Jesse Stephens	Florida State University
George Swanson	University of Colorado Medical Center
Aylmer H. Thompson	Texas A & M
Val Veirs	Colorado College
Norman K. Wagner	University of Texas
David Whiteman	Colorado State University
Elizabeth Wright-Ingraham	Wright-Ingraham Institute

RESEARCH SYSTEMS FACILITY (RSF)

Mission and Goals of RSF

The Research Systems Facility maintains a scientific and engineering design capability with emphasis on the development of sensor, communication, and data acquisition systems. NCAR is in close communication with university and federal research and facility groups, in order to anticipate the instrument needs of the atmospheric science community and to be ready to undertake development as required. RSF's major goals are:

1. To develop new instrumentation and data processing systems for use by other ATD facilities and to meet requirements for special national and international programs such as the Global Weather Experiment (GWE).

2. To provide engineering services to NCAR through the Machine Shop, the Mechanical Design Group, and the Instrument Shop.

A strong development program is essential to maintain a research facility program that can provide research systems to university and NCAR scientists and enable them to make the greatest possible progress in atmospheric research. Through transfer of technological advances to other organizations, RSF and ATD also contribute significantly to advances in national capabilities for atmospheric research.

Strategies

In planning for the future, the following strategies are involved in decisions regarding selection of projects, growth rate, etc.

Important, Specific Need - A proposed development must satisfy an important specific atmospheric research need to be selected. Evaluation of this need is based on inputs such as scientific user requests, advisory panel review, etc.

Breadth of Use - Higher priority is given to projects which will serve a large number of university and NCAR scientists through established NCAR facilities. As a result, RSF development resources are not normally available to an individual scientist or program within NCAR.

Balance of Customers - In recent years, a major effort has been undertaken to enhance the capabilities of FOF and RAF. During this period, development resources have been split roughly 40% FOF, 40% RAF, and 20% to others. Now that the initial goals of this development have been met, the balance may be expected to change somewhat with a slight, gradual decrease in support to FOF and RAF, and a similar increase in support to others such as NSBF, for example.

Balance within RSF - It is important to keep balance within RSF in several respects. Generally we can handle only two large projects at a time, with present staff. An important new project should not enter its start-up phase until the other is mature. This minimizes peaks and valleys, while giving proper attention to each. Similarly, there needs to be a balance between larger projects and smaller projects and long-term and short-term projects. Generally, we strive to have three or four smaller projects along with the larger ones, giving some flexibility in adjusting work loads without excessive problems of managing a large number of small projects.

Accomplishments of the Past Year

Machine Shop and Mechanical Design Group. Two important parts of RSF are the Machine Shop and the Mechanical Design Group, both of which work in close cooperation with NCAR scientists and engineers to produce new equipment for atmospheric research. The level of shop activity has been unusually high over the past 18 months, partly in support of instrumentation construction requirements for a large number of large field experiments. Another significant proportion of the instrumentation designed and constructed for NCAR researchers consisted of equipment for making chemical measurements, such as sampling filters for use on aircraft, an ozone sensor, a chlorine sampler, balloon air sampling systems, and instrumentation outfittings of the NCAR Electra for the Global Atmospheric Measurements Experiment on Tropospheric Aerosols and Gases (GAMETAG). Other projects included a hail camera, a humidity chamber, an inertial navigation system nose boom for the NCAR Queen Air aircraft, and differential temperature probes for the Portable Automated Mesonet system.

Instrument Shop. RSF maintains an Instrument Shop to repair and calibrate ATD laboratory equipment. In doing so, this shop both saves money and contributes toward better research by providing accurately calibrated instruments needed to develop and test new field equipment. While primarily an electronic shop, NBS-traceable pressure and temperature reference instruments have been added recently, and a humidity console is now being developed.

Technical Documentation. While the new equipment developed by RSF is important, the technical documentation which goes with it is nearly as important. This documentation--papers, reports and manuals--is essential to the operation and maintenance of the equipment in the field, and also serves as an important mechanism for technology transfer from RSF to universities and other agencies. Lynn Post, RSF's technical editor, works with the engineering staff to gather the necessary data to document every RSF development.

ARIS IV. A team consisting of Michael Duncan, Bob Brown and Jacques Brun completed development of a new data acquisition system, called the Airborne Research Instrumentation System IV (ARIS IV), for use on light aircraft. The ARIS IV system provides a real-time, centralized meteorological and flight data collection and display facility for the Queen Air and Sabreliner aircraft operated by the NCAR Research Aviation Facility (RAF). The computer-compatible output from ARIS IV is expected to improve the quality of data obtained and to simplify the processing of aircraft data. Three of the systems have been delivered to RAF, along with ground support equipment and a set of spares.

The heart of the ARIS IV is a Digital Equipment Corporation LSI-11 microcomputer with 28,000 words of memory. Data from a variety of sensors aboard the aircraft can be sampled at ten rates from 1 to 1,000 Hz and recorded directly onto nine-track magnetic tape. The system is designed to support the complex aircraft and scientific instruments, such as the aircraft inertial navigation system and the scientific aerosol measurement probes, as well as instruments with simple digital or analog outputs.

ARIS handles as many as 100 parameters, any of which can be examined in real time as raw data or as calibrated values. Two displays are available, one on the control panel and one on a hand-held remote unit. Each display shows the time plus four user-selected parameters such as temperature, humidity, or winds. Selected parameters also are available as strip chart analog outputs, or on a hard-copy printer.

Research Data Support System. Victor Borgogno, Robert Brown, and Kenneth Norris last year completed the first phase of construction of an interactive computer system called the Research Data Support System (RDSS), designed to ease the problem of analyzing, editing, and sorting through large volumes of data. RDSS is now being used to examine data gathered by investigators using the NCAR Field Observing Facility's C-band doppler radars.

In addition to extensive use by FOF staff, the new RDSS also has been used by scientists from such institutions as the University of Chicago, the University of Wyoming, and NSSL, for the analysis of radar data. Other data sets have also been examined using the system as well, including data from Geostationary Operational Environmental Satellites and a coronagraph on the Skylab orbiting laboratory.

The RDSS central processing hardware consists of a Digital Equipment Corporation PDP 11/60 minicomputer with 128,000 16-bit words of memory. The computer drives a COMTAL "Vision One" color video display system that can display the data in image form. The system also has two magnetic tape drives and two disk drives, used in input and data storage.

The system's interactive capability is one of the most important features of the RDSS. By using its function memory and pseudo-color memory features, the investigator can enhance and color the data set to emphasize features difficult to see in the original image.

Output from the RDSS presently is available in publication-quality 35 mm color slides and 16 mm color movies. Film loops of images can be created by first processing the data set to obtain the desired magnification, contrast, stretching, false coloring, labeling, graphic overlays, etc., and then photographing it in time-lapse sequences.

While the RDSS is now in operational use, RSF has only begun to exploit the potential of the system. A continuing software and hardware development program is planned to provide more sophisticated displays and processing of data. For example, future plans for radar processing include velocity unfolding, coordinate transformations to merge separate data sets, three-dimensional wind analysis from multiple radars, etc. Similarly, we expect to be able to input and analyze data from GOES and other satellites. Particularly in this area, RSF will make use of development work done by others such as the University of Wisconsin, CSU, University of Miami, etc.

Aircraft Dropwindsonde. Until recently, it has been difficult to obtain good wind observations in the tropics because the equatorial regions contain large expanses of ocean. In order to obtain complete wind data for use in numerical weather prediction models, the GARP Global Weather Experiment has deployed aircraft dropwindsondes and shipborne radiosondes during its special observing periods from 5 January to 4 March, and will again from 1 May to 30 June of 1979. The dropwindsonde design chosen for the experiment was one created by NCAR and used successfully during the GARP Atlantic Tropical Experiment in 1974. Justin Smalley headed an RSF effort to improve the stability and reliability of the dropwindsondes for use in the Global Weather Experiment. The specifications for the new dropwindsondes were delivered to the National Oceanic and Atmospheric Administration, which contracted for the manufacture of 7,500 sondes for the Global Weather Experiment.

The dropsonde instrument package contains an Omega signal receiver in addition to pressure, temperature and humidity sensors. The Omega signal is used to measure the winds, a unique feature of this sonde. Sondes will be parachuted about every 350 km along the flight tracks of research aircraft flying at altitudes of 9-11 km. The nominal descent rate is 25 mb/min (300 m/min); as the sonde descends, the signal will be retransmitted to the aircraft, where it will be recorded and processed into real-time scientific data.

Scientists aboard the aircraft can obtain vertical wind profiles from 600 m below the aircraft to approximately 300 m above sea level with the sondes. Data on the other meteorological variables should be obtained from 500 m below the aircraft to the surface. Roughly every other sounding has been transmitted over the Global Telecommunications Service to provide worldwide "real-time" data.

MONEX and FGGE. RSF has a significant role in support of MONEX and FGGE this year. George Saum was in charge of the RAF Electra in Kuala Lumpur, supporting the dropwindsonde portion of the Winter MONEX program, and Justin Smalley is FGGE director of dropwindsonde operations at Ascension Island. RSF also has been providing considerable technical support relating to sonde production and aircraft system performance testing and improvement. In addition, we recently completed the construction of two Omega signal monitors, which have been shipped to Ascension and Canton Islands.

Lyman-alpha Hygrometer. RSF is nearing completion of the first of four new Lyman-alpha hygrometers being built for RAF. These hygrometers are fixed-path instruments capable of very rapid (5 ms) response. They will be used to obtain humidity variation data, and dew point instruments will be used to measure the mean absolute value. They will replace the microwave refractometers, and are expected to provide better performance, better reliability, and lighter weight.

Differential Temperature Sensor. Based on successful development tests, both in the laboratory and in the field at the Boulder Atmospheric Observatory (BAO), we are now building six complete ΔT instruments for use on the PAM system. These instruments will be deployed on selected stations in the PAM network to provide an estimate of stability and vertical heat flux.

Air Motion Sensing Vanes. RSF is developing a new de-iced air motion sensing vane assembly for RAF, requested because of the increasing number of missions flown in potential icing conditions. The need for de-icing is primarily for safety, although in marginal cases the new vanes also should improve the accuracy of the data. The prototype instrument has passed laboratory and wind tunnel tests and flight tests. Following successful flight tests and initial operations, we now are building enough instruments to outfit all RAF aircraft.

Radar Video Recorder. The RSF-developed Radar Video Recorder was used for the first time last summer to record doppler velocity data from the CP-2 radar at Grover, in support of the Convective Storms

Division program. Preliminary reports indicate that quality of the velocity data is excellent. Studies of techniques to provide reflectivity data over a wide dynamic range are underway.

Humidity Console. A new humidity test console is being built to allow us to calibrate humidity instruments and to develop state-of-the-art humidity sensors. We expect it to be fully operational in the coming year, and to provide a unique capability in this important but often neglected area.

Safesonde. RSF is beginning a project in cooperation with the NCAR Global Atmospheric Measurements Program to develop a safe (non-hazardous to aircraft), accurate vertical sounding system called the Safesonde system, intended primarily for use in boundary-layer, severe-storm, and mesoscale research. The basic technical goal is to provide much better accuracy than the obsolete GMD systems, at low cost.

Harold Cole is leading RSF's effort to develop the Safesonde system. In operation, a small sonde will be launched on a balloon, and tracked automatically by a ground receiving system. The ground system will both log the data and produce real-time sounding data in scientific units. A prototype unit is expected to be installed at the BAO in mid-1980. Following extensive field tests, a portable system will be built which FOF can deploy in support of research programs at various locations.

Work during the past year has been aimed at detailed analysis of the tracking system and testing of key tracking system components. The system development phase will start soon, following a system design review.

GLOBAL ATMOSPHERIC MEASUREMENT PROGRAM (GAMP)

Mission and Goals of GAMP

The mission of GAMP is to develop and demonstrate improved methods for measuring atmospheric parameters. Emphasis has been placed on global measurements using balloon systems, particularly those utilizing superpressure balloons, and satellites in complementary roles. The techniques we have developed primarily for the Global Atmospheric Research Program (GAMP) are now being applied to critical measurement problems involved in monitoring air quality and other parameters, in the development of improved vertical sounding systems, and providing support, coming within the framework of the GAMP mission, to the scientific community as required.

During this report period, our main goal has been to furnish support to the Global Weather Experiment (GWE) during the two Special Observing Periods (SOP's). This support effort for the world scientific community became necessary due to the substitution of an aircraft dropsonde in place of the Carrier Balloon System (CBS), also a development of GAMP, and the abandonment of the reference-level system by France.

Secondary goals have been to continue the development of both the Safesonde System and an extreme duration, latitude-keeping balloon system, known as the Long-lived Atmospheric Monitoring Airship (LLAMA). Also, we conducted an investigation and analysis of potential wind errors arising from the use of the Omega Navigation System by atmospheric wind-finding sounding systems being used in support of the GWE.

Strategies

The major expenditure of manpower has been on the special support project for the GWE, the Tropical Constant-level Balloon System (TCLBS). The fixed dates for the two SOP's, and hence for the launches, dictated that this receive the highest priority.

Next in priority was additional support given for the GWE. This consisted of studying potential errors in Omega-derived winds and assisting the National Oceanic and Atmospheric Administration (NOAA) in the on-board installations of the WMO Navaid shipboard sounding system equipment.

Continued effort, as possible, was given to the Safesonde and LLAMA projects.

Accomplishments of the Past Year

The TCLBS plans called for the launch of 330 balloon systems from Canton and Ascension Islands. The purpose of the program is to augment the data obtained by aircraftborne wind-finding dropsondes and by the WMO Navaid shipboard sounding systems. The balloons are tracked, and data received, by the TIROS-N satellite to obtain winds in the high tropical troposphere.

The costs for this program are shared by NSF and NOAA, with NOAA providing funds for special project staff, production of flight systems, and the cost of the logistics for and operation of the launch sites.

The project team was assembled within GAMP from the staff which collaborated with the University of Wisconsin on the successful Tropical Wind, Energy Conversion, and Reference Level Experiment (TWERLE). This team was augmented by two special projects engineers and four support personnel. Balloons, transmitters, and solar-cell panels were procured on contract; the transmitters and panels and all other elements were fabricated in-house. The oscillator, transmitter, and modulator were certified for flight in tests conducted at the Centre National d'Etudes Spatiales (CNES), Toulouse, in September 1977.

Since the objective of the TCLBS program is to obtain winds in the upper troposphere of the equatorial regions (where satellite radiometric data are useless), the pressure and altitude sensors of TWERLE were deleted; only the temperature sensor was retained. To this, a nighttime transmission capability was added to double the amount of wind data. The requirement for batteries and thermal control for nighttime operation precluded the development of an electronic package which would not present a hazard to aircraft. Much of the development program was devoted to safety systems to destroy the balloon if it flies in the airlanes or over those Northern Hemisphere countries which had not agreed to permit overflight.

The TCLBS flight system consists of a 4.15 meter balloon, solar panel, antenna, transmitter, encoder, magnetic cutdown, pressure cutdown, battery power supply, thermal enclosure, and temperature and vertical motion sensors. Emphasis throughout development has been on cost savings by redesign, by in-house fabrication of critical elements, and by computer-controlled testing of elements and system, both here and in the field.

The balloons fly at an equivalent pressure-altitude of 14.5 km. Location and telemetry acquisition are performed by the ARGOS system on the TIROS-N. These data are processed at Toulouse, France, and are relayed to NCAR for final processing, quality assurance, and archiving. Complete system tests were first conducted, successfully, from Ascension Island in November 1977, using the NIMBUS-VI satellite in lieu of the TIROS-N, which was not scheduled for launch until July 1978. Launch was not until mid-October. Four additional flights were launched from Canton Island in late August and early September. One was still aloft when the satellite checkout was completed and the system released for use. Location and data relay functions performed successfully.

During the first SOP, 153 launches were made. The Canton site team put up 75 flights and the Ascension team 78 in the period of 6 January to 4 February. Severe weather in the vicinity of Canton Island caused a large number of early flight failures. The electronic systems performed well; telemetry and location data derived from the French ARGOS system on the TIROS-N satellite were excellent.

Prior to the launch program, the Republic of China granted overflight permission. The magnetometer cutdown system was reprogrammed to permit China overflight with a significant increase in wind and temperature data in the Northern Hemisphere.

Analysis of trajectory data for TCLBS indicated poor coverage in the Indian Ocean. A third launch site has been established on Guam for the Second Special Observing Period during May-June 1979. NOAA will provide additional funds to cover the expenses of the third site.

The Safesonde system is being designed to meet the accuracy and cost requirements of major mesoscale and severe storm field programs. The design premise is that the expendable sonde should be the simplest possible device if it is to be low-cost and nonhazardous. System complexities should be kept on the ground. Also, complex mechanical systems are becoming more costly to build and more costly to maintain while electronic systems are decreasing in price as their capabilities increase. The system which was originally designed and tested consisted of four or more fixed receivers, separated by several kilometers, which relayed to a central station the difference in frequency between the sonde transmitter and a reference transmitter. A central computer determined the location in space of the sonde at 5-sec intervals. This system was built as a joint NOAA-NSF effort and tested by GAMP in July and December 1976. The test results showed a system of incomparable accuracy but with initialization requirements too severe for an operational system.

Additional design studies were undertaken by Michael Olson for the purpose of overcoming the initialization limitation. The most promising modifications are being tested in computer simulation. Field tests are being made when necessary to confirm important assumptions.

GAMP has joined forces with RSF to expedite this development. Several possible modifications are being investigated and tested. It is expected that a joint GAMP/RSF design review committee will be able to select the optimum modification soon.

The LLAMA program has grown out of the long-lived Atmospheric Monitoring Balloon (LLAMB) concept. LLAMB was a research effort to develop a balloon capability for flight in the lower stratosphere for durations of several years. While the Long-Duration Balloon Program of NCAR's National Scientific Balloon Facility has as its objective flights of months (with planned recovery) at the highest possible altitudes to float above the attenuating atmosphere, the LLAMB project had as its goal flight for years at the lowest safe altitude above the clouds and the airplanes. We are convinced that multi-year flights are not feasible using transparent balloon materials. Degradation of the material by high-energy protons will cause eventual destruction of materials strong enough to maintain adequate superpressure. Accordingly, we undertook studies of possible materials and analyzed their potential lifetimes.

Following this, a prototype 9-m LLAMB balloon was designed by Sig Stenlund, fabricated by Shedahl, and flown from our Christchurch, New Zealand launch site to determine how well a reflecting balloon would perform in situ. It carried both NIMBUS-VI and TIROS-N communications packages (in the event it outlived the NIMBUS satellite) for relaying the data from the extensively instrumented balloon. It also carried a cutdown that would terminate flight if the balloon moved north of 15°N latitude. This did, in fact, occur after one-and-one-quarter orbits in 40 days of flight.

In the early part of this report period, we completed our analysis of the excellent flight data. These data demonstrated that the concept is sound and that there are adequate design margins for a reflecting balloon to remain overpressured on the coldest night and within safe stress limits on the hottest day.

With the SP-747 aircraft now flying at 14 kilometers, and the Concorde authorized to fly as low as 15 kilometers, a safe window is no longer available for LLAMB-type flights. The flight level must be raised to 20 kilometers. Although balloon costs are increased, this higher level permits heavier payloads. The lighter winds at 20 km make it quite feasible to add a "latitude-seeking" capability to the platform. This possibility has given birth to the LLAMA.

A LLAMA flying at 20 km can be moved by a power plant using less than 100 watts at a speed of 5 knots. A simple 3-axis magnetometer can provide guidance to move the balloon to its mission latitude and maintain it there. Since the average meridonal velocity at 20 km is near zero, the LLAMA can be controlled within reasonable limits to stay south of the equator rather than being destroyed because of overflight restrictions, moved into or out of the Anarctic, or made to maintain some average latitude. It offers distinct logistical advantages: depending upon the state of the quasi-biennial stratospheric oscillation, it could be launched from an appropriate site, perhaps one with a blimp hanger, in the United States and then flown to the latitude of interest, drastically reducing transportation costs to distant launch sites.

Work on this project has necessarily been limited, despite the interest and encouragement we have received. Currently, as time has permitted, we have been working on:

a) Analysis of the flight-efficiency of the latitude-seeker for a variety of missions.

b) Determining optimum launch site in the U.S. for movement to tropics or the Southern Hemisphere.

c) Determining best altitude(s) for balloon for safety, for latitude-keeping, for cost, and for scientific missions.

d) Propeller and power-plant design.

e) Balloon material improvements indicated by 9-meter flight.

f) Communication systems.

g) Survey of potential users for uses such as:

   magnetic surveys
   Antarctic ice topography
   bench-mark station for satellite sensors
   quasi-biennial tracer
   ozone and other gas monitoring
   radiometric benchmark
   measurement of stratospheric gases and aerosols.

Upon completion of the second SOP launches, work will continue on this project. We expect to hold a workshop early in 1980 to further examine promising applications. Flights could begin as early as 1981.

Other projects that are being pursued, again on a limited basis, include support of flights from the Christchurch facility for several investigators and the development of an advanced nonhazardous ballooning system called MICROGHOST (GHOST stands for Global Horizontal Sounding Technique). This system will be able to fly in and under the aircraft lanes. It will be an inexpensive, lightweight system to be used for small-scale research projects as well as for global measurements of atmospheric motion. We plan to collaborate with the university community in establishing MICROGHOST projects to study gravity waves, turbulent exchange, and large-scale circulation. Flights could commence in 1982.

Other activities engaged in by GAMP were Omega surveys in support of the Monsoon Experiment (MONEX) by Michael Olson, Ranjit Passi, Aubrey Schumann and Brewster Rickel, and an Omega windfinding accuracy study (Olson and Passi). In addition, Olson assisted in the installation, and adaptation, of the WMO Nvaid windfinding systems aboard ships participating in the GWE.

NATIONAL SCIENTIFIC BALLOON FACILITY (NSBF)

Mission and Goals of NSBF

The mission and goals of the NSBF are to provide the scientific community with the most efficient and reliable operational balloon support possible and to conduct the research and development necessary to meet the demands of the scientific community.

NSBF supports a broad variety of scientific disciplines. The use of large balloons in atmospheric sciences has been growing steadily over the past several years. Thirty-one percent of the NSBF effort was devoted to atmospheric sciences during this reporting period.

The development of the long-duration flight system continued during the last twelve months. The goal of this development is thirty to ninety day flights at 36 km with payloads of approximately 250 kg.

An intensive effort within NSBF has been devoted to the problem of the high percentage of failures with heavy load flights (suspended loads in excess of 1590 kg).

Strategies

The NSBF Advisory Panel was asked at its meeting in January to address the question of future demands on NSBF and, in particular, the impact of the space shuttle program. The panel was unanimous in stating that they could see no decrease in future requirements. They agreed that the requirements could only increase in both number of flights and complexity.

They did not see the advent of the space shuttle as in any way competing with scientific ballooning. Access to the shuttle will be limited and expensive. The time delay between concept and exposure will be quite long.

The panel also reviewed the progress on the long-duration program. It was their opinion that progress is satisfactory and the goal of an operational system in FY 1981 is entirely reasonable. Looking ahead, the panel urged NSBF to consider requirements for increased payloads, 1000 to 2000 lbs, for the long-duration system.

With these comments, the strategy of NSBF becomes quite clear. We must continue to support an increasing demand for zero-pressure ballooning, from both Palestine and remote locations. Concurrently, we must plan for an operational long-duration system in FY 1981 and expand the capabilities of this system.

Accomplishments

A total of 78 flights were flown during this period. Of this total, 62 were in support of scientific experiments, 12 were connected with the heavy-load test program and 4 were NSBF test flights. The overall success rate was 85%.

Eleven flights were from remote sites. Of these, there was only one failure, a balloon failure in Australia. Four flights were flown from Alaska, three from Australia, one each from Argentina, Kingman, Arizona, Pierre, South Dakota; and Malden, Missouri.

A significant operational achievement was the support of the NIMBUS G (LIMS) satellite. Balloon flights were required to furnish "ground-truth" data for correlation with the satellite fly-overs. On two separate occasions, three flights were launched in one day for this purpose.

A second major undertaking was the operational testing conducted for NASA on heavy-load balloons. Twelve test flights were flown in this program. New balloon designs were tested and proven. A collar restraint device was developed and successfully tested. This device has proven useful in preventing large sail areas in the balloon bubble after release.

A new staging building was opened in July 1978. This building offers space for staging of six scientific experiments. The control tower and telemetry and computer functions will be moved to this building in the near future.

NATIONAL SCIENTIFIC BALLOON FACILITY USERS

J. Anderson
Harvard College

B. Bates
Queens University, Ireland

E. Chupp
University of New Hampshire

A. Clark
University of Calgary, Canada

T. Dean
University of Southampton, England

C. DeJager
SRL, The Netherlands

G. DiCocco
CNR, Italy

W. Evans
AES, Canada

G. Fazio
Smithsonian Observatory

H. Fischer
University of Munich

G. Frye
Case Western Reserve University

J. Harries
NPL, England

L. Haser
Max-Planck Institute

L. Heidt
NCAR

W. Hoffmann
University of Arizona

A. Jacobson
Jet Propulsion Laboratory

R. Jennings
University College, London

T. Kamperman
SRL, The Netherlands

N. Kjome
University of Wyoming

D. Kniffen
GSFC

Y. Kondo
GSFC

M. Leventhal
Sandia Laboratories

W. Lewin
MIT

J. Lockwood
University of New Hampshire

F. Low
University of Arizona

D. Martin
Queen Mary College, England

K. Mauersberger
University of Minnesota

R. Menzies
JPL

D. Murcray
University of Denver

T. Parnell
MSFC

D. Rabus
University of Munich

E. Reed
GSFC

G. Ricker
MIT

L. Sidwell
JPL

B. Teegarden
GSFC

A. Valenzuela
Max-Planck Institute

R. Van Duinen
University of Groningen

G. Villa
University of Milan

S. White
University of California, Riverside

D. Wilkinson
Princeton University

F. Witten
GSFC

R. Zander
University of Liege

ATD Director's Office

Clifford J. Murino (Director)
Byron Phillips (Deputy Director)[1]
Diane Eulian (Administrative Secretary)

[1] Effective 17 March 1979, Byron Phillips is on temporary assignment as Acting Manager of the Research Aviation Facility.

RAF Personnel

Lawrence Abbott
Theodore Adkisson
Harold Barber
Carl Beck
Edward Brown
Robert Burris
Robert Carl
James Covington
Charles Cullian
John Dee
Mary Dick
Margaret Earley
Carl Friehe
Richard Friesen
Richard Garrelts
Keith Griffith
Terry Kelly
Alex Kennel
Christopher Kilgus
Annabelle Kintz
Donald Lenschow
James Lugo
James Lundahl
David McFarland
Roger McIntosh
Thomas McQuade
Nelder Medrud, Jr.
George Naegele
Loyd Newcomer
Clay Orum
Victor Padilla
Byron Phillips
Charles Purdy
Matthew Reynolds
Paul Ruberg
Ronald Ruth
Paul Spyers-Duran
John Stone
Gilbert Summers
George Tate
Richard Taylor
Harry Vaughan III
George White
William Whelpley
Lester Zinser
M. Norman Zrubek

COMPUTING FACILITY STAFF (As of 31 March 1979)

Jeanne Adams
John Adams
Daniel Anderson
Frank Banks
Mary Bartels
Julia Bartram
Linda Besen
Robert Biro
Gerald Browning
Mary Buck
Beverley Chavez
Betsey Chen
Bang-Yaw Chin
Frederick Clare
Gaynez Connell
Ann Cowley
Willard Crittenden
Sylvia Darmour
Glen Davenport
Astrik Deirmendjian
Cynthia Del Pizzo
Benedict Domenico
John Donnelly
Margaret Drake
Salvador Farfan
Dean Frey
Karen Friedman
William Frye
David Fulker
Sandra Fuller
Bonnie Gacnik
John Gary
Shirley Gentry
Nancy Goldstein
Gilbert Green
Kenneth Hansen
Sue Hartter
Lofton Henderson
Stuart Henderson
Michael Hendrickson
Darrell Holley
John Humbrecht
Suzanne Hunter
Basil Irwin
Jesse James, III
Roy Jenne
Sue Jensen
Dennis Joseph
Wanda Keeney
David Kennison
David Kitts
Robert Lackman
Sara Ladd
Richard Lindenmoyer
Stephen Long
Jack Martindale
Stan McLaughlin
John Merrill
Pamela Moore
Donald Morris
Paul Mulder
Cindy Myers
Robert Niffenegger
Bernard O'Lear
Barbara O'Neil

Barbara Ostermann
Richard Oye
Harsh Passi
G. S. Patterson, Jr. (Manager)
Kelton Penner
Percy Peterson
Vickie Pinedo
Russell Rew
Cicely Ridley
Andrew Robertson
David Robertson
Paul Rotar
Richard Sato
Susan Schemel
Eugene Schumacher
Larry Scott
Valerie Shanahan
John Snyder
Wilbur Spangler
Kari Stordahl
David Strayer
Paul Swarztrauber
Roland Sweet
Linda Thiel
Mary Trembour
Alfonso Trujillo
Richard Valent
Colleen Velie
Fred Walden
Jo Walsh
Gregg Walters
Gloria Williamson
Marie Working
Thomas Wright

Field Observing Facility - Staff

Paul Ahlstrom
Gerald Albright
Harold Baynton
Richard Bobka
Robert Bowie
Joseph Boyajian
William Bragg
Fred Brock
Richard Carbone
Dana Dixon
Edward Elsberry
Gerald English
Don Ferraro
Charles Frush
Grant Gray
Brian Lewis
Robert McBeth
Gail Rust
Steven Semmer
Robert Serafin (Manager)
Joseph Vinson
James Wilson
Dale Zalewski

Field Observing Facility - Visitors

Mario Schaffner	Unaffiliated to 31 May 1978 Jan.-April 1979
Peter H. Hildebrand	Illinois State Water Survey From 1 July 1978

Research Systems Facility

Development

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

Engineering Services

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

Management/Administration

David Bargen (Manager)
Carol Nicolaidis
Mary Ann Pykkonen

Global Atmospheric Measurements Program

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

Special Project Staff

Jean Ebel
Paul Howes
Bernice McCain
William Whelpley

Visitors (Cooperative Program, NCAR/U. of Tenn.)

Neil Nevils
Alan Plunkett

National Scientific Balloon Facility

Charles Burris
James Carroll
Grady Cole
Robert Collett
Oscar Cooper
Alice Cradler
Bruce Cunningham
Harold Dean
Lawrence Farley
Atlee Fritz
Bettie Furman
Don Gage
Mack Gore
Arthur Gusa
Ralph Harju
William Harriman
Billy Harrison
Clarence Heide
Delbert Hoefling
Lawrence Huffman
Johnny Mack Ingram
Theo Johnson
Robert Kubara
Lloyd Lasiter
Jarvis Lehmann
Danny Masur
Charles Palmer
Robert Perrin
Spencer Petri
Michael Poarch
Javiel Quintanilla
Mary Beth Reno
Bert Ricard
Marvin Riley
William Schumacher
Alfred Shipley (Manager)
Titus Sigler
Delwyn Sims
Earl Smith
Steve Smith
John Sparling
Eileen Turner
Virgil Vice
Emmer Woodard
Homer Woody
Nuel Woolverton
Boyce Worley

PUBLICATIONS

Publications of NCAR staff and visitors that either appeared or were accepted between 1 April 1978 and 31 March 1979 are listed below. Publications that appeared too late to be included in last year's report are also listed. An asterisk indicates a non-NCAR coauthor.

Atmospheric Analysis and Prediction Division

BAUMHEFNER, D., and P. DOWNEY: Forecast intercomparison from three numerical weather prediction models. *Mon. Weather Rev. 106,* 1245-1279, 1978.

______ and T. W. BETTGE: Spectral decomposition of the NMC operational 500 mb geopotential during the Global Weather Experiment SOP-1. *The GARP Programme on Numerical Experimentation,* Report No. 19, in press, 1979.

BRANSTATOR, G. W., S. D. WHITAKER, L. G. THIEL, and T. W. SCHLATTER: Quality control of Global Weather Experiment data using an interactive graphics system. In *Proc. Conference on Weather Forecasting and Analysis and Aviation meteorology,* 16-19 Oct. 1978, Silver Spring, Md., 197-200, 1978.

BRETHERTON, F. P., and J. C. McWILLIAMS: *Spectral Estimation from Irregular Arrays.* Technical Note NCAR/TN-138+STR, NCAR, Boulder, Colo., 1979.

BROWN, J. M.: *Central Iowa Tornado Family, 13 June 1976.* Final report under grant No. 01-7-022-13204 from National Oceanic and Atmospheric Administration to Iowa State University, 132 pp., 1979.

______: Mesoscale unsaturated downdrafts driven by rainfall evaporation: A numerical study. *J. Atmos. Sci. 36,* 313-338, 1979.

______ and *A. R. HANSEN: Considerations regarding the atmospheric water budget over south Florida. Part II of final report under grant No. 04-7-022-44030 from National Oceanic and Atmospheric Administration to Iowa State University, John M. Brown, principal investigator, 32 pp., 1978.

CHERVIN, R. M.: Response of the NCAR atmospheric general circulation model to changed sea-surface temperature. In *Proc. JOC Study Conference on Climate Models: Performance, Intercomparison and Sensitivity Studies,* 3-7 April 1978, Washington, D. C., in press, 1979.

______: Response of the NCAR atmospheric general circulation model to changed albedo. In *Proc. JOC Study Conference on Climate Models: Performance, Intercomparison and Sensitivity Studies,* 3-7 April 1978, Washington, D. C., in press, 1979.

______: Sampling considerations in estimating second moment climate quantities. In *Proc. JOC Study Conference on Climate Models: Performance, Intercomparison and Sensitivity Studies,* 3-7 April 1978, Washington, D. C., in press, 1979.

______: Sensitivity of the NCAR general circulation model to change in surface albedo: Implications for regional droughts. In *Proc. Bilateral United States-Argentinian Workshop on Droughts,* 4-9 December 1978, Mar del Plata, Argentina, in press, 1979.

COAKLEY, J. A. Jr.: A study of climate sensitivity using a simple energy balance climate model. *J. Atmos. Sci. 36,* 260-269, 1979.

*COLEMAN, B. R., and T. W. SCHLATTER: An exactly reversible calculation of the rotational and divergent wind potentials in a limited area. In *Summer Fellowship in Scientific Computing,* Technical Note NCAR/TN-135+PROC, NCAR, Boulder, Colo., 45-61, 1979.

DALEY, R.: Variational nonlinear normal mode initialization. *Tellus 30,* 201-218, 1978.

______: The application of nonlinear normal mode initialization to an operational forecast model. *Atmos.-Ocean 17,* in press, 1979.

______ and *Y. BOURASSA: Rhomboidal versus triangular spherical harmonic truncation: Some verification statistics. *Atmos.-Ocean 16,* 187-196, 1978.

DICKINSON, R. E., *S. C. LIU, and *T. M. DONAHUE: Effect of chlorofluoromethane infrared radiation on zonal atmospheric temperatures. *J. Atmos. Sci. 35,* 2142-2152, 1978.

*DOBOSY, R. J., and R. C. J. SOMERVILLE: Tests of simple momentum boundary-layer parameterizations in a numerical weather prediction model. *Contrib. Atmos. Phys.,* in press, 1979.

DURNEY, B. R.: *On the Interaction between Mesoscale Eddies and Topography.* Technical Note NCAR/TN-136+STR, NCAR, Boulder, Colo., 1979.

*GALL, R. L., *R. BLAKESLEE, and R. C. J. SOMERVILLE: Baroclinic instability and the selection of the zonal scale of the transient eddies of middle latitudes. *J. Atmos. Sci.*, in press, 1979.

*______, *______, and ______: Cyclone-scale forcing of ultra-long waves. *J. Atmos. Sci.*, in press, 1979.

GENT, P.: Standing equatorial wave modes in bounded ocean basins. *J. Phys. Oceanogr.*, in press, 1979.

*GHAZI, A., V. RAMANATHAN, and R. E. DICKINSON: Acceleration of upper atmospheric radiative damping: Observational evidence. *Geophys. Res. Lett.*, in press, 1979.

*GROTJAHN, R.: *The Influence of Thermal Fronts upon the Solutions of an Analytical Model of a Mid-Latitude Wave-Cyclone.* NCAR/CT-52, NCAR, Boulder, Colo., 151 pp., 1979.

*HANSEN, A. R., and J. M. BROWN: A water-budget study of south Florida thunderstorm clusters. Part I of final report under grant No. 04-7-022-44030 from National Oceanic and Atmospheric Administration to Iowa State University, John M. Brown, principal investigator, 183 pp., 1978.

*HART, J. E., *G. V. RAO, H. van de BOOGAARD, *J. A. YOUNG, and *J. FINDLATER: Aerial observations of the East African low-level jet stream. *Mon. Weather Rev. 106,* 1714-1724, 1978.

HERRING, J. R., and *R. H. KRAICHNAN: A numerical comparison of velocity-based and strain-based Lagrangian-history turbulence approximations. *J. Fluid Mech.*, in press, 1979.

______ and *G. R. NEWMAN: A test field model study of a passive scalar in isotropic turbulence. In *Proc. Second Symposium on Turbulent Shear Flows,* 2-4 July 1979, Imperial College, London, England, in press, 1979.

HOLLAND, W. R.: The general circulation of the ocean and its modeling. *Dyn. Atmos. Oceans,* in press, 1979.

______ and *D. B. HAIDVOGEL: The mixed instability of idealized ocean currents. *Dyn. Atmos. Oceans,* in press, 1979.

______ and *P. B. RHINES: An example of eddy-induced ocean circulation. *Dyn. Atmos. Oceans,* in press, 1979.

*JENSEN, N. O., and D. H. LENSCHOW: An observational investigation of penetrative convection. *J. Atmos. Sci. 35,* 1924-1933, 1978.

JULIAN, P. R., and R. M. CHERVIN: A study of the southern oscillation and Walker circulation. *Mon. Weather Rev. 106,* 1433-1451, 1978.

*KÅLLBERG, P., T. W. SCHLATTER, et al.: Results of the FGGE End-to-End Test during SOP-1, conducted with global data from 15-19 January 1979. European Centre for Medium Range Weather Forecasts, Shinfield Park, Reading, U.K., 11 pp., 1979.

KASAHARA, A.: Further studies on a spectral model of the global barotropic primitive equations with Hough harmonic expansions. *J. Atmos. Sci. 35,* 2043-2051, 1978.

______: Toward achieving the goal of atmospheric scientists—Understanding our atmosphere. *Atmos. Technol. 11,* in press, 1979.

KELLOGG, W. W.: Effect of carbon dioxide on climate. *Annu. Rev. Earth Planet. Sci. 7,* 1978.

______: Potential consequences of a global warming. In *Man's Impact on Climate* (W. Bach, J. Pankaath, and W. W. Kellogg, Eds.), Elsevier Scientific Publ. Co., Amsterdam, 1978.

______: Modeling the climate effects of increased CO_2. *A Comprehensive Plan for Carbon Dioxide Research,* Department of Energy, Washington, D. C., 1978.

______: Implications of climatic change for patterns of agriculture. *Ceres* (FAO Journal), 1978.

*KRAICHNAN, R. H., and J. R. HERRING: A strain-based Lagrangian-history turbulence theory. *J. Fluid Mech. 88,* 355-367, 1978.

KREITZBERG, C. W., and *C. B. CHANG: Potential impact of small-scale short-range numerical weather prediction models on aviation weather forecasting. In Preprint Vol., Conference on Atmospheric Environment of Aerospace Systems and Applied Meteorology, New York, N. Y., 13-17 November 1978.

______ and *R. G. RASMUSSEN: Treatment of cloudiness in regional scale numerical weather prediction models. In Preprint Vol., Conference on Cloud Physics and Atmospheric Electricity, Issaquah, Wash. AMS, Boston, Mass., 506-513, 1978.

KUETTNER, J., *Z. LEVIN, and D. SARTOR: Inductive or noninductive electrification of thunderstorms. In Preprint Vol., Conference on Cloud Physics and Atmospheric Electricity, Issaquah, Wash. AMS, Boston, Mass., 649-654, 1978.

LEITH, C. E.: Predictability of climate. *Nature 276 (23),* 352-355, 1979.

______: Mechanisms of short-period climate fluctuations. In *Proc. Conference on Evolution of Planetary Atmospheres and Climatology of the Earth,* 16-20 October 1978, Nice, France, in press, 1979.

______: Review of atmospheric general circulation models. In *Proc. JOC Study Conference on Climate Models: Performance, Intercomparison and Sensitivity Studies,* 3-7 April 1978, Washington, D. C., in press, 1979.

______: Climate predictability. In *Proc. 13th International Symposium on Remote Sensing of Environment,* 23-27 April 1979, Ann Arbor, Mich., in press, 1979.

LILLY, D. K.: On the upper boundary condition of a cloud-topped mixed layer. *Proc. Boundary Layer Workshop,* 14-18 August, Boulder, Colo., 1978.

———: The dynamical structure and evolution of thunderstorms and squall lines. *Annu. Rev. Earth Planet. Sci. 7,* 1979.

MADDEN, R. A.: Problems in detecting and predicting climate change. In *General Circulation: Theory, Modeling and Observations,* NCAR/CQ-6+1978-ASP, NCAR, Boulder, Colo., in press, 1979.

———: Further evidence of traveling planetary waves. *J. Atmos. Sci. 35,* 1605-1618, 1978.

———: A simple approximation for the variance of meteorological time averages. *J. Appl. Meteorol.,* in press, 1979.

———: Observations of large-scale traveling Rossby waves. *Rev. Geophys. Space Phys.,* in press, 1979.

——— and D. J. SHEA: Estimates of the natural variability of time-averaged temperatures over the United States. *Mon. Weather Rev. 106,* 1695-1703, 1978.

MASTERSON, J.: Wind measurements by meteorological rockets. *Atmos. Technol. 10,* 61-64, Winter 1978-79.

MATSUNO, T., and *K. NAKAMURA: The Eulerian and Lagrangian mean meridional circulations in the stratosphere at the time of a sudden warming. *J. Atmos. Sci.,* in press, 1979.

McWILLIAMS, J. C.: A review of research on mesoscale ocean currents. *Rev. Geophys. Space Phys.,* in press, 1979.

——— and *G. R. FLIERL: On the evolution of isolated non-linear vortices. *J. Phys. Oceanogr.,* in press, 1979.

——— and P. R. GENT: Corrigendum. *J. Atmos. Sci. 36,* 181, 1979.

——— and *R. HEINMILLER: *The POLYMODE Local Dynamics Experiment: Objectives, Location, and Plan.* U. S. POLYMODE OFFICE, MIT 54-1417, Cambridge, Massachusetts, 28 pp., 1978.

MEEHL, G. A.: *Tropical Teleconnections to the Seesaw in Winter Temperatures between Greenland and Northern Europe.* NCAR/CT-51, NCAR, Boulder, Colo., 110 pp., 1978.

——— and H. van LOON: The seesaw in winter temperatures between Greenland and Northern Europe. Part III: Teleconnections with lower latitudes. *Mon. Weather Rev.,* in press, 1979.

THE *MODE* GROUP: The mid-ocean dynamics experiment. *Deep-Sea Res. 25,* 859-910, 1978.

*NEWMAN, G. R., and J. R. HERRING: A test field model study of a passive scalar in isotropic turbulence. *J. Fluid Mech.,* in press, 1979.

NEWTON, C. W., and *S. L. BARNES: Thunderstorms in the synoptic setting. Chapter IV in Part II of *Thunderstorms: A Social, Scientific, and Technological Documentary* (E. Kessler, Ed.), University of Oklahoma Press, in press, 1979.

*NORTH, G. R., and J. A. COAKLEY Jr.: Simple seasonal climate models. *Meteorologiya i Gidrologiya* No. 5, 26-32, 1978 (in Russian).

*OWEN, T., *R. D. CESS, and V. RAMANATHAN: Early earth: An enhanced carbon-dioxide greenhouse to compensate for reduced solar luminosity. *Nature,* in press, 1979.

*PENNELL, W. T., D. H. LENSCHOW, and M. A. LeMONE: Some aspects of turbulence in the atmospheric boundary layer. In *Heat Transfer Studies: A festschrift for E.R.G. Eckert* (T. S. Irvine et al., Eds.), Hemisphere Publishing Corp., Washington, D. C. In press, 1979.

RAMANATHAN, V., and R. E. DICKINSON: The role of stratospheric ozone in the zonal and seasonal radiative energy balance of the earth-troposphere system. *J. Atmos. Sci.,* in press, 1979.

———, *M. S. LIAN, and *R. D. CESS: Increased atmospheric CO_2: Zonal and seasonal estimates of the effect on the radiation energy balance and surface temperature. *J. Geophys. Res.,* in press, 1979.

*RHINES, P., and W. R. HOLLAND: A theoretical discussion of eddy-driven mean flows. *Dyn. Atmos. Oceans,* in press, 1979.

*ROGERS, J. C., and H. van LOON: The seesaw in winter temperatures between Greenland and Northern Europe. Part II: Some oceanic and atmospheric effects in middle and high latitudes. *Mon. Weather Rev.,* in press, 1979.

SARTOR, J. D.: Cloud particle distributions and microstructure in the USSR and the continental USA. In *Some Problems of Cloud Physics,* published by the Soviet Geophysical Committee, Academy of Sciences of the USSR, Commission on Cloud Physics, Gidrometeoizdat, 186-193, 1978.

SCHLATTER, T. W.: NCAR's role in the Global Weather Experiment. *Atmos. Technol. 11,* in press, 1979.

——— and G. W. BRANSTATOR: Estimation of errors in Nimbus 6 temperature profiles and their spatial correlation. *Mon. Weather Rev. 107,* in press, 1979.

SCHNEIDER, S. H.: Climatic change and the human predicament. In *The Future of Human Settlements in the Rocky Mountain West* (T. J. Minger, Ed.), The Printery at Vail, Ltd., Vail, Colo., 211-219, 1978.

______: Climatic limits to growth: How soon? How serious? In *Carbon Dioxide, Climate and Society,* International Institute for Applied Systems Analysis, Laxenburg, Austria, 219-225, 1978.

______: Comparative risk assessment of energy systems. *Energy,* in press, 1979.

______ and R. S. LONDER: The Genesis strategy. *Politics Today 5,* 14, 1978.

______ and ______: Waiting for warmer weather. *Human Nature 1,* 76, 1978.

______, *B. L. TAYLOR, and *T. GAL-CHEN: Volcanic eruptions and long-term temperature records: An empirical search for cause and effect. *Q. J. R. Meteorol. Soc.,* in press, 1979.

______ and S. THOMPSON: Ice ages and orbital variations: Some simple theory and modeling. *Quat. Res.,* in press, 1979.

______, W. M. WASHINGTON, and R. M. CHERVIN: Cloudiness as a climatic feedback mechanism: Effects on cloud amounts of prescribed global and regional surface temperature changes in the NCAR GCM. *J. Atmos. Sci. 35,* 2207-2221, 1978.

SHEN, C., and J. C. McWILLIAMS: *Optimal Arrays for Estimating Horizontal Derivatives in a Potential Vorticity Balance: A Contribution to the Design of the POLYMODE Local Dynamics Experiment. University of Washington Special Report No. 85,* 46 pp., 1978.

SOMERVILLE, R. C. J.: Effects of initial data and computational domain on numerical predictions of ultra-long waves. *The GARP Programme on Numerical Experimentation,* Report No. 19, in press, 1979.

______ and T. GAL-CHEN: Numerical simulation of convection with mean vertical motion. *J. Atmos. Sci.,* in press, 1979.

______ and B. SHKOLLER: The effect of computational resolution on two-day 500 mb forecasts. *The GARP Programme on Numerical Experimentation,* Report No. 18, 50-52, 1978.

*STANIFORTH, A., and R. W. DALEY: A baroclinic finite-element model for regional forecasting with the primitive equations. *Mon. Weather Rev. 107,* 107-121, 1979.

*TAYLOR, P. A., and P. R. GENT: Modification of the boundary layer by orography. *Orographic Effects in Planetary Flows,* GARP Publication Series, in press, 1979.

*TEMPERTON, C., and D. L. WILLIAMSON: *Normal Mode Initialization for a Multi-Level Grid Point Model.* ECMWF Technical Report No. 11, European Centre for Medium Range Weather Forecasts, Shinfield Park, Reading, England, 91 pp., 1979.

THIEL, L. G., and G. W. BRANSTATOR: *The quality control program – A detailed description of data checking procedures in the NCAR multivariate statistical objective analysis system.* Report No. 0501-78/02, NCAR, Boulder, Colorado, 46 pp., 1978.

THOMPSON, P. D.: The mathematics of meteorology. In *Mathematics Today: 12 Informal Essays* (Arthur Lynn Steen, Ed.), Springer-Verlag, 1978.

THOMPSON, S. L., and S. H. SCHNEIDER: A seasonal zonal energy balance climate model with an interactive lower layer. *J. Geophys. Res.,* in press, 1979.

Van LOON, H.: Changes in eddy heat flux in the winter and their significance for temperature trends at the surface. In *General Circulation: Theory, Modeling and Observations,* NCAR/CQ-6+1978-ASP, NCAR, Boulder, Colo., in press, 1979.

______: Changes in eddy heat flux in winter and their significance for temperature trends at the surface. Summary of a report given at the USA-USSR Symposium on CO_2 and Climate, Dushanbe, October 1978, in press, 1979.

______: The association between latitudinal temperature gradient and eddy transport. Part I: Transport of sensible heat in winter. *Mon. Weather Rev.,* in press, 1979.

______: Reply, *Mon. Weather Rev. 107,* 90, 1979.

*WARREN, S. G., and S. H. SCHNEIDER: Seasonal simulation as a test for uncertainties in the parameterizations of a "Budyko-Sellers" zonal climate model. *J. Atmos. Sci.,* in press, 1979.

WASHINGTON, W. M.: A review of general circulation model experiments on the Indian Monsoon. In *Monsoon Dynamics* (Sir James Lighthill and Prof. R. P. Pearce, Eds.), Cambridge University Press, Cambridge, England, in press, 1979.

______ and R. M. CHERVIN: Regional climatic effects of large-scale thermal energy consumption: Simulation studies with the NCAR general circulation model. *J. Appl. Meteorol. 18(1),* 3-16, 1979.

______, R. DICKINSON, V. RAMANATHAN, T. MAYER, D. WILLIAMSON, G. WILLIAMSON, and R. WOLSKI: Preliminary atmospheric simulation with the third-generation NCAR general circulation model: January and July. In *Proc. JOC Study Conference on Climate Models: Performance, Intercomparison and Sensitivity Studies,* 3-7 April 1978, Washington, D. C., in press, 1979.

WILLIAMS, J., and H. van LOON: Trends of winter temperature in the southern hemisphere. In *Climatic Change and Variability – A Southern Perspective* (A. B. Pittock et al., Eds.), Cambridge University Press, 1978.

WILLIAMSON, D. L.: Difference approximations for fluid flow on a sphere. Chapter 2 of *Numerical Methods Used in Atmospheric Models,* Volume 2, to appear in GARP publications series, 1979.

ZIPSER, E. J., and A. H. MILLER: Aircraft penetrations of cumulonimbus clouds during GATE. In Preprint Vol., Conference on Cloud Physics and Atmospheric Electricity, Issaquah, Wash. AMS, Boston, Mass., 430-434, 1978.

Atmospheric Quality Division

BAILEY, P. L., and J. C. GILLE: An approximate method for nonlinear inversion of limb radiance observations. In *Remote Sensing of the Atmosphere: Inversion Methods and Applications* (A. L. Fymat and V. E. Zuev, Eds.), Elsevier Scientific Publishing Company, Amsterdam, 115-122, 1978.

CADLE, R. D.: Collection and analysis of stratospheric particles. *Atmos. Technol. 9,* 14-19, 1978.

———: Discussion of measurements of the photochemical production of aerosols in ambient air near a freeway for a range of SO_2 concentrations. *Atmos. Environ. 12,* 1246, 1978.

———: Review of *Environmental Pollutants. Detection and Measurement. J. Coll. Interface Sci. 69,* 196-197, 1979.

———, M. A. SHAPIRO, and G. LANGER: Concentrations of condensation nuclei in the vicinity of jetstream maxima. *Archives for Meteorology, Geophysics, and Bioclimatology,* in press.

CRUTZEN, P. J.: Chlorofluoromethanes: Threats to the ozone layer. *IUGG Quadrennial Report,* in press, 1979.

———: The role of NO and NO_2 in the chemistry of the troposphere and stratosphere. *Annu. Rev. Earth Planet. Sci.,* in press, 1979.

———, *J. FISHMAN, and *S. SOLOMON: Observational evidence in support of a significant in-situ photochemical source of tropospheric ozone. *Tellus,* in press, 1979.

——— and *C. J. HOWARD: The effect of the HO_2 + NO reaction constant on one-dimensional model calculations of stratospheric ozone perturbations. *Pure Appl. Geophys. 116,* 497-510, 1978.

———, *I. S. A. ISAKSEN, and *J. R. MCAFEE: The impact of the chlorocarbon industry on the ozone layer. *J. Geophys. Res. 83,* 345-363, 1978.

*ELLINGSON, R. G., and J. C. GILLE: An infrared radiative transfer model. Part I: Model description and comparison of observations with calculations. *J. Atmos. Sci. 35,* 523-545, 1978.

*FISHMAN, J., and P. J. CRUTZEN: The origin of ozone in the troposphere. *Nature 274,* 855-858, 1978.

*——— and ———: The distribution of the hydroxyl radical in the troposphere. Atmospheric Science Paper No. 284, Department of Atmospheric Science, Colorado State University, Fort Collins, 87 pp., 1978.

GILLE, J. C.: Middle atmosphere processes revealed by satellite observations. *J. Atmos. Terr. Phys. 41,* 1-16, 1979.

———: Introduction. *Atmos. Technol. 9,* 1-2, 1978.

——— and P. L. BAILEY: Information content and results of non-linear inversion of Nimbus 6 Limb Radiance Inversion Radiometer data. In *Remote Sensing of the Atmosphere: Inversion Methods and Applications* (A. L. Fymat and V. E. Zuev, Eds.) Elsevier Scientific Publishing Company, Amsterdam, 107-113, 1978.

———, M. T. COFFEY, W. G. MANKIN, *V. G. KUNDE, and *A. T. STAIR Jr.: The Cryogenic Limb Scanning Interferometer-Spectrometer and Radiometer (CLIR) for Space Shuttle. In Technical Digest, OSA Topical Meeting on Atmospheric Spectroscopy, Keystone, Colo. OSA, Washington, D. C., 1978.

——— and W. G. MANKIN: Observing the upper atmosphere from satellites. *Atmos. Technol. 9,* 80-93, 1978.

HAAGENSON, P. L.: Meteorological and climatological factors affecting Denver air quality. *Atmos. Environ. 13,* 79-85, 1978.

*HARTMANN, D. L., and R. R. GARCIA: A mechanistic model of ozone transport by planetary waves in the stratosphere. *J. Atmos. Sci. 36,* 350-364, 1979.

*HAYS, P. B., and R. G. ROBLE: Coupling of magnetospheric electrical effects into the global atmospheric electrical circuit. *Proc. Chapman Conference on Quantitative Modelling of Magnetospheric Processes* (W. P. Olson, Ed.).

*——— and R. G. ROBLE: Quasi-static model of global atmospheric electricity I. The lower atmosphere. *J. Geophys. Res.,* in press, 1979.

*———, R. G. ROBLE, and *J. W. MERRIWEATHER: Nighttime thermospheric winds at high latitudes. *J. Geophys. Res.,* in press, 1979.

———, *D. W. RUSCH, R. G. ROBLE, and *J. C. G. WALKER: The OI (6300 A) airglow. *Space Sci. Rev. 16,* 225-232, 1978.

HEIDT, L. E.: Whole air collection and analysis. *Atmos. Technol. 9,* 3-7, 1978.

*HERNANDEZ, G., and R. G. ROBLE: Observations of large-scale thermospheric waves during geomagnetic storms. *J. Geophys. Res. 83,* 5531-5538, 1978.

*______ and ______: On divergences of thermospheric meridional winds at midlatitudes. *Geophys. Res. Lett.,* in press, 1979.

*______ and ______: A relationship between midlatitude thermospheric winds and the time rate of change of Dst. *Geophys. Res. Lett. 5,* 835-838, 1978.

*______ and ______: Thermospheric dynamics investigations with very high resolution spectrometers. *Appl. Opt.,* in press, 1979.

*KLEY, D., and E. J. STONE: Measurement of water vapor in the stratosphere by photodissociation with Ly α (1216A) light. *Rev. Sci. Instrum. 49,* 691-697, 1978.

LAZRUS, A. L., B. W. GANDRUD, and J. P. GREENBERG: Indophenal ammonia test in measurement of HNO_3 and NO_3^-. In *Current Methods to Measure Atmospheric Nitric Acid and Nitrate Artifacts* (R. K. Stevens, Ed.), EPA-600/2-79-051, 45-50, 1979.

*LEE, T.-H., and J. C. GILLE: Design and construction of a temperature wave generator. *Rev. Sci. Instrum. 49,* 1112-1115, 1978.

MANKIN, W. G.: Fourier transform method for calculating the transmittance of inhomogeneous atmospheres. *Appl. Opt. 18,* 1979.

______: A Fourier transform method for calculating atmospheric transmittances. In Technical Digest, OSA Topical Meeting on Atmospheric Spectroscopy, Keystone, Colo. OSA, Washington, D. C., 1978.

______: Spectroscopic measurements from aircraft. In Preprint Vol., Fourth Symposium on Meteorological Observations and Instrumentation, Denver, Colo. AMS, Boston, Mass., 542-546, 1978.

______ and M. T. COFFEY: Airborne Fourier transform spectroscopy. In Technical Digest, OSA Topical Meeting on Atmospheric Spectroscopy, Keystone, Colo. OSA, Washington, D. C., 1978.

MARTELL, E. A.: Bronchial cancer in cigarette smokers from alpha emitting "warm particles." In *Proc. DOE Hearings on the Draft Environmental Impact Statement,* ERDA-1545-D, Rocky Flats Plant Site, Denver, Colorado, 24 May 1978.

______: Production of nuclei in the atmosphere by alpha interactions. In *Proc. Ninth International Conference on Atmospheric Aerosols, Condensation and Ice Nuclei,* Pergamon Press, 1979.

*MOORE, H. E., S. E. POET, and E. A. MARTELL: The size distribution and origin of ^{210}Po on airborne particles in the troposphere. In *Proc. Houston Conference, Natural Radiation Environment IIIV,* 1979.

*OLYSZYNA, K., R. D. CADLE, and *R. G. de PENA: Stratospheric decomposition of ozone. *J. Geophys. Res.,* in press, 1979.

*PERKINS, F. W., and R. G. ROBLE: Ionospheric heating by radiowaves: Predictions for Arecibo and the satellite power station. *J. Geophys. Res. 83,* 1611-1624, 1978.

*REES, R. G., and R. G. ROBLE: The morphology of N and NO in auroral substorms. *Planet. Space Sci.,* in press, 1979.

*REID, G. C., *J. R. MCAFFEE, and P. J. CRUTZEN: Effects of intense stratospheric ionisation events. *Nature 257,* 489-492, 1978.

*RICHMOND, A. D., and R. G. ROBLE: Dynamic effects of aurora-generated gravity waves on the midlatitude ionosphere. *J. Atmos. Terr. Phys.,* in press, 1979.

ROBLE, R. G., R. E. DICKINSON, E. C. RIDLEY, and *Y. KAMIDE: Thermospheric response to the 8-9 November 1969 magnetic disturbances. *J. Geophys. Res.,* in press, 1979.

______ and *P. B. HAYS: Electrical coupling between the upper and lower atmosphere. *Proc. Solar-Terrestrial Influences on Weather and Climate Symposium/Workshop* (B. M. McCormac, Ed.), 1978.

______, *A. D. RICHMOND, *W. L. OLIVER, and *R. M. HARPER: Ionospheric effects of the gravity wave launched by the September 18, 1974 sudden commencement. *J. Geophys. Res. 83,* 999-1009, 1978.

______ and *G. SCHMIDTKE: Calculated ionospheric variations due to changes in the measured solar EUV flux. *J. Atmos. Terr. Phys. 41,* 153-160, 1979.

______, *A. I. STEWART, *M. R. TORR, *D. W. RUSCH, and *R. H. WAND: The calculated and observed ionospheric properties during Atmospheric Explorer-C satellite crossings over Millstone Hill. *J. Atmos. Terr. Phys. 40,* 21-33, 1978.

ROSE, W. I. Jr., R. D. CADLE, L. E. HEIDT, *I. FRIEDMAN, A. L. LAZRUS, and B. J. HUEBERT: Gas and H isotopic analyses of volcanic eruption clouds in Guatemala sampled by aircraft. *J. Volcanology Geothermal Res.,* in press, 1979.

*RUSSELL, J. M., and J. C. GILLE: The Limb Infrared Monitor of the Stratosphere (LIMS) experiment. *The Nimbus 7 Users' Guide,* 71-103, 1978.

SHAPIRO, M. A.: Further evidence of the mesoscale and turbulent structure of upper level jet stream-frontal zone systems. *Mon. Weather Rev. 106,* 1101-1111, 1978.

*TAYLOR, F. B., *D. J. DINES, *D. J. McCLEER, *L. S. ELSON, *J. V. MARTINCHICK, *J. DETTERFIELD, *J. T. SCHOFIELD, *S. E. BRADLEY, M. T. COFFEY, and J. C. GILLE: Temperature, cloud structure and dynamics of the middle atmosphere of Venus from infrared remote sensing. *Science,* in press, 1979.

*THOMAS, G. E., *C. BARTH, *E. HANSON, *C. HORDE, *G. LAWRENCE, *G. MOUNT, *G. ROTTMAN, *D. RUSCH, *A. I. STEWART, *R. THOMAS, *J. LONDON, P. L. BAILEY, P. J. CRUTZEN, R. E. DICKINSON, J. GILLE, *S. LIU, *J. NOXON, and *C. FARMER: Scientific objectives of the Solar Mesosphere Explorer mission. *Pure Appl. Geophys.*, in press, 1979.

*ZIMMERMAN, P. R., *R. B. CHATFIELD, *J. FISHMAN, P. J. CRUTZEN, and *P. L. HANST: Estimates on the production of CO and H_2 from the oxidation of hydrocarbon emissions from vegetation. *Geophys. Res. Lett. 5,* 679-682, 1978.

High Altitude Observatory

ANZER, U., and A. I. POLAND: Mass flow in loop type coronal transients. *Solar Phys.*, in press, 1979.

*ARIGO, R., *K. CZUHAI, *E. HUBBARD, P. NOERDLINGER, and *K. WISNER: Binary galaxy statistics. II. Observed axis ratios and position angles for galaxies in pairs. *Astrophys. J. 223,* 410-420, 1978.

ATHAY, R. G.: Modeling the solar photosphere and chromosphere. *Mem. S. A. It.*, 401-437, 1978.

______: Chromospheric motions observed by the University of Colorado experiment on OSO8. *Mem. S.A. It.*, 509-523, 1978.

______: Evolution of the physical universe. In *Science and Religion: Toward a More Useful Dialogue*, Vol. I (W. M. Hess and R. T. Matheny, Eds.), Paladin Pub., Geneva, Ill., approx. 40 pp.

______: Energy flow in the chromosphere and corona. Scientific Report, Commission 12, IAU, in press, 1979.

______ and O. R. WHITE: Chromospheric and coronal heating by sound waves. *Astrophys. J. 226,* 1135-1139, 1978.

______ and ______: Chromospheric oscillations observed with OSO-8. II. Average power spectra for Si II. *Astrophys. J. Suppl. Ser. 39,* 333-346, 1979.

______ and ______: Chromospheric oscillations observed with OSO-8 IV: Power and phase spectra for C IV. *Astrophys. J.*, in press, 1979.

AUER, L. H., and *J. N. HEASLEY: The origin of broad-band circular polarization in sunspots. *Astron. Astrophys. 64,* 67-71, 1978.

______ and *W. F. van ALTENA: Digital image centering II. *Astron. J. 83,* 531, 1978.

______, *K. AUER, *E. D. HOFFLEIT, and *W. F. van ALTENA: Trigonometric parallaxes for southern hemisphere stars. *Astron. J. 83,* 640, 1978.

*BECKERS, J. M., and T. M. BROWN: Solar circulation measurements: Considerations and plans. Paper presented at JOSO Workshop on Future Solar Optical Observations, Florence, 7-10 November 1978.

*______ and P. A. GILMAN: Rotation at high solar latitudes and the depth of the solar convection zone. *Proc. Workshop on Solar Rotation,* Catania, Italy, 16-29 September 1978, Astrophysical Observatory of Catania Publication No. 162.

*BONNET, R. M., *P. LEMAIRE, *J. C. VIAL, *G. ARTZNER, *P. GOUTTEBROZE, *A. JOUCHOUX, *J. LEIBACHER, A. SKUMANICH, and *A. VIDAL-MADJAR: The LPSP instrument of OSO-8. II. In flight performance and preliminary results. *Astrophys. J. 221,* 1032-1061, 1978.

BROWN, J. C.: Analysis of Bremsstrahlung source spectra in terms of integral moments. *Astrophys. J. 225,* 1076-1082, 1978.

______ and Y. NAKAGAWA: On the theoretical significance of density measurements in XUV flare kernals. *Astrophys. J. 225,* L153-L156, 1978.

______, *D. B. MELROSE, and *D. S. SPICER: Production of a collisionless conduction front by rapid coronal heating and its role in solar hard X-ray bursts. *Astrophys. J.*, in press, 1979.

BROWN, T. M.: Reconstruction of turbulence-degraded images using non-redundant aperture arrays. *J. Opt. Soc. Am. 68,* 883-889, 1978.

______: Performance of image-plane sharpness criteria in image reconstruction. *J. Opt. Soc. Am. 68,* 890-892, 1978.

______: The effect of seeing fluctuations on solar limb measurements. Sacramento Peak Observatory Research Memorandum 1, 1978.

______: Observed brightness oscillations at the solar limb. *Astrophys. J.*, in press, 1979.

______ and *R. L. HARRISON: Solar continuum brightness oscillations — A progress report. Paper presented at University of Arizona Workshop on Solar and Stellar Pulsation, 12-16 March 1979.

______, *R. T. STEBBINS, and *H. A. HILL: Long-period oscillations of the apparent solar diameter: Observations. *Astrophys. J. 223,* 324-338, 1978.

BRUNING, D. H.: A wavelength calibration device for large dispersion spectrographs. *Astron. Astrophys.*, in press, 1979.

*BURLAGA, L. F., *K. W. BEHANNON, S. F. HANSEN, G. W. PNEUMAN, and W. C. FELDMAN: Sources of magnetic fields in recurrent interplanetary streams. *J. Geophys. Res. 83,* 4177-4185, 1978.

*CANN, M. W. P., *R. W. NICHOLLS, *W. F. J. EVANS, *J. L. KOHL, *R. KURUCZ, *W. H. PARKINSON, and E. M. REEVES: High resolution atmospheric transmission calculations down to 28.7 km in the spectral range 200 to 243 nm. *Appl. Opt. 18,* 964-976, 1979.

EDDY, J. A.: Climate and the changing sun. *1979 Encyclopaedia Britannica Yearbook of Science and the Future,* Encyclopaedia Britannica, Inc., Chicago, Ill., 145-160, 1978.

———: 'In the Neolithic Age' - An editorial. *Climatic Change 1,* 191-193, 1978.

———: Historical and arboreal evidence for a changing sun. In *The New Solar Physics* (J. A. Eddy, Ed.), AAAS, Washington, 1978.

———: Sunspots and our weather, U. S. Information Agency, Washington, D. C., 1978.

———: The 'Maunder Minimum': Sunspots and climate in the reign of Louis XIV. In *The General Crisis of the Seventeenth Century* (Geoffrey Parker, Ed.), Routledge and Kegan Paul, London, 226-268, 1978.

———: A review of *Effects of Solar Activity on the Earth's Atmosphere and Biosphere,* M. N. Gnevyshev and A. I. Ol', Eds. *Icarus 37,* 476-477, 1979.

———: A review of *Crystals in the Sky,* by Travis Hudson and Ernest Underhay. *Sky and Telescope,* May 1979.

———: A review of *Sun, Moon and Standing Stones* by John E. Wood. *J. Hist. Astron.,* in press, 1979.

———: The history of the sun and climate. *J. Interdisc. Hist.,* in press, 1979.

———, *R. W. NOYES, *J. G. WOLBACH, and *A. A. BOORNAZIAN: Secular changes in solar rotation, 1888-1964. *Bull. Am. Astron. Soc. 10,* 400-401, 1978.

FISHER, R. R.: λ5303 Fe XIV density models of the inner solar corona. *Solar Phys. 57,* 119-128, 1978.

*FRAZIER, E. N., and J. O. STENFLO: Magnetic, velocity and brightness structure of solar faculae. *Astron. Astrophys. 70,* 789-800, 1978.

*GERGLEY, T., *M. KUNDU, A. POLAND, and R. MUNRO: Radio and white light studies of the 21 August 1973 coronal transient. *Astrophys. J.,* in press, 1979.

GILMAN, P. A.: Nonlinear dynamics of Boussinesq convection in a deep rotating spherical shell II: Effects of temperature boundary conditions. *Geophys. Astrophys. Fluid Dyn. 11,* 157-179, 1978.

———: Nonlinear dynamics of Boussinesq convection in a deep rotating spherical shell III: Effects of velocity boundary conditions. *Geophys. Astrophys. Fluid Dyn. 11,* 181-203, 1978.

———: Polar deceleration and convection zone depths for the sun. *Bull. Am. Astron. Soc. 10,* 400, 1978 (abstract).

———: Long term variations in the solar dynamo. *Trans. Am. Geophys. Union 59,* 1155, 1978 (abstract).

———: Model calculations concerning rotation at high solar latitudes and the depth of the solar convection zone. *Astrophys. J.,* in press, 1979.

———: Large scale circulation on the sun: Research progress 1976-1978. *IAU Reports in Astronomy,* in press, 1979.

———: Book review of *Rotating Fluids in Geophysics* (P. H. Roberts and A. M. Soward, Eds.). *Geophys. Astrophys. Fluid Dyn.,* in press, 1979.

——— and P. FOUKAL: Angular velocity gradients in the solar convection zone. *Astrophys. J.,* in press, 1979.

——— and G. A. GLATZMAIER: Equations for convection of a compressible fluid in a rotating spherical shell. HAO Research Memorandum 192, 1978.

——— and J. MILLER: A spherical shell convection and dynamo model. *Atmos. Technol. 11,* in press, 1979.

HABBAL, S. R., T. E. HOLZER, and E. LEER: Heating of coronal loops by fast-mode MHD waves. In *Physics of Solar Prominences, Proc. IAU Colloq. 44,* 228-232, 1978.

*HATHAWAY, D. H., P. A. GILMAN, and *J. TOOMRE: Convective instability when the temperature gradient and rotation vector are oblique to gravity I. Fluids without diffusion. *Geophys. Astrophys. Fluid Dyn.,* in press, 1979.

*HENOUX, J. C., and Y. NAKAGAWA: Dynamics of an atmosphere irradiated by soft X-rays in flares. *Astron. Astrophys. 66,* 385-393, 1978.

HOLLWEG, J. V.: Alfven waves in the solar atmosphere. *Solar Phys. 56,* 305-333, 1978.

———: Fast wave evanescence in the solar corona. *Geophys. Res. Lett. 5,* 731-734, 1978.

———: Some physical processes in the solar wind. *Rev. Geophys. Space Phys. 16,* 689-720, 1978.

———: Cosmic rays: Solar system effects. Invited paper, *Encyclopedia of Physics,* in press, 1979.

———: Helium and heavy ions. *Proc. Fourth Solar Wind Conference,* Burghausen, 1978. In press, 1979.

———: A new resonance in the solar atmosphere. 1. Theory. *Solar Phys.,* in press, 1979.

——— and C. G. LILLIEQUIST: Geometrical MHD wave coupling. *J. Geophys. Res. 83,* 2030-2036, 1978.

HOLZER, T. E.: The solar wind and related astrophysical phenomena. In *Space Plasma Physics: The Study of Solar System Plasmas,* Vol. 2, Part 1, 3-126, National Academy of Sciences, 1979.

_______ and E. LEER: Theory of mass and energy flow in the solar wind. *Proc. Fourth Solar Wind Conference*, Burghausen, 1978. In press, 1979.

HOYNG, P., *D. B. MELROSE, and J. C. ADAMS: Relaxation and Bremsstrahlung of thick target electron streams. *Astrophys. J.*, in press, 1979.

HUNDHAUSEN, A. J.: Solar wind spatial structure: The meaning of latitude gradients in observations averaged over solar longitude. *J. Geophys. Res. 83*, 4186-4192, 1978.

_______: Streams, sectors, and solar magnetism. In *The New Solar Physics* (J. A. Eddy, Ed.), AAAS, Washington, D. C., 59-134, 1978. (Article reprinted from *Coronal Holes and High-Speed Wind Streams* (J. B. Zirker, Ed.), Colorado Associated University Press, Boulder, 1977.)

_______: Solar activity and the solar wind. *Rev. Geophys. Space Phys.*, in press, 1979.

JACKSON, B. V., and E. HILDNER: Forerunners: Outer rims of solar coronal transients. *Solar Phys. 60*, 155-170, 1978.

JACQUES, S. A.: Solar wind models with Alfven waves. *Astrophys. J. 226*, 632-649, 1978.

*JOSELYN, J. A., R. H. MUNRO, and T. E. HOLZER: The validity of ionization equilibrium in highly ionized astrophysical plasmas. *Astrophys. J. Supp.*, in press, 1979.

*_______, _______, and _______: Mass flow and the validity of ionization equilibrium on the sun. *Solar Phys.*, in press, 1979.

*KAHLER, S. W., E. HILDNER, and M. A. I. VAN HOLLEBEKE: Prompt solar proton events and coronal mass ejections. *Solar Phys. 57*, 429-443, 1978.

KAMIDE, Y., and S. MATSUSHITA: A unified view of substorm sequences. *J. Geophys. Res. 83*, 2103-2108, 1978.

_______ and _______: Simulation studies of ionospheric electric fields and currents in relation to field-aligned currents, 1. Quiet periods. *J. Geophys. Res. 84*, in press, 1979.

_______ and _______: Simulation studies of ionospheric electric fields and currents in relation to field-aligned currents, 2. Substorms. *J. Geophys. Res. 84*, in press, 1979.

*KOHL, J. L., E. M. REEVES, and *B. KIRKHAM: In *New Instrumentation for Space Astronomy* (K. A. Van der Hucht and G. Vaiana, Eds.), Pergamon Press, Oxford, 91-94, 1978.

LANDI DEGL'INNOCENTI, E.: Magneto-optical effects and the interpretation of linearly polarized intensity distributions observed with a vector magnetograph. *Solar Phys.*, in press, 1979.

LEER, E., and T. E. HOLZER: Constraints on the solar coronal temperature in regions of open magnetic field. *Solar Phys.*, in press, 1979.

*LEMAIRE, P., *J. CHARRA, *A. HOUCHOUX, *A. VIDAL-MADJAR, *G. E. ARTZNER, *J. C. VIAL, *R. M. BONNET, and A. SKUMANICH: Calibrated full disk solar HI Lyman α and β profiles. *Astrophys. J. 223*, L55-L58, 1978.

*LIVINGSTON, W. C., and J. O. STENFLO: Small scale solar magnetic fields: New observations and physical interpretations. Review for the Report of IAU Commission 12, in press, 1979.

MATSUSHITA, S.: IMF and lower thermospheric currents and motions — A review. *J. Geomag. Geoelect.*, in press, 1979.

_______ and *Y. KAMIDE: Model calculations of electric fields and currents in the high-latitude E region for predictions of ionospheric variations. *Proc. Internat. Solar-Terrest. Predictions Workshop*, in press, 1979.

McKENNA, P. M., and S. MATSUSHITA: Correlations of geomagnetic activity with IMF intensity and plasma velocity. *EOS 59*, 1169, 1978.

MIHALAS, D.: Report on IAU Commission No. 36. D. Reidel Publishing Co., in press, 1979.

*MOORE, R. L., *D. L. McKENSIE, *Z. SVESTKA, *K. G. WIDING, *S. K. ANTIOCHOSE, *K. P. DERE, *H. W. DODSON-PRINCE, *E. HIEI, *K. R. KRALL, *A. S. KRIEGER, *H. E. MASON, *R. D. PETRASCO, G. W. PNEUMAN, *J. K. SILK, *J. A. VORPAHL, and *G. L. WITHBROE: The thermal x-ray plasma. Big Bear Observatory Report, BBSO #0181, to appear in Skylab Workshop Monograph on Solar Flares, 1979.

MUNRO, R. H., *J. T. GOSLING, E. HILDNER, R. M. MACQUEEN, A. I. POLAND, and C. L. ROSS: The association of coronal mass ejection transients with other forms of solar activity. *Solar Phys.*, in press, 1979.

NAKAGAWA, Y., and J. O. STENFLO: Concentration of axisymmetric magnetic flux by rotational shearing motions. *Astron. Astrophys. 72*, 67-72, 1978.

_______, *S. WU, and *E. TANDBERG-HANSSEN: Global constant-α force-free magnetic fields and coronal structures. *Astron. Astrophys. 69*, 43, 1978.

NEWKIRK, G. Jr.: NCAR/HAO report covering the period October 1976-September 1977. *Bull. Am. Astron. Soc. 10*, 271-277, 1978.

_______ and *D. G. WENTZEL: Rigidity-independent propagation of cosmic rays in the solar corona. *J. Geophys. Res. 83*, 2009-2015, 1978.

NOERDLINGER, P.: A modified Feutrier Method for expanding atmospheres. *J. Quant. Spectrosc. Radiat. Transfer 20*, 621-626, 1978.

_______: Binary galaxy statistics III: Correlations in angular measures, sense of rotation, and type. *Astrophys. J.*, in press, 1979.

———: Positrons in compact radio sources. *Phys. Rev. Lett.*, in press, 1979.
PNEUMAN, G. W.: Coronal manifestations of erupted prominences — Theory. Invited review, *Physics of Solar Prominences*, IAU Colloq. No. 44, Oslo, Norway, August, 1978, p. 281.
———: The physical structure of coronal holes; Influence of magnetic fields and coronal heating. *Astron. Astrophys.*, in press, 1979.
———: Flare loops and two-ribbon solar flares. In *Solar Flare Magneto-hydrodynamics* (E. Priest, Ed.), Gordon and Breach, New York, Paris, London, in press, 1979.
——— and *R. A. KOPP: Downflow in the supergranulation network and its implications for transition region models. *Solar Phys. 57*, 49-64, 1978.
———, S. F. HANSEN, and R. T. HANSEN: On the reality of potential magnetic fields in the solar corona. *Solar Phys. 59*, 313-330, 1978.
POLAND, A. I.: Motions and mass changes of a persistent coronal streamer. *Solar Phys. 57*, 141-153, 1978.
REEVES, E. M., and *M. V. ZOMBECK: In *New Instrumentation for Space Astronomy* (K. A. Van der Hucht and G. Vaiana, Eds.), Pergamon Press, Oxford, 95-98, 1978.
RICHMOND, A. D.: Gravity wave generation, propagation, and dissipation in the thermosphere. *J. Geophys. Res. 83*, 4131-4135, 1978.
SIME, D. G., and *B. J. RICKETT: The latitude and longitude structure of the solar wind speed from IPS observations. *J. Geophys. Res. 83*, 5757-5762, 1978.
SKUMANICH, A., *A. JOUCHOUX, *J. CASTELLI, *P. LEMAIRE, *G. ARTZNER, *P. GOUTTEBROZE, *J. C. VIAL, and *R. M. BONNET: OSO-9, radio and x-ray observations of the 19 April 1977 flare. *Bull. Am. Astron. Soc. 10*, 441, 1978.
———, *V. GAIZAUSKAS, and *W. H. KU: A comparison of the 19 April 1977 two ribbon disk flare with x-ray flares observed at the limb. *Bull. Am. Astron. Soc. 11*, 1979.
SMITH, D. F., and D. R. NICHOLSON: Nonlinear effects involved in the generation of type III solar radio bursts. *Astrophys. Space Phys.*, in press, 1979.
——— and D. S. SPICER: Plasma radiation diagnostics of the primary energy release region in solar flares. *Solar Phys.*, in press, 1979.
SPRUIT, H. C.: Convective collapse of flux tubes. *Solar Phys.*, in press, 1979.
——— and E. G. ZWEIBEL: Convective instability of thin flux tubes. *Solar Phys.*, in press, 1979.
STENFLO, J. O.: Resonance-line polarization: III. The Hanle effect in a compact non-LTE radiative-transfer formulation. *Astron. Astrophys. 66*, 241, 1978.
———: The measurement of solar magnetic fields. *Rep. Prog. in Phys. 41*, 865, 1978.
*STENHOLM, L. G., and J. O. STENFLO: Multi-dimensional non-LTE transfer of polarized radiation in magnetic fluxtubes. *Astron. Astrophys. 67*, 33-45, 1978.
TROTTER, D. E., and S. MATSUSHITA: IMF-sector behavior deduced from geomagnetic data. *EOS 60*, 349, 1979.
*VERNAZZA, J. E., and E. M. REEVES: Extreme ultraviolet composite spectra of representative solar features. *Astrophys. J. Suppl. Series 37*, 485-513, 1978.
WHITE, O. R., and R. G. ATHAY: Chromospheric oscillations observed with OSO-8. I. Basic measurements and analytical methods. *Astrophys. J. Suppl. Ser. 39*, 317, 1979.
——— and ———: Chromospheric oscillations observed with OSO-8. III. Average phase spectra for Si II. *Astrophys. J. Suppl. Ser. 39*, 347, 1979.
——— and W. LIVINGSTON: Solar luminosity variation. II. Behavior of calcium H and K at solar minimum and the onset of cycle 21. *Astrophys. J. 226*, 679-686, 1978.
YEH, T.: Topological structure of coronal-interplanetary magnetic field. *Solar Phys. 56*, 439-447, 1978.
YOSHIMURA, H.: Nonlinear astrophysical dynamos: Bifurcation of steady dynamos from oscillating dynamos. *Astrophys. J. 221*, 1088-1099, 1978.
———: Nonlinear astrophysical dynamos: Multiple-period dynamo wave oscillations and long-term modulations of the 22 year solar cycle. *Astrophys. J. 226*, 706-719, 1978.
———: The solar-cycle period-amplitude relation as evidence of hysteresis of the solar cycle nonlinear magnetic oscillation and the long-term (55 year) cyclic modulation. *Astrophys. J. 227*, 1047-1058, 1979.
ZWEIBEL, E. G.: Energetic particle trapping by Alfven wave instabilities. *Proc. La Jolla Institute Workshop on Particle Acceleraton Mechanisms in Astrophysics*, in press, 1979.

Convective Storms Division

BREED, D. W.: *22 June 1976: First Echo Case.* Technical Note NCAR/TN-130+STR, NCAR, Boulder, Colo., 49 pp., 1978.
———: *22 July 1976: First Echo Case.* Technical Note NCAR/TN-132+STR, NCAR, Boulder, Colo., 59 pp., 1978.
———: *8 June 1976: First Echo Case.* Technical Note NCAR/TN-134+STR, NCAR, Boulder, Colo., 89 pp., 1979.

CLARK, T. L., and W. D. HALL: A numerical experiment on stochastic condensation theory. *J. Atmos. Sci.*, in press, 1979.

______ and ______: Small scale cloud physical-dynamical interactions: Preliminary findings. Preprint Vol., Conference on Cloud Physics and Atmospheric Electricity, Issaquah, Wash. AMS, Boston, Mass., 92-96, 1978.

COOPER, G.: An atomizer of high stability. *Am. Ind. Hyg. Assoc. J.*, in press, 1979.

______, G. LANGER, and J. ROSINSKI: Submicron aerosol losses in aluminized Mylar bags. *J. Appl. Meteor. 18*, 57-68, 1979.

CROW, E. L.: Approximate confidence intervals for a proportion from Markov dependent trials. *Commun. Stat. B8*, No. 1, 1-24, 1979.

______: Confidence limits for seeding effect in single-area weather modification experiments. *J. Appl. Meteorol. 17*, 1652-1660, 1978.

______: Discussion of "Nonparametric statistical data modeling" by E. Parzen. *J. Am. Stat. Assoc. 74*, 129, 1979.

______, A. B. LONG, J. E. DYE, A. J. HEYMSFIELD, and P. W. MIELKE: Results of a randomized hail suppression experiment in northeast Colorado. Part II: Surface data base and primary statistical analysis. Conditionally accepted for publication in *J. Appl. Meteorol.*, 1979.

______, ______, ______, and C. W. ULBRICH: Results of a randomized hail suppression experiment in northeast Colorado. Part III: Analysis of hail size distributions for seeding and yearly effects. Conditionally accepted for publication in *J. Appl. Meteorol.*, 1979.

______ and M. J. MILES: Validation of estimators of a proportion from Markov dependent trials. *Commun. Stat. B8*, No. 1, 25-52, 1979.

DYE, J. E., and D. W. BREED: The microstructure of clouds in the high frequency hail area of Kenya. *J. Appl. Meteorol. 18*, 95-99, 1978.

______ and B. E. MARTNER: The relationship between radar reflectivity factor and hail at the ground for northeast Colorado thunderstorms. *J. Appl. Meteorol. 17*, 1335-1341, 1978.

FOOTE, G. B., and C. A. KNIGHT: Results of a randomized hail suppression experiment in northeast Colorado: Part I. Design and conduct of the experiment. Conditionally accepted for publication in *J. Appl. Meteorol.*, 1979.

______ and C. G. MOHR: Results of a randomized hail suppression experiment in northeast Colorado: Part VI. Post hoc stratification by storm intensity and type. Conditionally accepted for publication in *J. Appl. Meteorol.*, 1979.

______, R. E. RINEHART, and E. L. CROW: Results of a randomized hail suppression experiment in northeast Colorado: Part IV. Analysis of radar data for seeding effect and correlation with hailfall. Conditionally accepted for publication in *J. Appl. Meteorol.*, 1979.

______, C. G. WADE, J. C. FANKHAUSER, P. W. SUMMERS, and M. E. SOLAK: Results of a randomized seeding experiment in northeast Colorado: Part VII. Seeding logistics and post hoc stratification by seeding coverage. Conditionally accepted for publication in *J. Appl. Meteorol.*, 1979.

HEYMSFIELD, A. J., J. E. DYE, and C. J. BITER: Overestimates of entrainment from wetting of aircraft temperature sensors in cloud. *J. Appl. Meteorol. 18*, 92-95, 1979.

______, P. N. JOHNSON, and J. E. DYE: Observations of moist adiabatic ascent in northeast Colorado cumulus congestus clouds. *J. Atmos. Sci. 35*, 1689-1703, 1978.

______, C. A. KNIGHT, and J. E. DYE: Ice initiation in unmixed updraft cores in northeast Colorado cumulus congestus clouds. *J. Atmos. Sci,.* in press, 1979.

______ and J. L. PARRISH: A computational technique for increasing the effective sampling volume of the PMS 2-D particle size spectrometer. *J. Appl. Meteorol. 17*, 1566-1572, 1978.

______ and ______: *Techniques Employed in the Processing of Particle Size Spectra and State Parameter Data Obtained with the T-28 Aircraft Platform.* Technical Note NCAR/TN-137+IA, NCAR, Boulder, Colo., 1979.

JOHNSON, P. J., A. J. HEYMSFIELD, and G. VALI: 21 June 1976: A case study of precipitation initiation in the NHRE observational area. In Preprint Vol., Conference on Cloud Physics and Atmospheric Electricity, Issaquah, Wash. AMS, Boston, Mass., 330-336, 1978.

KNIGHT, C. A.: Ice nucleation in the atmosphere. In *Adv. Colloid Interface Sci. 10*, 369-395, 1979.

______, G. B. FOOTE, and P. W. SUMMERS: Results of a randomized hail suppression experiment in northeast Colorado: Part IX. Overall discussion and summary in the context of physical research. Conditionally accepted for publication in *J. Appl. Meteorol.*, 1979.

______ and N. C. KNIGHT: Results of a randomized hail suppression experiment in northeast Colorado: Part V. Hailstone embryo types. Conditionally accepted for publication in *J. Appl. Meteorol.*, 1979.

______: Observations of the morphology of melting snow. *J. Atmos. Sci.*, in press, 1979.

———, T. ASHWORTH, and N. C. KNIGHT: Cylindrical ice accretions as simulations of hail growth: II. The structure of fresh and annealed accretions. *J. Atmos. Sci. 35,* 1997-2009, 1978.

LANGER, G., G. MORGAN, C. T. NAGAMOTO, M. SOLAK, and J. ROSINSKI: Generation of ice nuclei in the surface outflow of thunderstorms in northeast Colorado. *J. Atmos. Sci.,* in press, 1979.

LOBL, E., and A. J. HEYMSFIELD: An evaluation of the performance of the 1-D PMS (Knollenberg) probe. *J. Appl. Meteorol.,* in press, 1979.

LOZOWSKI, E. P., R. ERB, L. WOJTIW, M. WONG, G. S. STRONG, R. MATSON, A. LONG, D. VENTO, and P. ADMIRAT: The hail sensor intercomparison experiment. *Atmos.-Ocean 16,* 94-106, 1978.

MODAHL, A. C.: Low-level wind and moisture variations preceding and following hailstorms in northeast Colorado. *Mon. Weather Rev.,* in press, 1979.

MORGAN, G. M.: Observation and measurement of hailfall. In *Thunderstorms: A Social and Technological Documentary* (E. Kessler, Ed.), University of Oklahoma Press, in press, 1979.

———: Summary of the panel discussions: Hail instrument calibration. *Atmos.-Ocean 16,* 137-140, 1978.

——— and P. W. SUMMERS: Hailfall and hailstorm characteristics. In *Thunderstorms: A Social and Technological Documentary* (E. Kessler, Ed.), University of Oklahoma Press, in press, 1979.

PELTIER, W. R., and T. L. CLARK: The evolution and stability of finite amplitude mountain waves: II. Surface wave drag and severe downslope windstorms. *J. Atmos. Sci.,* in press, 1979.

———, J. HALLÉ, and T. L. CLARK: The evolution of finite amplitude Kelvin-Helmholtz billows. *Geophys. Astrophys. Fluid Dyn. 10,* 53-87, 1978.

PRODI, F., C. T. NAGAMOTO, and J. ROSINSKI: A preliminary study of ice grown by droplet accretion using water insoluble particles as tracer. *J. Appl. Meteorol.,* in press, 1979.

ROSINSKI, J.: The role of natural and man-made ice-forming nuclei in the atmosphere. *Adv. Colloid Interface Sci. 10,* 315-367, 1979.

———, C. A. KNIGHT, C. T. NAGAMOTO, G. M. MORGAN, N. C. KNIGHT, and F. PRODI: Further studies of large, water-insoluble particles within hailstones. *J. Atmos. Sci.,* in press, 1979.

———, C. T. NAGAMOTO, and G. LANGER: Large aerosol particles in a convective storm environment. *J. Aerosol Sci.,* in press, 1979.

SUMMERS, P. W.: Comments on "An analysis of a possible crop response to hail suppression seeding: The Nelspruit Hail Suppression Project." *J. Appl. Meteorol. 17,* 1084-1090, 1978.

———, J. C. FANKHAUSER, G. M. MORGAN Jr., G. B. FOOTE, and A. C. MODAHL: Results of a randomized seeding experiment in northeast Colorado: Part VIII. The representative draw analysis. Conditionally accepted for publication in *J. Appl. Meteorol.,* 1979.

Advanced Study Program

ANDREWS, D. G., and M. E. McINTYRE: On wave-action and its relatives. *J. Fluid Mech. 89,* 647-664, 1978.

ARNASON, G., and Z.-H. WEIGEL: A numerical simulation of the formation and maintenance of the tradewind inversion and the associated mixed layer. *Papers in Meteorol. Res.,* in press, 1979.

ASHE, S.: A nonlinear model of the axially-asymmetric flow induced by topography and diabatic heating. *J. Atmos. Sci. 36,* 109-126, 1979.

ASHWORTH, T., and C. A. KNIGHT: Cylindrical ice accretions as simulations of hail growth: I. Effects of rotation and of mixed clouds. *J. Atmos. Sci. 35(10),* 1987-1996, 1978.

BERG, W. W., and *J. W. WINCHESTER: Aerosol chemistry of the marine atmosphere (J. P. Riley and R. Chester, Eds.), In *Chemical Oceanography,* 2nd ed., Academic Press, 173-231, 1978.

———: *J. Great Lakes Res. 4,* 243 (letter), 1978.

———: Review of *The Chemistry of the Atmosphere and Oceans,* by H. D. Holland. *Bull. Am. Meteorol. Soc.,* in press, 1979.

BERGEN, W. R., and A. H. MURPHY: Response. *Bull. Am. Meteorol. Soc. 59(8),* 1037, 1978.

BLACKMON, M. L., R. A. MADDEN, *J. M. WALLACE, and *D. S. GUTZLER: Geographical variations in the vertical structure of large scale transient disturbances. *J. Atmos. Sci.,* in press, 1979.

BOGART, R. S., and *P. J. GIERASCH: Meridional circulation and the redistribution of heat in the solar convective envelope. *Astrophys. J. 228,* 624-629, 1979.

———: Rotation and horizontal heat transport in the solar convective envelope. *Bull. Am. Astron. Soc. 10(4),* 678, 1978.

BOYD, J. P.: A Chebyshev polynomial method for computing analytic solutions to eigenvalue problems with application to the anharmonic oscillator. *J. Math. Phys.* (Cambridge, Mass.) *19(6),* 1445-1456, 1978.

BROWN, T. M., R. T. STEBBINS, and H. A. HILL: Long-period oscillations of the apparent solar diameter: Observations. *Astrophys. J. 223,* 324-338, 1978.

CAHALAN, R. F., and *G. R. NORTH: A stability theorem for energy-balance climate models. *J. Atmos. Sci.,* in press, July 1979.

CURRY, J. H.: Bounded solutions of finite dimensional approximations to the Boussinesq equations. *SIAM J. Math. Anal. 10(1),* 71-77, 1979.

———: A generalized Lorenz system. *Commun. Math. Phys. 60,* 193-204, 1978.

———: Transition to turbulence in finite-dimensional approximations to the Boussinesq equations. *Proc. Springer Lecture Notes in Mathematics,* 668, 1978.

ESBENSEN, S.: Bulk thermodynamic effects and properties of small tropical cumuli. *J. Atmos. Sci. 35(5),* 826-837, 1978.

FRIED, A.: Laser optoacoustic detection of NO_2 in a flow system. Paper presented to the 1979 Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy.

FRITTS, D. C.: The excitation of radiating waves and Kelvin-Helmholtz instabilities by the gravity wave-critical level interaction. *J. Atmos. Sci. 36,* 12-23, 1979.

GLANTZ, M. H., Ed.: *Multidisciplinary Research Related to the Atmospheric Sciences* (with Harry van Loon and Elmer Armstrong), NCAR/3141-78/1, Boulder, Colo., June 1978.

———: Saskatchewan spring wheat production 1974: a preliminary assessment of a reliable long-range weather forecast. To be published by the Canadian Climate Centre, 1979.

———: Render unto weather . . . *Climatic Change 1,* 305-306, 1978.

———: The science, politics and economics of the Peruvian anchoveta fishery. *Mar. Policy,* in press, July 1979.

*GOLDEN, J. H., *C. F. CHAPPELL, *C. G. LITTLE, A. H. MURPHY, *E. B. BURTON, and *E. W. PEARL: What should the NWS be doing to improve short-range weather forecasting? *Bull. Am. Meteorol. Soc. 59(10),* 1334-1342, 1978.

GREENHUT, G. K.: Correlations between rainfall and sea surface temperature during GATE. *J. Phys. Oceanogr. 8,* 1135-1138, 1978.

HABBAL, S. R., T. E. HOLZER, and *E. LEER: Heating of coronal loops by fast mode MHD-waves. *Proc. Physics of Solar Prominences,* Oslo, Norway, 14-18 August 1978.

HALL, W. D., and T. L. CLARK: A numerical experiment on stochastic condensation theory. *J. Atmos. Sci.,* in press, 1979.

HELD, I. M.: A severely truncated spectral model. *Proc. JOC Study Conference on Climate Models,* Washington, D. C., April 1978.

———: The sensitivity of an energy balance climate model to variations in the orbital parameters. *J. Geophys. Res.,* in press, 1979.

———: The vertical scale of an unstable baroclinic wave and its importance for eddy heat flux parameterizations. *J. Atmos. Sci. 35(4),* 572-576, 1978.

———: The tropospheric lapse rate and climatic sensitivity: experiments with a two-level atmospheric model. *J. Atmos. Sci. 35(11),* 2083-2098, 1978.

HERRING, J. R.: Subgrid scale modeling: an introduction and overview. *Proc. First International Conference on Turbulent Shear Flow,* 1978.

———: Statistical theory of two- and quasi two-dimensional turbulence. Euromech 105 Conference, Grenoble, France, 6-8 September 1978.

HILL, J. C.: Models for turbulent transport processes. *Chem. Eng. Ed. 8,* 34-39, 1979.

———: Simulation of chemical reaction in a turbulent flow. *Proc. Second B. F. Ruth Chemical Engineering Research Symposium,* 27-53, 1979.

HUEBERT, B. J., and A. L. LAZRUS: Global tropospheric measurements of nitric acid vapor and particulate nitrate. *Geophys. Res. Lett. 5(7),* 577-580, 1978.

——— and ———: Tropospheric measurements of nitric acid vapor and particulate nitrate. In *Nitrogenous Air Pollutants, Chemical and Biological Implications* (D. Grosjean, Ed.), Ann Arbor Science Publishers, Inc., 307-315, 1979.

KATZ, R. W.: Persistence of subtropical African droughts. *Mon. Weather Rev. 106,* 1017-1021, 1978.

——— and M. H. GLANTZ: Weather modification as a potential resource: panacea or placebo? *J. Soil Water Conserv.,* in press, 1979.

———: Sensitivity analysis of statistical crop-weather models. *Agri. Meteorol.,* in press, 1979.

——— and A. H. MURPHY: Assessing the value of frost forecasts to orchardists: a decision-analytic approach. In Preprint Vol., 14th Conference on Agriculture and Forest Meteorology and Fourth Conference on Biometeorology, 2-6 April 1979, Minneapolis, Minn. AMS, Boston, Mass., 34-37, 1979.

*KERR, R. M., and E. D. SIGGIA: Cascade model of fully developed turbulence. *J. Stat. Phys. 19(5),* 543-551, 1978.

*KRAICHNAN, R. H., and J. R. HERRING: A strain-based Lagrangian-history turbulence theory. *J. Fluid Mech. 88,* 355-367, 1978.

LAU, N. C.: On the three-dimensional structure of the observed transient eddy statistics of the Northern Hemisphere wintertime circulation. *J. Atmos. Sci. 35,* 1900-1923, 1978.

______: *The Observed Structure and Energetics of Transient and Stationary Motions in the Northern Hemisphere Wintertime Circulation.* Cooperative Thesis NCAR/CT-50, NCAR, Boulder, Colo., 1978.

______: On the structure and energetics of the transient disturbances in the Northern Hemisphere wintertime circulation. *J. Atmos. Sci.,* in press, 1979.

______: The observed structure of tropospheric stationary waves and the local balances of vorticity and heat. *J. Atmos. Sci.,* in press, 1979.

LOESCH, A. Z., and R. C. DEININGER: Dynamics of closed systems of resonantly interacting equatorial waves. *J. Atmos. Sci.,* in press, August 1979.

McINTYRE, M.: An introduction to the generalised Lagrangian-mean theory of wave, mean-flow interaction. *Pure Appl. Geophys.,* in press, 1979.

MUMPOWER, J., V. VEIRS, and *K. R. HAMMOND: Scientific information, social values, and policy formation: the application of simulation models and judgment analysis to the Denver regional air pollution problem. *IEEE J. Cybernetics, Systems and Man,* in press, 1979.

MURPHY, A. H.: On the evaluation of point precipitation probability forecasts in terms of areal coverage. *Mon. Weather Rev. 106(12),* 1680-1686, 1978.

______: Hedging and the mode of expression of weather forecasts. *Bull. Am. Meteorol. Soc. 59(4),* 430-431, 1978.

______: Assessing the value of meteorological services (extended abstract and bibliography). Joint Summer Conference on the Value of Meteorological Services (Melbourne, Australia), Royal Meteorological Society Australian Branch/Economic Society of Australia and New Zealand/Australian Agricultural Economics Society, 1979.

______: On the value of weather forecasts to the general public (extended abstract and bibliography). Joint Summer Conference on the Value of Meteorological Services (Melbourne, Australia), Royal Meteorological Society Australian Branch/Economic Society of Australia and New Zealand/Australian Agricultural Economics Society, 1979.

______: Subjective quantification of uncertainty in real-time weather forecasts in the United States. In *Real-Time Forecasting/Control of Water Resources* (E. Wood and A. Szollosi-Nagy, Eds.), Wiley, New York, in press, 1979.

______: Forecasting skill of beginners (Letter to the Editor). *Bull. Am. Meteorol. Soc. 60(6),* in press, 1979.

______: and *R. L. WINKLER: Probabilistic temperature forecasts: The case for an operational program. *Bull. Am. Meteorol. Soc. 60(1),* 12-19, 1979.

NICHOLSON, S. E.: Revised rainfall series for the West African subtropics. *Mon. Weather Rev.,* in press, 1978.

NORWINE, J.: Twentieth-century semi-arid climates and climatic fluctuations in Texas and northeastern Mexico. *J. Arid Environ. 1,* 313-325, 1978.

PAEGLE, J.: A linearized analysis of diurnal boundary layer convergence over the topography of the United States. *Mon. Weather Rev. 106,* 492-502, 1978.

______: The transient mass-flow adjustment of heated atmospheric circulations. *J. Atmos. Sci. 35,* 1678-1688, 1978.

PAEGLE, J. N., and J. PAEGLE: Frictional effects in strongly divergent flows. *J. Atmos. Sci. 35,* 1197-1203, 1978.

POUQUET, A., and G. S. PATTERSON Jr.: Numerical simulation of helical magnetohydrodynamic turbulence. *J. Fluid Mech. 85,* 305-323, 1978.

*RIEHL, H., G. GREENHUT, and *B. R. BEAN: Energy transfer in the tropical subcloud layer measured with DC-6 aircraft during GATE. *Tellus 30,* 524-536, 1978.

ROSE, W. I. Jr.: Activity of Guatemalan volcanoes, February 1978. *Trans. Am. Geophys. Union 59(12),* 1221-1223, 1978.

______, R. D. CADLE, L. E. HEIDT, *I. FRIEDMAN, A. L. LAZRUS, and B. J. HUEBERT: Gas and H isotropic analyses of volcanic eruption clouds in Guatemala sampled by aircraft. *J. Vol. Geother. Res.,* in press, 1979.

ROTUNNO, R.: A study in tornado-like vortex dynamics. *J. Atmos. Sci. 36(1),* 140-155, 1979.

______: A note on the stability of a cylindrical vortex sheet. *J. Fluid Mech. 87(4),* 761-771, 1978.

SALSTEIN, D.: Limitations to the accuracy of energy resource allocation based on weather predictions. *Proc. Conference on Climate and Energy,* Asheville, N. C., 8-12 May 1978. AMS, Boston, Mass., 153-156, 1978.

SCHAFFNER, M. R.: Special-purpose versus general-purpose machines in signal processing. *Proc. International Conference on Digital Signal Processing,* Florence, Italy, 30 August-2 September 1978, 616-623.

______: Processing by data and program blocks. *IEEE Trans. Comput. 27(11),* 1015-1028, 1978.

SCHUMANN, U., and G. S. PATTERSON Jr.: Numerical study of pressure and velocity fluctuations in nearly isotropic turbulence. *J. Fluid Mech. 88,* 685-709, 1978.

______ and ______: Numerical study of the return of axisymmetric turbulence to isotropy. *J. Fluid Mech. 88,* 711-735, 1978.

SIGGIA, E. D., and G. S. PATTERSON Jr.: Intermittency effects in a numerical simulation of stationary three-dimensional turbulence. *J. Fluid Mech. 86,* 567-592, 1978.

*SNELLMAN, L. W., and A. H. MURPHY: Man-Machine symposium (Meeting Review). *Bull. Am. Meteorol. Soc. 60,* in press, 1979.

*SRIVASTAVA, R. C., *A. R. JAMESON, and P. H. HILDEBRAND: Time-domain computation of mean and variance of doppler spectra. *J. Appl. Meteorol. 18(2),* 189-194, 1979.

*STAËL von HOLSTEIN, C.-A. S., and A. H. MURPHY: The family of quadratic scoring rules. *Mon. Weather Rev. 106(7),* 917-924, 1978.

STREET, R. L.: Turbulent heat and mass transfers across a rough, air-water interface: a simple theory. *Int. J. Heat Mass Transfer,* in press, 1979.

TRIBBIA, J. J.: Nonlinear initialization on an equatorial beta-plane. *Mon. Weather Rev.,* in press, June 1979.

WARREN, S. G.: Seasonal simulation as a test for uncertainties in the parameterizations of a "Budyko-type" zonal climate model. *Proc. E.O.S. 59,* 1083, December 1978.

——— and S. H. SCHNEIDER: Seasonal simulation as a test for uncertainties in the parameterizations of a "Budyko-Sellers" zonal climate model. *J. Atmos. Sci.,* in press, 1979.

WEARE, B. C.: Temperature statistics of short-term climatic change. *Mon. Weather Rev.,* in press, 1979.

Atmospheric Technology Division

ADAMS, J. C.: FORTRAN subprograms for finite difference formulas. *J. Comput. Phys. 26(1),* 113-116, 1978.

*ANTONIA, R. A., *A. J. CHAMBERS, C. A. FRIEHE, and *C. W. VAN ATTA: Temperature ramps in the atmospheric surface layer. *J. Atmos. Sci. 36(1),* 99-108, 1979.

BECK, C. E.: A modular approach to airborne research instrumentation. In Preprint Vol., Fourth Symposium on Meteorological Observations and Instrumentation, Denver, Colo., 10-14 April. AMS, Boston, Mass., 1978.

BROWNING, G. L.: *A New System of Equations for Numerical Weather Forecasting.* Dissertation submitted to New York University, New York, New York, 79 pp.

CARBONE, R. E., and *L. D. NELSON: The evolution of raindrop spectra in warm-based convective storms as observed and numerically modeled. *J. Atmos. Sci. 35,* 2302-2314, 1978.

——— and *———: Temporal evolution of raindrop spectra in warm-based convective storms as observed and numerically modeled. In Preprint Vol., Conference on Cloud Physics and Atmospheric Electricity. AMS, Boston, Mass., 162-167, 1978.

COLE, H. L.: Air temperature and differential temperature measurement using IC temperature sensors. Presented at the Fourth Symposium on Meteorological Observations and Instrumentation, Denver, Colo., 10-14 April. AMS, Boston, Mass., 25-30, 1978.

DUNCAN, T. M., and R. C. BROWN: A data acquisition system for airborne meteorological research. *Bull. Am. Meteorol. Soc. 59(9),* 1128-1134, 1978.

FRIEHE, C. A., and *S. E. PAZAN: Performance of an air-sea interaction buoy. *J. Appl. Meteorol. 17(10),* 1488-1497, 1978.

FRIESEN, R. B., and R. BROWN: A new airborne data system for atmospheric research. Presented at the Fourth Symposium on Meteorological Observations and Instrumentation, Denver, Colo., 10-14 April. AMS, Boston, Mass., 382-384, 1978.

GOVIND, P. K.: Microprocessor control of aircraft DME. Presented at the Fourth Symposium on Meteorological Observations and Instrumentation, Denver, Colo., 10-14 April. AMS, Boston, Mass., 385-390, 1978.

JENNE, R. L., and D. H. JOSEPH: *Management of Atmospheric Data.* NASA Conference Publication 2055, 1978.

JOHNSON, P. H., D. H. LENSCHOW, and K. DANNINGER: A new fixed vane for air motion sensing. Presented at the Fourth Symposium on Meteorological Observations and Instrumentation, Denver, Colo., 10-14 April. AMS, Boston, Mass., 467-470, 1978.

KELLY, T. J., and D. H. LENSCHOW: Thunderstorm updraft velocity measurements from aircraft. In Preprint Vol., Fourth Symposium on Meteorological Observations and Instrumentation, Denver, Colo. 474-478, 1978.

LENSCHOW, D. H., C. A. CULLIAN, R. B. FRIESEN, and K. N. BROWN: The status of air motion measurements on NCAR aircraft. In Preprint Vol., Fourth Symposium on Meteorological Observations and Instrumentation, Denver, Colo., 433-438, 1978.

———, C. A. FRIEHE, and *J. C. LARUE: The development of an airborne hot-wire anemometer system. In Preprint Vol., Fourth Symposium on Meteorological Observations and Instrumentation, Denver, Colo., 463-466, 1978.

——— and *P. L. STEPHENS: Airborne measurements of the structure of thermals. Paper prepared for 16th OSTIV Conference, Châteauroux, France, 1978.

LHERMITTE, R. M., *C. LENNON, and R. J. SERAFIN: Observations of electrical radiation and kinematical structure of thunderstorms during the TRIP-78 experiment. Paper presented at the annual fall meeting of the American Geophysical Union, San Francisco, Calif., 1978.

OLSON, M. L.: Global accuracy of omega-derived winds. *Atmos. Technol. 10,* 14-23, 1978.

———: The global positioning system. *Atmos. Technol. 10,* 51-52, 1978.

——— and R. M. PASSI: Error estimation of omega-derived wind measurements. PLANS, IEEE, 359-370, 1978.

———, ———, and A. P. SCHUMANN: *Omega Wind-Error Estimation.* Technical Note NCAR/TN-131+EDD, NCAR, Boulder, Colo., 106 pp., 1978.

PASSI, R. M.: Linear model estimation with extraneous estimates of a parameter subset. *Technometrics,* in press, 1979.

———: Overdetermined windfinding systems. *Atmos. Technol. 10,* 65-75, 1978.

———: Reply: Use of nonlinear least squares in meteorological application. *J. Appl. Meteorol. 17,* 1580, 1978.

——— and J. S. WILLIAMS: Sample size requirements for confidence bounds of prescribed precision on multivariate normal quantiles. *Commun. Stat. – Theory and Methods A7(8),* 739-753, 1978.

PATTERSON, G. S. Jr.: Prospects for computational fluid mechanics. *Annu. Rev. Fluid Mech. 10,* 289-300, 1978.

SATO, R. K., and G. L. BROWNING: *Description of the General Program Structure of the Third-Generation NCAR General Circulation Model.* Technical Note NCAR/TN-127+IA, NCAR, Boulder, Colo., 48 pp., 1977.

*SCHMITT, K. F., C. A. FRIEHE, and *C. H. GIBSON: Sea surface stress measurements. *Boundary-Layer Meteorol. 15,* 215-228, 1978.

SCHUMANN, U., and G. S. PATTERSON Jr.: Numerical study of the return of axisymmetric turbulence to isotropy. *J. Fluid Mech.,* in press, 1978.

——— and ———: Numerical study of pressure and velocity fluctuations in nearly isotropic turbulence. *J. Fluid Mech.,* in press, 1978.

SMALLEY, J. H.: Aircraft dropwindsonde system. *Atmos. Technol. 10,* 24-28, 1978.

SWARZTRAUBER, P. N.: The methods of cyclic reduction, Fourier analysis of the FACR algorithm for the discrete solution of Poisson's equation on a rectangle. *SIAM Rev. 19(3),* 490-501, 1977.

———: A parallel algorithm for solving general tridiagonal equations. *Math. Comput. 33,* 185-199, 1979.

———: On the spectral approximation of discrete scalar and vector functions on the sphere. *SIAM J. Numer. Anal.,* in press, 1979.

———: Efficient FORTRAN subprograms for the solution of elliptic partial differential equations. *ACM Trans. Math Soft.,* in press, 1979.

WHARTON, J. J., C. H. FRUSH, and N. S. NAHMAN: A video recorder for coherent radar. *IEEE Trans. Geosci. Electron.,* in press, 1978.

WRIGHT, T.: Machine independent metacode translation, *Comput. Graph. 11(2),* 128-130, Summer 1977.

NCAR Annual Scientific Report April 1978 - March 1979 - Link Page