GEOPHYSICAL FLUID DYNAMICS LABORATORY

ACTIVITIES – FY80
PLANS – FY81

WITH A REVIEW OF TWENTY-FIVE YEARS OF RESEARCH 1955-1980

U.S. DEPARTMENT OF COMMERCE
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Preface

This document is intended to serve as a summary of the work accomplished at the Geophysical Fluid Dynamics Laboratory (GFDL) and to present a glimpse of the near future direction of its research plans. Because the laboratory is celebrating its twenty-fifth anniversary in the fall of 1980, a survey of twenty-five years of research at GFDL has been included in this years report.

The report has been prepared within GFDL and its distribution is primarily limited to GFDL members, to the Director and planning staffs of the Environmental Research Laboratories in Boulder, Colorado, to interested offices of the National Oceanic and Atmospheric Administration in Rockville, Maryland, and to other relevant government agencies and national organizations.

In addition to the review of twenty-five years of research, the document includes an overview, project activities and plans for the past and current fiscal years, and appendices. The overview includes a description of the contemporary scope of the Laboratory's efforts, some specialized highlights of the past year and some immediate objectives. In the body of the text are present goals, specific recent achievements and future plans for the following major research categories: Climate Dynamics; Middle Atmosphere Dynamics and Chemistry; Experimental Prediction; Oceanic Circulation; Planetary Circulations; Observational Studies; Hurricane Dynamics; Mesoscale Dynamics; Convection and Turbulence. It should be emphasized that these categories are somewhat arbitrary and are far from being mutually exclusive. Interaction occurs among the various groups and is strongly encouraged.

The appendices contain the following: a list of GFDL staff members and affiliates during Fiscal Year 1980; a cumulative bibliography of research papers published by staff members and affiliates during their tenure with GFDL (these are referred to in the main body according to the appropriate reference number or letter); a description of the Laboratory's computational support and its plans for FY81; a listing of seminars presented at GFDL during Fiscal Year 1980; a listing of seminars and talks presented during Fiscal Year 1980 by GFDL staff members and affiliates at other locations.

Although the specific names of individuals are not generally given in the main text, an entire listing of project participants can be found in Appendix A. Publishing staff personnel can normally be identified by consulting the cited Appendix B references.

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A REVIEW OF TWENTY-FIVE YEARS OF RESEARCH AT GFDL

A survey of this length that attempts to summarize twenty-five years of research at GFDL must necessarily be incomplete. Several works of consequence have not been mentioned. The reader interested in a more complete picture is encouraged to examine the bibliography following the annual report. More importantly, it has not been possible in such a survey to recognize the multitude of ways in which research outside of the laboratory, by individual scientists and by other meteorological and oceanographic institutions, has been vital to the development of the laboratory's own research.

Numerical models of the atmosphere based on the primitive equations of motion are presently utilized routinely by weather forecasting centers and meteorological researchers throughout the world. These "general circulation models" (or GCMs) incorporate with more or less fidelity the effects of moisture, boundary layer turbulence, and radiation, and are generally capable of being integrated forward in time indefinitely. Twenty-five years ago models of this sort did not exist. Pioneering work in the late 1940's and early 1950's had demonstrated the value of numerical atmospheric models for research and their potential for improving weather forecasts. Yet the possibility still seemed remote that numerical models could simulate the global atmosphere sufficiently well to allow one to use them to address such questions as the predictability of weather and the sensitivity of climate. The feasibility of long term integrations with the primitive equations, particularly for a moist atmosphere, was not at all apparent. The demonstration of this feasibility was the focus of the laboratory's research in the first years after its founding. In the following quarter century, GFDL has played a leading role in the further development and exploitation of these models.

Some of the earliest papers published under the auspices of the laboratory concerned the development of methods for the integration of the primitive equations for a baroclinic atmosphere (5,9)*. This work culminated in a numerical experiment with the primitive equations for a "two-level" dry atmosphere, published in 1963 (17). A key element in this calculation was the incorporation of a scale-selective dissipative mechanism that damped small scales and maintained computational stability without affecting the larger scales of motion significantly. The growth and decay of several generations of extratropical cyclones was simulated. On the basis of this calculation one could safely assume that long term integrations of the primitive equations were indeed feasible (at least for a dry atmosphere).

Simultaneously with this work, several lines of research essential to the construction of more realistic models were being carried forward. The problem of predicting precipitation and including the effects of latent heat release in numerical models were being addressed (2,8). Both non-convective and convective rainfall had to be treated in the model, the latter being of particular importance for the simulation of the tropical atmosphere. A simple parameterization of moist convection,

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*Reference numbers correspond to GFDL Bibliography in Appendix B.

the so-called "moist convective adjustment" was developed (26,33) and has since been utilized in a number of models around the world. Techniques for computing radiative heating rates suitable for inclusion in numerical atmospheric models had to be developed (13,14,26). New numerical methods were analyzed. The importance for numerical stability of exact numerical analogues of integral constraints, particularly constraints quadratic in the flow variables, were emphasized in a series of papers (28,30,34). Grid systems for the integration of the primitive equations on a sphere were developed (30). New implicit and iterative time integration schemes were devised (29). Some of these developments had almost immediate application; others made an impact on model development at a later date.

This work culminated in the integration of a nine-level model of a moist atmosphere (32,33). This model can be considered the prototype for most general circulation models constructed in the intervening years, at GFDL and elsewhere. The grid resolution in the vertical, the relative amounts of computational time committed to various parts of the problem, the detailed treatment of radiation, the idealized treatment of moist convection, of boundary layer turbulence, and of dissipation in the free atmosphere -- all of these features are still more or less discernible in the general circulation models in use today.

While intensive research has continued on improving these atmospheric models, research at the laboratory has gradually become more diverse, as described in the following survey. A large part of the laboratory's research has involved the application of these atmospheric models to the problem of extending the range of useful weather forecasts and to various problems in climate dynamics and the general circulation of the atmosphere. GCM's have also been constructed for investigating the dynamics and chemistry of the stratosphere and mesosphere. After the feasibility of long term integrations of primitive equation atmospheric models had been demonstrated, it quickly became apparent that similar techniques could be used for models of the ocean circulation. Atmospheric and oceanic modeling thereafter developed in parallel. Extensive observational studies of the atmosphere and the oceans were also carried out, partly to help in the evaluation of the numerical models, but also because of the light they shed in their own right on atmospheric and oceanic dynamics. Research also developed on scales of motion in the atmosphere smaller than those treated explicitly in general circulation models: hurricanes, squall lines and other mesoscale phenomena, boundary layer turbulence, and individual convective clouds. Problems on these smaller scales were often attacked with large numerical models resembling in many ways the atmospheric GCMs. Important research has also been conducted at GFDL on the fundamental problem of placing the earth's atmosphere in context among the other planetary atmospheres, and, more generally, in the context of the flow of rapidly rotating stratified fluids. Once again, research in this area has been marked by a willingness to tackle these problems with large nummerical models whenever this appeared to be the most advantageous approach.

The hope of extending the range of useful weather forecasts was one of the prime motivations for developing atmospheric GCM's, and the laboratory's research on weather prediction has always been closely intertwined with work on model development. As an early example, forecasts were utilized in an attempt to validate the methods used for computing precipitation in the first moist primitive equation calculations at GFDL (2,8). As a more recent example, efficient spectral atmospheric models developed by the laboratory's prediction group (180-A) (based on a model developed originally at the Australian Meteorology Research Center) are now used by several of the other research groups at GFDL and by graduate students at Princeton University (233,307,326,342,360-A).

The first extended prediction experiments (four-day forecasts) with a multi-level GCM at GFDL were published in 1965 (58). The same model was then utilized for two-week forecasts (72). This work had a significant impact on the planning of the Global Atmospheric Research Program (GARP) in the late 1960's, particularly on the formulation of one goal of the program -- the improvement of weather forecasts beyond one week. A "predictability" study was then conducted with this model, examining the theoretical limits to deterministic prediction set by the growth due to instabilities of small errors in the initial data. The results reinforced earlier indications that this limit was in the range of 2-3 weeks for synoptic scale variables (74). Of prime practical interest is the extent to which this limit can be approached using the relatively sparse network of real meteorological observations as initial conditions. Using the hemispheric GCM, two week forecasts were computed for twelve January and twelve July cases in order to address this question, a project that required 13 years to complete (139,154,328,oo). Measureable skill was found for up to 10 days in the 500 mb geopotential height field, although skill of practical value remained for only 4 to 5 days.

In parallel with these benchmark calculations, numerical experiments were conducted to determine the effects on predictions of initial conditions (91), the equatorial boundary in the hemispheric model (158), horizontal grid resolution (109), and the treatment of various sub-grid scale processes (107,185,295,311). Although complex and to some extent still controversial, the general results were that useful 5 to 10 day forecasts were within reach if some improvements could be made in the model in all of these areas. As of 1980, useful 10 day forecasts remain a much sought after goal.

If one confines one's interest to planetary and sub-planetary scale weather anomalies (half the width of the North American continent, for example) and ignores the positions of the rapidly moving cyclones and anticyclones, it seems possible that the direct integration of the dynamic equations will be of value for one month or even 3-4 month forecasts. Work in the experimental prediction group has slowly shifted over the years from "extended range" forecasting (up to 10 days) to this longer range problem. However, before such problems could be attacked productively, a lengthy period of model development was required. A global model had first to be adapted for long range prediction studies. This work began shortly after the development of the first GFDL global model. Global data for March 1-5, 1965 were collected and analyzed for use as initial conditions in the model, calculations beginning in the summer of 1968. (32 hours were required for a one-day forecast on the computer then available!) The results of this first global forecast were not outstanding (122,180), but it was later demonstrated that they could be improved appreciably simply by doubling the number of grid-points (266).

Since the treatment of the model "physics" (convective and non-convective latent heat release, boundary layer turbulence, sub-grid-scale mixing in the free atmosphere, and radiation) increases in importance as the length of the forecast increases, work has also continued on improving the way in which these effects are incorporated in the prediction models. Anticipating the eventual necessity of a prediction system with an active upper ocean, an ocean mixed layer model suitable for coupling to the atmospheric model has also been under investigation, and was utilized recently to study the predictability of 1976-77 sea surface temperatures, given real atmospheric data (l,m). After this lengthy period of model development, work has now begun in earnest on long range prediction problems. Using several models, both spectral and finite-differenced, and with various treatments of the model "physics," the predictability of the 1976-77 anomalous wintertime circulation over North America is currently being examined.

The processing of real atmospheric data into a form suitable for use in a primitive equations prediction model (the "initialization" problem) is a research area of continuing interest. A number of initialization techniques have been examined at the laboratory (60,291). The prediction group has focused in particular on the development of "four-dimensional assimilation," in which atmospheric data are inserted into an ongoing model integration as they become available. Problems arise in trying to avoid rejection of data by the model when these data are inconsistent with the model generated field. Another problem that has arisen is that temperature data alone have been found to be insufficient in tropical areas; wind data are needed to supplement the temperatures (132).

The prediction group conducted global four-dimensional analyses for 101 days in near real time for GATE (GARP Atlantic Tropical Experiment), using a massive amount and diverse kinds of data (227). The resulting analyses were found to be viable, but the patterns were excessively smooth. This experience with the four-dimensional analysis method suggested a number of modifications to the pure continuous injection procedure. Using a modified procedure, the GATE case was treated again, and the analyses now succeeded in accurately reproducing African-Atlantic easterly waves (*ll*). The prediction group has also been involved in the Basic Data Set project sponsored by GARP, and the Data Systems Testing sponsored by NASA. At present, four-dimensional analysis is being applied to the unprecedented amounts of data from the Global Weather Experiment, the final GARP observational project, with the goal of producing a dynamically consistent global atmospheric data set for a full one year period.

General circulation models have proven to be of great importance not only for weather prediction, but also for research in climate dynamics. GFDL has been a pioneer in the utilization of these models for climate research. A hierarchy of climate models has been developed, ranging from the relatively simple radiative-convective models of the global-mean vertical temperature profile, to the most comprehensive coupled ocean-atmosphere models in existence.

The development of detailed radiative transfer algorithms for use in the first multi-level atmospheric GCMs in the early 1960's proved to be of immediate value in climate research. The relative importance of different atmospheric absorbers (water vapor, ozone, carbon dioxide, and clouds) for radiative heating in different parts of the troposphere and stratosphere was quantitatively examined for the first time (14,26, 50). The coupling of this radiative transfer model with a simple "convective adjustment" produced a simple model of the global-mean tropospheric and lower stratospheric structure (26). These "radiative-convective" models are now commonly used to obtain energetically consistent first estimates of the temperature response to perturbations in atmospheric composition. An important modification to this model introduced in 1967 (50), the assumption of fixed tropospheric relative humidity rather than fixed specific humidity, allowed the qualitative effects of the water-vapor temperature feedback on climatic sensitivity to be taken into account. This modification has since been incorporated into almost all such calculations.

The simulation of a realistic atmospheric hydrologic cycle, first in a hemispheric model with annual mean solar insolation (49,87), then in an annual mean global model (92,108), and then in a seasonally varying model with realistic topography (163,177,195), opened up a host of climatic problems for investigation. These first seasonally varying models demonstrated that a number of aspects of the seasonal cycle of the atmospheric circulation could be simulated successfully with GCM's. A simple treatment of ground hydrology was incorporated in an atmospheric model in 1969 (79), allowing the prediction of soil wetness as controlled by precipitation, evaporation, runoff, and snowmelt. The complex of questions related to desert formation was discussed in several papers (79,195).

It was encouraging to discover that these general circulation models successfully reproduced the seasonal and geographical variations in the stationary flow field and precipitation rate in the tropics, despite the extremely idealized parameterization of moist convection (92,163). This success allowed one to use these models to explore the dynamics of the tropical circulation. The energetics of tropical disturbances determined by analyzing the models (49,92,163,165) was confirmed by the observational studies of other investigators.

By modifying various features of the model, the interplay of forces maintaining the general circulation of the atmosphere was examined in a number of calculations. These included experiments with and without topography, designed to examine the effects of mountains on time-averaged and transient atmospheric flows (162), particularly the South Asian

Monsoon (206), and sea surface anomaly experiments designed to isolate the effects of tropical sea surface temperatures on the mid-latitude flow (127) and of Arabian Sea surface temperatures on the Indian monsoon (194).

The coupling of atmospheric with oceanic general circulation models has long been a major goal of the laboratory's climatic research program. The first such coupled model was constructed at GFDL (76,79,80,81). By comparing climates produced by an atmospheric model alone with that produced by this joint model, some of the various effects of ocean circulation on climate could be investigated. An idealized continent-ocean basin configuration was utilized to help isolate these effects. A joint model with realistic continental configuration was constructed and analyzed by 1975 (190,191). Because typical abyssal ocean response times are much larger than the time over which it is practical to integrate an atmospheric model, schemes for accelerating the convergence of the joint model toward climatic equilibrium had to be devised. This acceleration has proven to be particularly complex in a seasonally varying model. Results from the first seasonally varying global ocean-atmosphere model were presented in 1979 (347).

The problem of calculating the climatic response to the predicted increase in CO_2 concentration due to fossil fuel combustion has been investigated at the laboratory with a series of models of increasing complexity. Estimates of global mean temperature changes were provided by the radiative-convective model in 1967 (50). The response of an atmospheric general circulation model with highly idealized lower boundary conditions to a doubling of CO_2 was presented in 1975 (192). Results from a similar model in which a first attempt was made to compute changes in cloud cover were described in 1980 (361). The seasonal dependence of the CO_2-induced warming has recently been examined with a spectral atmospheric model coupled to a highly simplified "ocean" (a well-mixed layer of 70 meters of stagnant water, supplying the heat capacity needed to obtain a reasonable seasonal cycle) (360,y). A complicated interplay of changes in snowcover over land and sea ice thickness over the ocean control the seasonal dependence of the temperature response. Results from this series of studies have been utilized by the National Academy of Sciences and other groups in their assessment of the climatic impact of the projected CO_2 increase. The sensitivity of model climates to solar constant variations has also been investigated (216,319) in order to gain a better understanding of climatic sensitivity and to compare with the CO_2 calculations.

Continued research on radiative transfer and its incorporation into large atmospheric models has been essential to the success of the climate modeling effort. In the past five years, a number of related infrared transfer algorithms have been developed specifically for GCMs (196,204, 351). These offer high speed while retaining accuracy comparable to that achieved with much slower benchmark calculations. At the same time, an efficient coding of a more accurate solar heating computation was completed. These improvements are of particular importance for the radiative calculations in the GFDL extended prediction models possessing a diurnal cycle and in the new stratospheric GCM.

Although GCMs remain the best available means of computing the eddy fluxes of heat, momentum, and moisture needed to compute the time mean fields of particular interest in climatic studies, there has long been an interest at GFDL in the fundamental problem of incorporating eddy fluxes into climate models without explicitly computing the time evolution of individual eddies (23,31,96,141,319). Closely related work has included the study of linear barotropic (86,255) and baroclinic (38,82, 167,204-A,342) instabilities of zonal flows, the barotropic instability of non-zonal flow (159-B), and the structural differences between linear and nonlinear baroclinic waves (221).

Detailed analysis of results of GCM experiments and comparison with observations is of value not only for determining the strengths and weaknesses of the models, but also for helping to understand the observations. Novel analysis techniques based on space-time spectral analysis have been developed at GFDL (147,267,292,336,338). These techniques have been used for an in-depth analysis of the equatorially trapped waves generated by the model, and a comparison of these waves with observations and linear wave structures (165,320). The eddies produced by the GCMs in midlatitudes have also been analyzed in detail (260) and compared to the predictions of linear instability and wave-mean flow interaction theories (223).

Interest in paleoclimatology at GFDL has grown in recent years. An experiment with an atmospheric model with boundary conditions provided by the recent CLIMAP geological project shed light on the changes in hydrologic cycle that occurred during the peak of the last ice age, 18,000 years ago (278). Work with simple energy balance climate models has proven to be particularly valuable for the evaluation of the Milankovitch, or astronomical, theory of the ice ages (161-A,243,352). These paleoclimatic studies have the potential for providing unique tests of the models' ability to simulate large climatic changes.

The recent introduction of very efficient spectral atmospheric models (180-A) has increased the variety and the length of the integrations that can be performed and the flexibility one has in the choice of model resolution. Research with these new models is presently being focused on obtaining improved estimates of the CO_2 climatic response and on examining the interannual variability of the circulations predicted by a hierarchy of models.

Research on stratospheric dynamics and chemistry at GFDL evolved naturally out of the early GCM modeling efforts. Work in the early 1960's (14,26) resulted in algorithms for computing radiative fluxes in the stratosphere that were utilized in the first multi-level GCM (32,33). The simulated stratospheric circulation in the model was encouraging: a reversed meridional temperature gradient in the stratosphere was produced, and the model's upward propagating planetary waves played an important role in the energetics of the region. A model with somewhat greater resolution, but still forced with annual mean insolation and with idealized lower boundary conditions, was then specifically constructed to examine these effects in greater detail (63,70). This model was used to perform the first GCM stratospheric tracer experiments (64). Early attempts to address the ozone chemistry problem (35,37) were incorporated in some of these calculations.

As the general circulation models were improved, becoming global in extent and including realistic orography, a realistic hydrologic cycle, and seasonally varying insolation, the models' simulation of the stratosphere improved as well. For example, the stratospheric mid-latitude warm belt and cold equatorial tropopause were more clearly defined and Kelvin and mixed Rossby-gravity waves similar to those observed in the atmosphere were identified in the models' equatorial stratosphere (133, 165,244).

Time varying winds from a more realistic GCM of this sort were used in a number of experiments examining the three-dimensional behavior of trace constituents. Various numerical modeling problems related to tracer calculations had to be addressed in the process (239,263,308). In the first experiment, the evolution of a tracer released instantaneously in a local region (somewhat analogous to a nuclear weapon detonation) was examined (149,308). The average poleward-downward slope of lines of constant mixing ratio, the transfer rate and strong mixing ratio gradients across the tropopause, and some aspects of interhemispheric exchange in the stratosphere were simulated in a realistic fashion. In a series of further experiments, the model was modified progressively until the trace constituent became analogous to atmospheric ozone (149,367). The models helped clarify the relationships between ozone chemistry and transport in the middle and lower stratosphere.

The tracer model was also used in a series of calculations with nitrous oxide, an important chemical precursor to stratospheric ozone (323,dd). These experiments enabled one to study the stratospheric structure and factors determining the variability in the troposphere of a very long-lived tracer. The results have led to quantitative predictions for the behavior of the reactive nitrogen compounds produced by the stratospheric destruction of nitrous oxide (379). These considerations have led in turn to a revised theory for tropospheric ozone with photochemical production near the tropopause that is as large or larger than the ozone flux from the stratosphere (ii).

In 1975 work began on the development of a new GCM of high vertical resolution covering the troposphere, stratosphere, and mesosphere. Although development on this model continues, it has already exhibited some important improvements, particularly in terms of eliminating a cold bias in the polar mid-stratosphere of earlier GCMs (301-A,k,u). Also, this model has apparently been the first to simulate successfully the semi-annual oscillation of zonal winds in the equatorial upper stratosphere (u). A version of this model has been utilized in a recent study of the effects of increases in carbon dioxide and decreases in ozone on the climate of the stratosphere (k). This work has demonstrated that much of the stratospheric response can be predicted with appropriately designed radiative models, but that dynamical responses can be significant, particularly in the tropics.

Stratospheric research has also included observational studies of the dynamics of stratospheric sudden warmings (20), of the jet structure at the tropopause and its impact on the lower stratosphere (150), and of the Southern Hemisphere stratosphere during winter (206-A,237,241). A theoretical study of a possible mechanism for sudden warmings was also conducted at GFDL (117). Practical applications of this varied basic research in stratospheric dynamics and chemistry include the forecasting of a sudden warming (85), the prediction of effluent dispersion from a fleet of supersonic aircraft (153), the prediction of surface radioactive fallout patterns (176), and an evaluation of the effects of spatial and temporal sampling errors on the estimation of trends in total atmospheric ozone (j).

As climates produced by these various GCM's began to resemble the real world fairly closely, the need became clear for in-house observational research to test the results of model experiments. For a number of years, support in the form of free computer time was given to the MIT Planetary Circulations Project to conduct their extensive statistical studies. Part of the MIT data set over North America was used at GFDL for an in-depth study of the kinetic energy balance. An important secondary maximum in kinetic energy dissipation away from the surface boundary layer was found at jet stream levels (36,41), closely resembling earlier model results. A curious and still not understood diurnal variation in this dissipation was also discovered (54). Another area of active research concerned the atmospheric water cycle. The dense data network over North America made detailed local studies (40,52,57,66,104) of the ground hydrology possible, thereby providing support for the development of the moist GCMs.

Much of the processing of the basic MIT 5-year hemispheric data set was gradually undertaken by the observational studies group at GFDL. This led to extensive documentation of the average annual cycle in the mean meridional circulation (90), the poleward energy fluxes (106), the angular momentum (287) and energy cycles (140,171,174,219,223,232) and the entire climatology of zonal mean conditions in the Northern Hemisphere (115). These studies have become the standard for comparison with model results both in and outside of GFDL during the last decade.

Documentation of the observed interannual variability was a natural step following the study of the average annual cycle (169,188,197,279). Knowledge of the year-to-year variability has proven essential to the evaluation of one-year runs of GCM's and also the more recent multi-year integrations. A large 5-year downward trend in the vertical mean hemispheric temperature was found for the 1958-63 period (145,175). This trend was sufficiently large that it could not have persisted for a much longer period, thus emphasizing the difficulty of interpreting climatic trends in view of the large short term variability. Over the past several years, much effort has gone into the preparation of a 15-year global data set, extending the earlier MIT data to the period May 1958 through April 1973.

The combination of satellite radiation data with poleward atmospheric energy fluxes allowed the observational studies group, in collaboration with other investigators, to determine the poleward oceanic heat flux (148). A surprisingly large oceanic flux was found at low latitudes, undergoing strong seasonal variations (245). These findings have stimulated observational, theoretical, and numerical work on a national and international level aimed at discovering more about this apparently crucial climatic component. This work is presently being expanded to include the Southern Hemisphere heat balance, as well as regional budgets on the scale of continents and individual oceans. Detailed studies of the global diurnal cycle and of regional budgets are planned with the forthcoming Global Weather Experiment data set. The possibility of sampling errors in all such observational studies is a constant source of concern. The influence of gaps in the rawinsonde network on general circulation statistics was evaluated in a novel way using the output from a GCM integration (290).

In the early years of the laboratory it was recognized that progress in oceanography was as important as progress in the atmospheric sciences for an improvement in fundamental understanding of the Earth's climate. Although twenty years ago quantitative models of the ocean that could be used for climate studies were not available, a basis on which to start building ocean models did exist. The basic elements were 1) data from nearly one million hydrographic stations giving the gross structure of the temperature and salinity fields of the World Ocean, 2) estimates of the time scales of large scale overturning based on radioactive tracer work, and 3) crude estimates of the heat and water balance of the oceans. In addition, simple analytical models of thermocline formation and the wind-driven circulation could be used as a starting point for more general models.

The experience of the laboratory in building numerical models of the atmospheric general circulation suggested that a similar approach might be useful for the ocean. In retrospect this judgement may appear naive, given the limited understanding of many oceanographic processes at that time coupled with the limited capabilities of computers. However, the experience gained by making an early start in ocean circulation modeling has proven invaluable over the years. Numerical models had been built to study tide surges with encouraging results, but the logical starting points for numerical models of ocean circulation were the analytical wind-driven ocean models. Numerical methods provided a means of extending these models to nonlinear regimes of considerable physical interest. The results of early models (19,21) at GFDL showed that including inertial terms in the wind driven ocean theory produced much more realistic results, and provided a purely barotropic mechanism for the separation of the western boundary current from the coast. This mechanism is still a viable contender among the many ideas advanced to explain the separation of the Gulf Stream at Cape Hatteras.

The next step was the construction of a three-dimensional ocean circulation model which could include the effects of stratification and density advection. Efficient numerical methods were developed for the ocean circulation problem that filtered out external gravity waves (78). The analytic thermohaline theories available at that time again provided a convenient starting point. The numerical model (45,68,69) was able to synthesize the results of the thermohaline theories with the earlier results of wind-driven ocean theory in complete solutions for an entire ocean basin. This model with slight modifications has been widely adopted by other laboratories. From the standpoint of climate research, it is particularly significant that such a model is able to simulate poleward heat transport by the oceans. Results from the GFDL ocean models (191) suggested that the effect of wind drift currents and the thermohaline circulation cooperate to produce large poleward heat transport at low latitudes, but the wind drift and thermohaline currents tend to transport heat in opposing direction at higher latitudes, thus helping to explain why the oceanic flux peaks at low latitudes.

The Asian monsoon causes a spectacular seasonal reversal of ocean currents in the western Indian Ocean. For this reason the Indian Ocean was chosen for testing the model with realistic basin geometry and boundary conditions. The relative importance of local and distant winds for the generation of these currents has been debated by oceanographers for over a decade. In the model study (88), local winds were found to be the most likely mechanism for the initial generation of the coastal current during the southwest monsoon, with winds over the interior of the basin subsequently modifying the evolution of the current. Another regional study was carried out for the Southern Oceans (113). This study illustrated the usefulness of numerical models for examining the constraints imposed by basin geometry on the circulation. Potential applications of such models in paleoceanography suggested by this work are still to be exploited.

These models were first applied to problems of marine geochemistry in 1971 (121). The oceanography group is presently returning to this problem in an attempt to validate the thermohaline circulations generated by the models by comparing observed and model generated tracer distributions. Questions about the role of "mesoscale eddies" (50-300 kms wide) in the ocean circulation motivated a study of Gulf Stream meanders (146). Later, models of the wind driven circulation over an entire ocean basin were constructed that were capable of resolving mesoscale eddies (178-B,210,211). These results indicated that these eddies are extremely effective in conveying energy from the surface to deeper layers. Topographic generation of mesoscale eddies was the subject of another study (240).

Much of the recent work of the ocean circulation group has been concerned with the response of the tropical oceans to large scale wind variations. In low latitudes, the oceans adjust rapidly to changes in wind conditions, and the associated variations in heat storage in the upper ocean have very large effects on sea surface temperatures. Variability of this type primarily occurs seasonally in the Indian and

Atlantic Oceans and interannually in the Pacific Ocean (during El Nino events). Studies (348,349) of similarities and differences between these ocean basins, attributable primarily to differences in atmospheric forcing and different dimensions of the basins, have provided much information about the dynamics of oceanic variability in low latitudes.

In addition, a high resolution model of the Pacific circulation (p) has provided an excellent simulation of waves which form in the shear zone between the South Equatorial Current and the Equatorial Countercurrent and which are strikingly evident in satellite infrared images. Stability analyses suggest that these waves are indeed shear instabilities (310).

The computation and compilation of wind stresses over the world oceans from the observed near-surface winds was an early project of the oceanography group (29-A,55). These computations have become a standard reference in ocean modeling research. Parallel to its atmospheric work, the observational studies group is in the process of analyzing the general circulation of the world oceans as well (285). A first project was the determination of the average seasonal cycle in ocean heat storage on a zonal mean (245) and global mean (299) basis. The analyses of temperature, salinity, density, and oxygen are already widely used in diagnostic model and tracer studies, and in the initialization of oceanic GCM's.

While the primary focus of research activity at GFDL has been on large-scale dynamics of the atmosphere and oceans, research efforts have also developed over the years concerned with understanding a number of equally important smaller scale phenomena. A decision was made in 1970, for example, to establish a project that would concentrate on the life cycle of tropical cyclones and make a contribution to one of NOAA's important service functions - tropical cyclone prediction.

In 1971, a three-dimensional hurricane model and a simpler axisymmetric version of this model were constructed. Special attention was paid to the treatment of boundary layer processes and to the parameterization of the effects of cumulus convection. In particular, a modified scheme of moist convective adjustment was formulated by incorporating the effect of entrainment of the surrounding air into the cloud (156). These primitive equation models were capable of simulating the development of a weak vortex in a large closed domain into a hurricane-like system (172,189,193). The results obtained proved to be of value for the construction and improvement of the first generation hurricane prediction model at the National Meteorological Center. Analysis of model results and a subsequent theoretical study (230) shed light on various features of spiral band structure in a hurricane. The model was also used to study the structural changes and the cause of decay of a tropical cyclone at its landfall (293).

In order to study the formation of tropical storms, incipient disturbances have to be treated within the context of the larger scale environment. The influence of the environment on the development or non-development of a tropical disturbance is certainly one of the most intriguing research subjects in tropical meteorology. Efforts at upgrading the hurricane model so as to be able to address this subject have been continuing since 1975. Related to this effort, a method of dynamic initialization of the planetary boundary layer has been proposed (286,354). A channel model with open lateral boundaries is currently being used to investigate the genesis of a tropical storm from an easterly wave. Preparation for the construction of a movable nested-mesh model began in 1975. After a series of design tests (231,327), this complex model was used to simulate a small vortex (s). More recently, simulation of a hurricane eye was carried out with a quadruply nested system. This movable nested-mesh model will be used in the future for experimental prediction of the movement and changes in intensity of a tropical cyclone.

A research effort has also developed over the past ten years in the study of "mesoscale" phenomena in the atmosphere and oceans. A large variety of phenomena are classified as mesoscale, ranging from internal gravity waves and organized convective systems at the small-scale end of the spectrum - "meso γ" - to frontal systems at the large scale end - "meso α" (200). Researchers at GFDL have employed analytic techniques, numerical models, and laboratory experiments at various times in the investigation of these phenomena. Relationships between processes in the atmosphere and the ocean have been emphasized, an example being the suggestion that baroclinic instability of boundary currents in the ocean might be the mechanism by which oceanic eddies are generated (82,146).

The generation and dissipation of internal gravity waves in both atmosphere and ocean is of central importance in mesoscale dynamics but is also significant as a subgrid-scale feature which requires parameterization in GCM's. The breaking of internal waves, in particular, is recognized as one of the primary dissipative mechanisms in a variety of stratified flows. In 1969, wave overturning (the generation of gravitationally unstable regions within the wave) was suggested as the primary cause of internal wave breaking (84). Laboratory experiments were then designed to study the growth of internal waves and the wave breaking process. Aspects of these experiments were simulated with analytical and numerical models (130). A recent study of energy transfer among internal waves in a fully non-linear regime (h) clearly indicated that energy is dissipated very efficiently by localized overturning when the spectrum is "saturated," as it is in the ocean, and that this process controls the shape of the spectrum.

Another area of interest to the mesoscale group at GFDL has been the effects of diurnal variation of the planetary boundary layer on the atmosphere. The discovery was made with numerical and analytical models that this diurnal variation could be a major source of large scale internal gravity waves (152,173,224). The theory of this "trapeze instability" indicated the possible existence of a wave in equatorial regions with a two-day period and a horizontal scale of several hundred kilometers, and an analysis of satellite photographs of cloud cover over Africa suggested the presence of such a wave (288). A recent study of the land-sea breeze circulation indicates that wave generation effects of this sort can also have an important effect on this phenomenon.

The structure of frontal systems is one of the central problems in mesoscale meteorology. The mesoscale cross-stream circulation that develops in a vertical plane perpendicular to the surface front is a crucial feature of frontal dynamics, not only for maintaining the mature system but also as a triggering mechanism for moist convection along the front. The generation of this circulation by an established frontal system was investigated at GFDL for a dry atmosphere using a two-dimensional numerical model (227). The resulting solutions exhibited ageostrophic rolls aligned along the front. When moisture was added, the lifting associated with this circulation produced deep convection when the air ahead of the front was convectively unstable (296,301).

These solutions for simplified frontal and convective systems have recently been extended to a three-dimensional simulation of an observed frontal squall line in the U.S. (355). The numerical model used is similar in some ways to GCM's but also has a number of distinct features. Just as in hurricane simulation, resolution requirements necessitate the use of limited-area models with open boundaries and nested meshes. Techniques for treating open boundaries in numerical models developed at GFDL (249) are currently being used by a number of other researchers. Unlike the GCMs, a mesoscale model may need to resolve non-hydrostatic motions. Recently, a "quasi-hydrostatic" model has been designed (mm) which performs as well as the full non-hydrostatic system for mesoscale simulations but is much more efficient. A new model with nesting capability is also in development, that will allow one to focus on a particular disturbance in order to study the environmental conditions which lead to severe storm activity.

GFDL has also had a continuous research program studying still smaller scale phenomena - individual convective cells and clouds. Convection is of interest in its own right, but the fact that the parameterization of subgrid-scale convection is a problem of central importance in large-scale GCMs provides further motivation for this work. Research on small-scale convection was, in fact, an integral part of the laboratory at its inception. The first studies of convection at the laboratory, very early in its history, were two-dimensional numerical simulations of dry thermals (15,24). This research indicated that the use of numerical models for studying the dynamics of buoyantly unstable non-hydrostatic flows was feasible. The large scale features of the thermals were reasonably well represented. Numerical models were then applied to the investigation of Benard convection as seen in laboratory experiments. Two-dimensional models were developed to examine the effects of a mean flow (103) and rotation (111) on the convective cells. The importance of including the third space dimension was clearly indicated by further studies (105,151,234).

The first research involving moist convection was a two-dimensional study (155) that included a detailed representation of the cloud microphysics. This model simulated moderately deep convection (5 km) with formation of rain in a fairly realistic fashion. For example, in the rain stage the model cloud had downdrafts associated with evaporative cooling and a bimodal form of the droplet spectrum. An unrealistic feature of this model and many other early cloud models was a "mushroom" appearance of the cloud. A later study (164) found that before the onset of rain the cloud microphysics could be greatly simplified by fixing the shape of the cloud droplet spectrum. More recently, work on cloud microphysics has broadened to a planetary context (247,259,313), analyzing and comparing the characteristics of clouds on Earth, Venus, Mars and Jupiter.

A three-dimensional moist convection model (280) was initially developed to simulate trade wind cumuli. In this study different forms of turbulence parameterizations representing subgrid-scale motions were tested. It was found that within the cloud the subgrid-scale turbulent energy was a significant fraction of the kinetic energy on the resolved scales, emphasizing the central role that the difficult subgrid-scale parameterization problem plays in cloud modeling. This cloud model has now been modified to simulate deep moist convection with "warm rain" cloud physics. A continuing effort is being made toward improving the quality of the model calculations. At the present time, research is directed toward studying the dynamical interaction between convective cells and larger scale wind shears and horizontal convergences. It is hoped that these calculations will lead to new insights into the role of convection in such phenomena as tropical cloud clusters and easterly waves.

The study of turbulence within the planetary boundary layers in the atmosphere and ocean has also become an active area of research at GFDL within the past decade. Much of the research in this field focuses on the "closure" assumptions required to obtain a set of equations for the mean flow and turbulence statistics as a function of height. Work at GFDL has resulted in a hierarchy of "second-order" closure models - in which equations are obtained for the mean fields and some or all of the variances and covariances of the turbulent eddy field - the closure assumptions being designed so that free parameters can be evaluated with experimental data on unstratified, non-rotating, turbulent boundary layers (159-A, 185). These models have been used with success in simulating boundary layer data from the Wangara experiment (217). The method has also been applied to the surface layers of the ocean (209,f), and has recently been extended to include the effects of non-precipitating clouds (261) for further atmospheric application.

Elements of this closure hierarchy have been used by a number of researchers at other institutions as well as at GFDL. Forecast experiments at GFDL have clearly indicated the importance of the accurate computation of turbulent fluxes in the boundary layer for medium and extended range forecasts (107,109,220,295), the most successful forecasts to date having been made with one of the more sophisticated closures in this hierarchy.

The generation and decay of turbulence has also been studied experimentally at GFDL. In particular, using a novel apparatus for generating turbulence behind a grid, new data on the decay of turbulence in neutral and stratified fluids have been obtained (e). The stratified fluid experiment has provided new information on the critical Richardson number for which turbulence breaks down to be replaced by weakly interacting internal waves.

Based on research into circulations on all scales, one hopes eventually to be able to formulate a general theory of the circulation of planetary atmospheres. The exploration of the solar system over the past two decades has certainly stimulated these efforts. The recent applications and extensions of conventional meteorological models to other atmospheres has also been encouraging, testifying as it does to the generality of the meteorological concepts developed for the Earth's atmosphere. Work at GFDL has focused not only on simulating the details of other planetary atmospheres, but more generally on the dependence of planetary circulations on external parameters such as the rotation rate and size of the planet. These studies can also be thought of as a type of nonlinear analysis, probing the interactions and balances within the system by modifying external parameters.

Ideas about possible forms for planetary circulations stem to some extent from laboratory annulus experiments. A substantial effort was made at GFDL in the years 1965-72 to identify the processes occurring in the annulus and determine the limitations of the planetary analogies. Numerical modeling (46,47,116,124) and linear analyses (167,184) showed that although the eddy field in the annulus is generated by a form of baroclinic instability, the zonal mean flow is essentially determined by the boundary layers at the sidewalls and horizontal surfaces. Thus, while the annulus remains of great value for the study of finite amplitude baroclinic instability in the presence of horizontal and vertical shear, its use as a planetary analog is limited by the sidewall boundary layers and by the absence of phenomena, such as Rossby waves, produced by the β-effect. Idealized experiments that omitted sidewall layering (71,94) led to the discovery by other investigators of the diffusive symmetric baroclinic instability, a mode of mesoscale interest.

To simulate the annulus waves it was necessary to devise a general numerical algorithm for solving the three-dimensional Navier-Stokes equations, an unsolved problem at the time and an important objective in its own right. The method used (75,101) has become a standard finite-difference technique, with widespread use in various branches of fluid dynamics. An ancillary fast Fourier transform, with fewer restrictions on the length of the data set being inverted than the transform then in use, was also created, and its flexibility has led to wide adoption.

By 1972 it appeared that the circulation of Jupiter could be particularly instructive in developing a terrestrially-relevant theory for planetary circulations. (Mars seemed too similar to the Earth, and Venus too dissimilar.) The preliminary issues to be resolved concerning the Jovian circulation were whether the circulation was convectively or baroclinically driven (that is, which processes converted potential to kinetic energy), and whether the zonality of the flow and the multiple jets were a direct consequence of an axisymmetric mode or secondary characteristics of a turbulent flow. Various axisymmetric theories were examined first. Although realistic motions were produced by convective overturning (129,152), excessive heating was needed to drive such an atmosphere. More recent studies suggest, however, that the equatorial zone may be of the form produced by the convective model. Axisymmetric models of Jupiter were abandoned in 1974, when it was realized that Rhine's hypothesis concerning the final state of a two-dimensional turbulent cascade in the presence of a β-effect could better explain the multiplicity, zonality, and turbulence of the Jovian jets (205,215).

With a simple barotropic model, it was demonstrated that a zonally banded circulation with alternating easterly and westerly jets does arise from the two-dimensional turbulent cascade on a rotating sphere (302). That such flows can be produced under more realistic Jovian conditions was then verified by a quasi-geostrophic model (335). The overall conclusion is that Jovian jets and eddies, including the Great Red Spot, are essentially quasi-geostrophic phenomena, except in the equatorial zone.

To clarify the relationship between the Jovian multiple jets and the single terrestrial extratropical jet, the parametric dependence of the quasi-geostrophic model was investigated (353). The β-effect and the strength of the surface drag were found to be the main factors determining circulation form. A simple connection between the Earth and Jupiter emerges - Jupiter has more jets because of its greater size and rotation rate and the jets are more zonal because of the weakness of surface effects.

Progress in the theory of the Venusian circulation has been less pronounced. Research at the laboratory has focused in particular on possible explanations for the cause of the strong upper level winds on Venus. The explanation in terms of forcing by thermal tides remains viable (163-A), but barotropic models suggest that the maintenance of these winds is consistent with non-linear two-dimensional energy cascades as well (326).

As is evident from this survey, many of the problems attacked at the laboratory have required substantial computer power. Constant growth of the laboratory's computational resources has, in fact, been essential to most of the projects detailed in this survey. The following list of computers used by GFDL describes this growth in computer power:

Type	Time Period	Approximate Relative Power
IBM 701	1956 - 57	1
IBM 704	1958 - 60	3
IBM 7090	1961 - 62	20
IBM 7030	1963 - 65	40
CDC 6600	1965 - 67	200
UNIVAC 1108 (#116)	1967 - 73	80 (*)
UNIVAC 1108 (#140)	1968 - 69	80 (*)
IBM 360/91	1969 - 73	400
IBM 360/195	1974 - 75	800 (*)
TIX4ASC	1974 - 82	3000 (*)

Those computers for which GFDL had (or has) unlimited use for its own research are labelled by an asterisk. The laboratory's use of the other systems was limited. Available computer power has therefore increased by more than a factor of 3000 over the past twenty-five years.

AN OVERVIEW

SCOPE OF THE LABORATORY'S WORK

The Geophysical Fluid Dynamics Laboratory is engaged in comprehensive long lead-time research fundamental to application areas in support of NOAA's mission.

The goal is to expand the scientific understanding of those physical processes which govern the behavior of the atmosphere and the oceans as complex fluid systems. These fluids can then be modeled mathematically and their phenomenology studied by computer simulation methods. In particular, research is conducted toward understanding:

- the predictability of weather, large and small scale;
- the particular nature of the Earth's atmospheric general circulation within the context of the family of planetary atmospheric types;
- the structure, variability, predictability, stability and sensitivity of climate, global and regional;
- the structure, variability and dynamics of the ocean over its many space-and-time scales;
- the interaction of the atmosphere and oceans with each other, and how they influence and are influenced by various trace constituents.

The scientific work of the Laboratory encompasses a variety of disciplines: meteorology, oceanography, hydrology, classical physics, fluid dynamics, chemistry, applied mathematics, high-speed digital computation, and experimental design and analysis. Research is facilitated by the Geophysical Fluid Dynamics Program which is conducted collaboratively with Princeton University. Under this program, regular Princeton faculty, visiting scientists, and graduate students participate in theoretical studies, both analytical and numerical, and in observational experiments, both in the laboratory and in the field. The program, in part, is supported by NOAA funds. Visiting scientists to GFDL may also be involved through institutional or international agreements, or through temporary Civil Service appointments.

SOME HIGHLIGHTS OF FISCAL YEAR 1980

An atmosphere-mixed layer ocean model with limited computational domain and idealized geography has predicted the following changes in climate resulting from an increase in the atmospheric concentration of carbon dioxide: poleward shrinkage of the area of cool snow-forest climate, poleward extension of warm temperate rainy climate, expansion of tropical rain-forest climate and shrinkage of the region of savanna climate. *** The effects of surface albedo feedback on climatic sensitivity have been studied in detail with a two-level primitive equation atmospheric model. In contrast to results obtained with the diffusive energy balance models described in the literature, the strength of the albedo-feedback does not increase monotonically as temperatures are lowered.

It has been demonstrated that the spatial structure of the most prominent and recurrent anomalous circulation pattern appearing in a 15-year integration of a general circulation model bears some resemblance to that observed in the atmosphere. The absence of this anomalous pattern in another simulation with no mountains suggests that orography plays a central role in the intermonthly variability of the extratropical atmosphere. *** Based on the analysis of a general circulation model, it has been suggested that one can understand the dominance of the Aleutian high in the winter stratosphere by interpreting the stationary flow field as an upward and eastward propagating planetary wave packet.

A series of N_2O tracer experiments has shown how such 3-D results can be used in cooperation with careful measurement programs to solve one of the most difficult problems in atmospheric chemistry, that of determining the sources and source strengths for long-lived trace constituents. *** Studies of the reactive nitrogen budget have led to the formulation of a revised hypothesis explaining the behavior of tropospheric ozone. *** The 40-level troposphere-stratosphere-mesosphere GCM appears to have produced the first successful simulation of the semi-annual zonal wind oscillation of the equatorial upper stratosphere.

The one-month evolution of two cases of blocking ridges, January 1977 and March 1965, have been successfully simulated with a global GCM. The treatment of subgrid-scale processes had a substantial impact on the maintenance of the blocking ridges in the model.

Using an integral mixed layer model, the spatial distribution of the sea surface temperature anomaly over the Northern Hemisphere oceans for 1976 and 1977 was predicted with positive skill for about four months.

The updated four-dimensional analysis of the GATE (GARP Atlantic Tropical Experiment) data set successfully reproduced the movement of African-Atlantic easterly waves as revealed in the University of Hawaii's hand analyses. *** The precipitation obtained from the four-dimensional analysis over the GATE special A/B ship array compared well with the estimates of condensation obtained from satellite infrared measurements.

Examination of the influence of rotation rate on the circulation of rapidly rotating atmospheres with GCM calculations has reproduced the equatorial flow pattern of Jupiter and clarified the role of cyclonic eddies and the Hadley Cell in producing the Earth's zonal motion.

The documentation of the three-dimensional structure of the global climate in the atmosphere and oceans has almost been completed. In addition to the normal annual cycle, measures of the year-to-year variability in the global atmosphere based on a 15-year upper air data set have been determined.

As part of a continuing study of low frequency variability in the tropical oceans, a series of numerical experiments have shown that changes in meridional winds are extremely effective in the east-west redistribution of heat in the upper ocean. In addition, the presence of strong equatorial currents has been shown to suppress certain linear mechanisms of adjustment to wind variability. *** Using the observed density structure, a general circulation model of the North Atlantic has been developed to predict the entry of bomb derived tritium into the upper ocean, with suitable allowance for wintertime convection. The model produces good agreement with geochemical data.

The genesis of a tropical storm from a weak shallow easterly wave was extensively analyzed. The warming of the middle troposphere and the development of an upper level divergent anticyclonic flow were consequences of the storm formation. *** Using a quadruply nested model, a persistent hurricane eye was simulated.

The simulation of a cold front with the primitive equations has provided clues as to the most important processes which produce, sustain, and then destroy the intense gradients characteristic of frontal regions. *** The well-known land-sea breeze circulation has been reviewed, and it has been found that a secondary larger scale standing gravity wave may be excited by the land-sea temperature contrast.

Numerical simulations of deep moist convection with a large-scale time-invariant convergence were carried out. In a preliminary calculation with a large-scale convergence and weak vertical wind shear typical of tropical conditions, a gust front developed, and successive transient cells formed at the leading edge of the gust front. This realistic type of transient cell development did not occur without the large-scale convergence.

SOME IMMEDIATE OBJECTIVES

To investigate the geographical distribution of climate change resulting from the anthropogenic increase in the concentration of atmospheric carbon dioxide, numerical experiments will be continued using a global atmosphere-mixed layer ocean model with improved computational resolution. *** Comparison of calculated and observed CO_2 spectra will be carried out to determine the effects of non-Lorentzian line wings. *** Diagnostic studies of long-term model simulations will be continued in order to assess the nature and relative importance of the factors contributing to atmospheric variability on various temporal scales. *** A series of control experiments using a spectral hemispheric general circulation model will be conducted to clarify the effects of condensation on growing and mature mid-latitude cyclone waves. *** A theory for the poleward eddy heat flux developed for the case of a horizontally uniform mean temperature gradient in a two-level model will be analyzed further to see if it has any relevance for horizontally inhomogeneous flows and for multi-level models.

Experiments designed to study various aspects of the structure and behavior of atmospheric nitrogen compounds and ozone will continue; development of a model capable of solving simultaneously for multiple trace constituents will be undertaken. *** Analyses of the annual mean and seasonal experiments with the troposphere-stratosphere-mesosphere GCM will continue with emphasis on the simulated equatorial zonal wind fluctuations.

Six one-month prediction experiments will be carried out. *** The Four-dimensional analysis system will be used to process the FGGE (First GARP Global Experiment) one year data set. *** The importance of cloud-radiation interaction for long range prediction will continue to be investigated. *** The study of the predictability of sea surface temperature anomalies will be continued; a turbulent closure model for the ocean mixed layer will be examined, and the effect of current advection and up- and down-welling will be studied with a full ocean model.

The oceanic heat transport will be examined in the Southern Hemisphere and in individual ocean basins using the indirect planetary energy balance method.

Models being prepared this year will be used in joint ocean-atmosphere studies to determine the climatic response on a 50-100 year time scale to changes in atmospheric carbon dioxide. Of particular interest will be the delayed response due to the ocean's heat reservoir.

Analysis of the main factors controlling planetary circulations will continue, including attempts to simulate the Great Red Spot using the GFDL GCM.

The analysis of numerical simulations of tropical storm genesis will continue. Application of the model to the prognosis of tropical disturbances will be attempted. *** A movable nested-mesh model will be used to study the dynamics of the eye of a hurricane as well as problems concerning hurricane movement and the effects of landfall.

The effects of mesoscale feedback to the synoptic scale will be investigated. A number of case studies using SESAME data will be performed, varying parameters such as moisture content and boundary layer physics in order to determine the factors controlling frontal occlusion. *** With the same data set, other case studies will be performed to investigate the environmental conditions in which severe storms may be generated (focussing on the Wichita Falls, April 10 storm).

Numerical simulations of deep moist convection with a large-scale time-invariant convergence will be be continued to determine how this large-scale factor modifies the vertical transfer of heat, water vapor and momentum in a tropical atmosphere.

Two- and three-dimensional coastal ocean models with vertical mixing based on a second moment turbulent closure model will be used to study tidal response and sediment transport in New York Harbor.

PROJECT ACTIVITIES - FY80 PLANS - FY81

1. CLIMATE DYNAMICS

Goals

* To construct mathematical models of the atmosphere and of the joint ocean-atmosphere system which simulate the global large-scale features of climate.

* To study the dynamical interaction between large-scale wave disturbances and the general circulation of the atmosphere.

* To identify the physical and dynamical mechanisms which maintain climate and cause its variation.

* To evaluate the impact of human activities on climate.

1.1 CLIMATIC EFFECTS OF CO_2 INCREASE

ACTIVITIES FY80

1.1.1 Global Model

The study of the climatic effect of the future anthropogenic increase in the atmospheric CO_2 concentration is continuing to receive strong emphasis. The FY79 report contained a brief description of preliminary results from a CO_2-climate sensitivity experiment using a mathematical model of climate with a global computational domain and realistic geography. The climate model consists of (a) a general circulation model of the atmosphere, (b) a heat- and water-balance model of the continents, and (c) a simple mixed layer model of the oceans. The climatic effect of a CO_2 increase was determined by comparing statistical equilibrium states of the model atmosphere with normal and four times the normal concentration of CO_2 (360). During this fiscal year, the output from this numerical experiment has been analyzed further. Some of the results from this study are extensively discussed in (y).

It was found that the response of the global model to an increase in the atmospheric CO_2 concentration has large seasonal and interhemispheric asymmetries. For example, as pointed out in the FY79 report, the CO_2-induced warming of surface air in high latitude is much larger in winter than in summer and thus reduces the amplitude of the seasonal temperature variation. The day-to-day variability of surface air temperature in high latitudes is also reduced, mainly because of a reduction in the meridional temperature gradient. This effect is particularly strong in winter.

The general warming of the model atmosphere results in an enrichment of the moisture content of the air and an increase in the poleward moisture transport. This enhancement of moisture transport is responsible for an increase in the rates of precipitation and runoff in high latitudes throughout the year. Owing to the warming, the time of maximum snowmelt and runoff occurs earlier in the spring.

1.1.2 Seasonal Variation

The influence of seasonal variation of insolation upon the sensitivity of climate has been investigated using an atmosphere-mixed layer ocean model. The basic structure of the model is identical to that of the global model described in Section 1.1.1 except that it has a limited computational domain with idealized geography. Two versions of the model have been constructed: in the first version, the seasonal variation of insolation is imposed at the top of the model atmosphere; in the second version, insolation is given its annual mean values. The response of the seasonal model to an increase in the atmospheric CO_2 concentration was compared with the corresponding response of the annual model. It was found that the high latitude response of the annual mean surface air temperature in the seasonal model is significantly less than the corresponding response of the annual model. The smaller sensitivity of the seasonal model is attributed to the absence of strongly reflective snow cover during summer, when the insolation has near-maximum intensity. Further details of this study are included in (z).

1.1.3 Geographical Distribution

The results from the seasonal model with idealized geography have also been used for a preliminary study of the geographical distribution of the CO_2-induced change in climate. Owing to the simplicity of the model geography, systematic changes in the distribution of climatic types are relatively easy to identify. Fig. 1 depicts the two horizontal distributions of climate (classified according to the system developed by Koppen) obtained from this seasonal model with the normal and four times the normal concentrations of CO_2. Climatic classes are determined from the seasonally varying temperatures and precipitation rates over land. In response to the quadrupling of CO_2, the area of C_f climate (warm temperate, rainy climate with no dry season) extends further poleward, resulting in a poleward retreat of the D_f region (cool snow-forest climate with no dry season). Because of the CO_2-induced increase in precipitation rate in the model tropics, the area of A_f climate (tropical rain forest) is increased significantly, whereas that of the A_w climate (tropical savanna) is reduced.

PLANS FY81

The distribution of the CO_2-induced climatic change described above was obtained from a model with highly idealized geography. It is obviously desirable to determine this climatic change using a model with realistic geography - such as the global model described in Section 1.1.1. Unfortunately, the computational resolution of this model is too coarse to accurately represent the influence of the detailed actual geography on the flow field and climate. A new CO_2-climate sensitivity study has been initiated using a global model with higher computational resolution. Time integrations of the model are now in progress. Detailed analyses of the results from this experiment will hopefully begin during the upcoming fiscal year.

The zonal mean distribution of cloud cover is prescribed in the global models described above. To investigate the influence of cloud cover variation upon the sensitivity of climate, the low resolution version of the global model has been modified so that cloud cover is a prognostic rather than a prescribed variable. Encouraged by the success of this modified version of the model in simulating the gross features of the observed distribution of total cloud cover, a CO_2-climate sensitivity study using this version of the global model is planned for this fiscal year. A completed study of the influence of cloud cover upon climate sensitivity using an atmospheric model with a limited computational domain and idealized geography (n) should be of value in analyzing these results.

The CO_2-climate sensitivity studies described so far deal with the final response of climate to an increase in atmospheric CO_2; these studies do not explore the transient characteristics of the adjustment

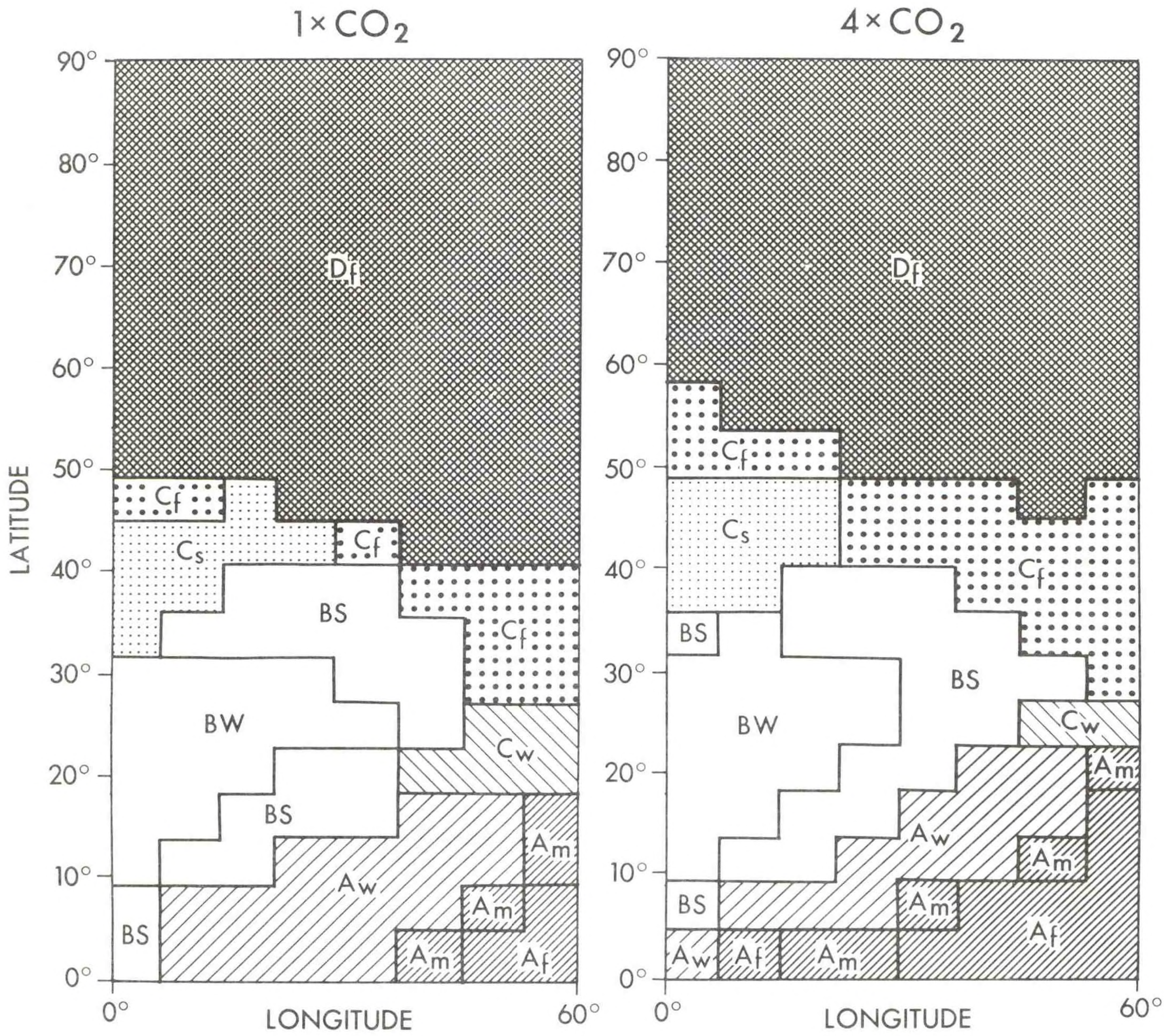

Fig. 1. Horizontal distribution of climate over the model continent, using the Köppen classification: A_f - Tropical rain forest climate; A_m - Tropical monsoon climate; A_w - Tropical savanna climate; Bw - Desert climate; Bs - Steppe climate; C_f, C_s, C_w - Warm temperature rainy climate; D_f, D_w - Cool snow forest climate; (The suffixes f, w, and s denote the absence of a dry season, dry season in winter, and dry season in summer, respectively.)

The computational domain of this seasonal model is bounded by two meridians 120° apart, cyclic continuity being assumed at these two meridians. A continent occupies one 60° longitude span of the domain; the other 60° of longitude are covered by ocean.

of climate to a new CO_2 level. For the study of the transient problem it is desirable to use an atmospheric circulation model coupled with a full ocean circulation model so that the effect of heat exchange between the mixed layer and deeper layers of the ocean can be incorporated into the study. A continuous effort has been made at GFDL to develop a model of this kind during the last dozen years (76,80,81,190,191,347). In collaboration with the ocean circulation group of the laboratory, an investigation of the responses of a joint model to an increase in the atmospheric CO_2-concentration is being planned.

1.2 ICE AGES

ACTIVITIES FY80

Work has continued on the analysis of climatic responses to perturbations in the Earth's orbital parameters in a series of seasonally varying energy balance models, aimed at testing the Milankovitch theory of the Ice Ages. Simple models have been devised which illuminate aspects of the often counter-intuitive responses to the precession of the perihelion with respect to the equinoxes.

Using a two-level, primitive equation atmospheric model designed for climatic sensitivity studies (294,319), the effects of ice and snow albedo feedback on the response to solar constant variations have been examined in detail. The results are markedly different from those described in the literature based on diffusive energy balance models. In the diffusive models, the sensitivity of temperatures to changes in incident solar flux generally increases monotonically as the solar constant decreases and the icecap expands. As the solar constant is lowered in the primitive equation model, however, sensitivity increases at first, then decreases, and finally increases again (Fig. 2). By successfully mimicing the primitive equation calculations with an energy balance model possessing an "effective heat diffusivity" that varies with latitude, it was found that the meridional structure of the diffusivity is responsible for this behavior.

PLANS FY81

The importance of the meridional structure of the effective diffusivity of the atmosphere for the Milankovitch theory of the Ice Ages will be examined. Work will continue on developing a coherent set of results on the climatic response to orbital parameter perturbations in a variety of simple models, in preparation for testing the Milankovitch theory with general circulation models.

Using the global model of the joint atmosphere-mixed layer ocean system described in Section 1.1.1, the influence of continental ice sheets upon the ice age climate will be examined. Two numerical experiments are in progress with prescribed ice sheet distributions, one with the present ice sheet distribution, and another with the ice sheet distribution at the peak of the last ice age (about 18,000 years ago). By comparing the results from these two experiments, the influence of

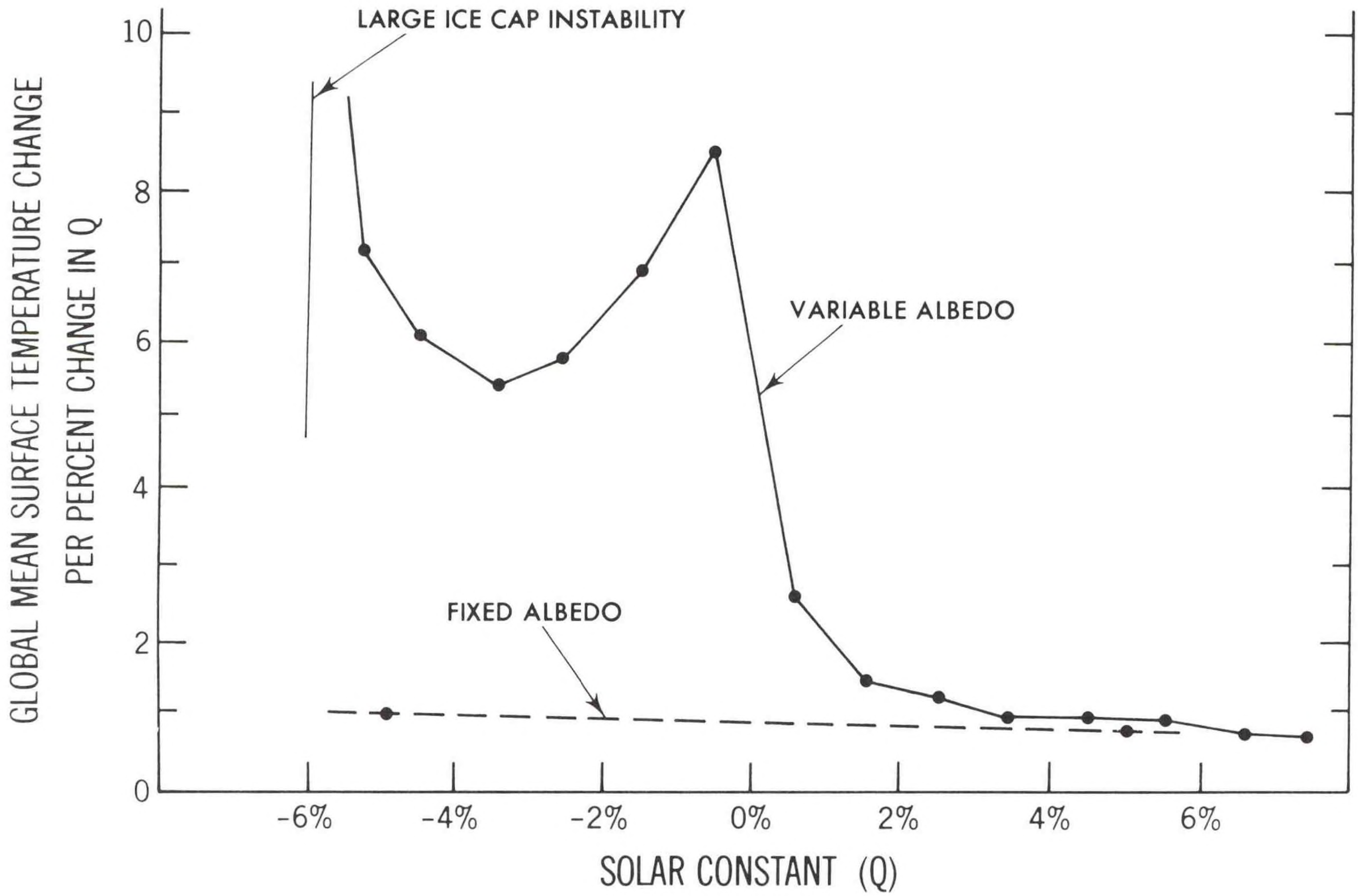

Fig. 2. Sensitivity to solar constant variations as a function of solar constant with and without surface albedo feedback in a two-level primitive equation model. The solar constant to which "0%" refers is sensitive to the albedo parameterization.

the extensive ice sheet upon the thermal and hydrological structure of climate during the last major glaciation can be identified.

1.3 CLIMATE VARIABILITY

ACTIVITIES FY80

1.3.1 Simulation

Since the last fiscal year, the variability of the climate generated by a 15 year integration of a general circulation model of the atmosphere has been extensively analyzed. The model has a global computational domain, realistic geography and seasonal variation of insolation. The annual variation of the distribution of sea surface temperature is prescribed. It was found that the model successfully reproduces many of the characteristics of the observed distribution of the standard deviations of daily and monthly averaged fields of the geopotential height, temperature, and wind velocity. However, as the time-averaging period is increased from one day to one month to one year, the ability of the model to simulate the observed atmospheric variability is reduced, particularly in the tropics. Some of the results from this analysis are summarized in a manuscript to be completed shortly.

The observational studies group of the laboratory has identified the three dimensional structure of the dominant circulation anomalies in the model atmosphere by an empirical orthogonal function analysis and by the construction of teleconnection patterns. It was found that those anomalous circulation regimes persisting on weekly and monthly time scales are characterized by well-defined geographical patterns. Some of these anomalies bear a close resemblance to those observed in the atmosphere during winter.

1.3.2 Orographic Influence

To investigate the influence of orography upon the variability of climate, a version of the global atmospheric model with a flat continental surface free of mountains has been constructed and integrated for a period of 10 years. The three dimensional structure of the dominant circulation anomalies in the atmosphere of this no-mountain model have been compared with the corresponding anomalies in the regular global model with mountains. It was found that the anomaly patterns are distinctly different in the two models. These model experiments suggest that the interaction of the large-scale flow with orography is an important contributing factor to atmospheric variability on monthly time-scales.

PLANS FY81

By diagnosing the pair of long-term simulations mentioned above, the effects of orography on the spatial structures of the stationary and transient waves, and the associated transport characteristics, will be explored in further detail. The onset and breakdown of prominent anomalous episodes in the simulations will be examined in light of the circulation in the vicinity of the major mountain complexes, transient eddy behavior, interactions between the tropical and extratropical latitudes, and other mechanisms. (This study of orographic influences has been and will be conducted in collaboration with the observational studies group of the laboratory.)

A long term integration of an atmospheric model without seasonal variation and with a flat "swamp" lower boundary condition will also be analyzed. This model has no mountains, no land-sea contrast, no surface albedo variations, and no soil moisture variations. It should therefore be useful as a standard with which to compare the other models. Preliminary results suggest that the variability of the monthly mean flow in this model is comparable in magnitude to that in the other models, but different in structure.

1.4 INFLUENCES OF SST-ANOMALIES

ACTIVITIES FY80

To understand the mechanism responsible for the Southern Oscillation, or the temporal variation of the Walker circulation, numerical experiments have been continued using a global circulation model of the atmosphere with realistic geography and a prescribed distribution of sea surface temperature. The numerical experiments explore the response of the model atmosphere to warm and cold anomalies in surface temperature over different longitudinal zones in the equatorial Pacific.

It was found that the anomalies produce an east-west "Walker response" in the equatorial atmosphere. Warm anomalies over the eastern Pacific weaken the Walker Circulation, whereas similar ones over the western Pacific strengthen it. Besides the large local increase in precipitation near the anomalies and a slight reduction to the west, there are significant global scale changes in the equatorial zonal winds (notably in the upper troposphere) and in tropical sea level pressure.

The anomalies also result in very interesting responses in the subtropics. The subtropical anticyclone and the subtropical jet stream are significantly strengthened, particularly in the winter hemisphere. The precipitation increases southeast and northeast of the anomalies, and the sea level pressure also decreases to the southeast. The diabatic heating anomalies associated with the central and western Pacific sea surface temperature anomalies induce circulation changes over south Asia similar to those observed during drought years.

PLANS FY81

Numerical experiments with more realistic anomalies and using models with higher resolution are planned.

1.5 DYNAMICS OF LARGE-SCALE ATMOSPHERIC WAVES

ACTIVITIES FY80

1.5.1 Dynamical Analysis of a General Circulation Model

The vertical-zonal propagation of a planetary wave packet has been analyzed (pp). It was proven that a stationary (traveling) planetary wave group attains its largest local amplitude (time variance) along the vertical-zonal ray path in the direction of the group velocity. This theorem was then utilized to identify the ray path of stationary and traveling planetary waves simulated by a general circulation model and isolated with space-time spectral analysis. It was found that the upward and eastward propagation of a stationary planetary wave packet results in the local intensification of the model's stratospheric high pressure pattern. This may explain why the observed Aleutian high is much stronger than the low pressure centers in the normal wintertime stratosphere.

In order to facilitate comparison of the model with observations, space-time spectral formulas have been modified to estimate wavenumber-frequency spectra correctly from space-time series data sampled by a polar-orbiting satellite at the same local time but at different hours of the day (384).

1.5.2 Control Experiments with a General Circulation Model

The effects of condensational heating on mid-latitude transient waves has been investigated by comparing moist and dry spectral general circulation models. Both models have ocean covered surfaces with prescribed zonally uniform temperature. The zonal mean state is fixed in time and at the same values in the moist and dry models. It was found that the steady state transient eddy kinetic energy is significantly enhanced at all wavenumbers by condensational heating. This increase is primarily due to an increase in baroclinic conversion from zonal available potential energy and only partly due to the direct generation of eddy available potential energy by condensation. The effect of condensation is more dramatic in the summer hemisphere than in the winter hemisphere.

1.5.3 Baroclinic Eddy Flux Parameterization

Research on theories of the fluxes of heat and momentum by baroclinic eddies for ultimate use in climate models has been pursued by analyzing several highly idealized dynamical models. The heat flux in the statistically steady states of a two-layer quasi-geostrophic model in the "homogeneous limit," in which the mean temperature gradient is assumed horizontally uniform, has been examined in detail (bb). The β-effect is found to be of dominant importance in determining the heat flux, although the strength of the surface drag becomes equally important when β is small. Linear theory proves to be a reliable guide to the dominant scale on which the heat transport occurs when β is large, but underestimates the scale when β is small. Results from this homogenous limit should be applicable when the mean flow is more or less uniform over distances comparable to the radius of deformation. Independent of any direct atmospheric applications, these results provide a constraint on theories for the eddy heat flux.

The problem of determining the sign of the momentum fluxes in linear unstable waves growing on zonal flows possessing both horizontal and vertical shears has been re-examined. A simple theorem combined with a series of numerical calculations were found to provide a rule of thumb for determining the sign of the momentum flux in waves which are essentially baroclinic, deriving most of their energy from the potential energy of the mean state. Short, strongly unstable waves typically transport momentum down-gradient (upgradient) if the horizontal scale of variation of the zonal wind is less (greater) than the radius of deformation. Longer waves tend to transport momentum down-gradient, independent of the scale of the zonal wind variations.

PLANS FY81

A preliminary space-time spectral analysis will be made of stratospheric and mesospheric planetary waves appearing in the SKYHI model constructed by the Middle Atmospheric Dynamics and Chemistry Group.

The effects of condensational heating on the initial growth of baroclinic waves will be investigated with a hemispheric spectral model, comparing the results with those given by a simple linear theory. The effects of nonlinear wave-wave interaction on the vertical structure of baroclinic waves will also be investigated by eliminating low wavenumber spectral components from the hemispheric spectral model.

The linear momentum flux analysis will be completed. The extent to which the "homogeneous limit" heat flux theory is applicable even when the mean winds are not horizontally uniform will be examined in a series of experiments with a 2-layer model.

2. MIDDLE ATMOSPHERE DYNAMICS AND CHEMISTRY

Goals

* To understand the interactive three-dimensional radiative chemical-dynamical structure of the middle atmosphere (10-100 km), and how it influences and is influenced by the regions above and below.

* To understand the dispersion and chemistry of atmospheric trace gases.

* To evaluate the sensitivity of the atmospheric system to human activities.

2.1 ATMOSPHERIC TRACER STUDIES

ACTIVITIES FY80

2.1.1 Atmospheric N_2O Tracer Experiments

Analysis has continued on a number of 3-D experiments simulating the behavior of atmospheric N_2O. In the first experiment, surface emission of N_2O is assumed to be horizontally uniform. Because of the very large uncertainty in the knowledge of the actual N_2O sources, two other source scenarios have been utilized. In one experiment the surface source is removed completely ("No Source"); in the other the source is allowed to emanate only from land areas with rainy climates, with the global source strength the same as in the first experiment ("Swamp Source").

Results from the "No Source" N_2O experiment show clearly that the lower tropospheric variability is strongly influenced by the local intensity of the surface source, while the downward flux of smaller values of N_2O from the stratosphere plays a lesser role. For the "Swamp Source" experiment, the surface layer concentrations and variabilities are strongly influenced by the locations of the source regions. This result provides a powerful tool for determination of the source locations and strengths in the actual atmosphere. Details are given in (dd).

2.1.2 Reactive Nitrogen in the Troposphere

One of the problems in tropospheric chemistry receiving attention is that of the budget of reactive nitrogen. This quantity is produced by anthropogenic processes at the ground (combustion) and aloft (aircraft) as well by the stratospheric destruction of N_2O. It is destroyed primarily through heterogeneous removal of nitric acid.

To explore the possible role of the stratospheric reactive nitrogen source, the results of a previous tracer experiment (367) were scaled by using the N_2O fields shown in (323). These results indicate that the stratospheric reactive nitrogen flux dominates the upper troposphere, and is significant in unpolluted regions of the lower troposphere.

2.1.3 A Revised Hypothesis for Tropospheric Ozone

The results from these N_2O experiments, combined with recent nitric oxide measurements conducted by members of the Aeronomy Laboratory/ERL, have led to a strongly altered view of the behavior of ozone in the troposphere. Tropospheric ozone has previously been thought to be either transport-controlled by flux from the stratosphere or photochemically controlled by ozone sources and sinks near the surface. The new view, which arose out of a collaboration with scientists from the Aeronomy Laboratory, seems to explain difficulties with both previous views. Calculations indicate that photochemical ozone production, due to the "smog chemistry" initiated by reactive nitrogen transported downward from the stratosphere, can produce as much or more ozone than is provided by the direct ozone flux. The added sink of ozone required, however, is found in the lower troposphere.

One implication of this work is that significant ozone production due to subsonic aircraft emissions of reactive nitrogen could occur. Interestingly, available ozonesonde records indicate an upper tropospheric ozone increase which is not inconsistent with those calculated. Details are provided in reference (ii).

2.1.4 Total Reactive Nitrogen Experiment

Over a year ago, a 3-D experiment was begun to attempt simulation of the complete budget of total reactive nitrogen from its mid-stratosphere source to its lower troposphere sink. Shortly thereafter, two sets of measurements were conducted which jeopardized this experiment. First, the stratospheric removal rate of N_2O was claimed to be significantly smaller than previous estimates. Second, the observed partitioning of reactive nitrogen among its various components appears to disagree with photochemical theory. In response, the experiment was delayed pending improved information.

This problem has led to the initiation of two additional N_2O experiments, however, one with "slow" N_2O removal ($\sim$ 180 year destruction time scale), and the other with "fast" N_2O removal ($\sim$ 100 year). These experiments will allow exploration of possible explanations for the actual stratospheric N_2O removal rates and reactive nitrogen sources and amounts.

PLANS FY81

Analysis of both the tropospheric and stratospheric parts of the N_2O experiments will continue along with exploration of various unresolved aspects of the tropospheric ozone problem. Efforts will be underway to develop an interactive, multiple tracer capability with the GCM/tracer model for application to the ozone and reactive nitrogen problems. Efforts to coordinate model tracer results with various observational problems will pursued along the lines suggested in (t).

2.2 MODELS OF THE TROPOSPHERE-STRATOSPHERE-MESOSPHERE

ACTIVITIES FY80

2.2.1 Model Improvements

During the year work continued on various improvements in the 40-level troposphere-stratosphere-mesosphere GCM(SKYHI).

A new model analysis package has been written which allows exact calculation of zonal mean balances for the first time. This has led to a careful investigation of a number of aspects of the interaction between waves and the mean flow in the stratosphere. An example is the development of an exact Lagrangian-oriented analysis which incorporates "Eliassen-Palm" fluxes and convergences.

A more systematic exploration of the effects of horizontal subgrid-scale fluxes has been pursued. Results are described in 2.2.3.

2.2.2 Low Resolution (N10) Annual Cycle Experiment

The low resolution (N10, 9°lat. by 10°long.) GCM has been run out to 3 years. The indication of a semiannual oscillation (SAO) reported previously has been sustained. This SAO appears to be quite realistic in the upper stratosphere. The basic model mechanisms for this SAO are as follows. The westerly phase is generated more or less continuously by momentum deposition from upward and eastward propagating equatorial Kelvin waves, the largest deposition of westerly momentum occurring near the maximum of the westerly phase. This westerly flow is interrupted twice a year by strong cross-equatorial flow producing advection of easterly momentum from the summer hemisphere. The cross-equatorial flow is excited by the unbalanced pressure gradient produced by differential heating between the summer and winter hemisphere. These results as well as other aspects of equatorial zonal wind behavior are described in (u).

2.2.3 "Low Diffusion" Medium Resolution (N18) Experiment

Analysis of previous experiments with this model, as well as comparisons with other finite difference and spectral models, led to the inference that low resolution finite difference models were unnecessarily diffusive. As a way of exploring this conjecture, the horizontal non-linear diffusion coefficient was altered by reducing the multiplicative constant by a factor of four while increasing the scale selectivity of the horizontal deformation operator. This change was applied to the N18 annual mean control model which was then integrated for another 100 days.

The alteration has had a number of significant effects. The tropospheric subtropical jets are significantly stronger, while the tropical upper tropospheric winds are much less westerly. An easterly acceleration is induced in the tropical middle stratosphere. The most dramatic effect, however, is that the mid-latitude mesospheric jets are reduced in magnitude and become completely closed off near their proper altitude. This behavior is related to an <u>increased</u> mesospheric mechanical dissipation resulting from the decreased horizontal diffusion. In this "low diffusion" experiment, increased wave activity is allowed to leave the troposphere and propagate upwards. The larger wave amplitudes lead to an increased excitation of the model's low Richardson number turbulent dissipation in the mesosphere.

2.2.4 Maintenance of Blocking Anticyclones

In the GFDL "Zodiac" GCM, some rather successful simulations of blocking anticyclones were achieved. A preliminary analysis of one of these blocks has led to some interesting inferences.

First, the block is composed of warm, moist air containing very low values of potential vorticity. These values are representative of air from much lower latitudes. In agreement with observations, the block itself is not truly steady, but tends to drift eastward with occasional periods of reformation on the west side. This reformation appears to be related to the effect of transient cyclones moving poleward along the western edge of the block and then decaying. Associated with the decaying stage, the warm, moist, low potential vorticity air swept poleward ahead of the cyclone appears to be deposited irreversibly. This leads to a reintensification of the blocking ridge. Other details are given in (358).

2.2.5 Simpler Models for the Interaction Between Waves and Mean Flows

The effects of tidal motions on the general circulation of the middle atmosphere have been investigated. The heat and momentum fluxes associated with the diurnal tide were computed using separable tidal theory. These fluxes were used in turn to force a simple axisymmetric model of the stratosphere, mesosphere and lower thermosphere. The results showed that the tide may induce significant mean zonal winds ($\sim$10-20 m/sec) in the vicinity of the equatorial stratopause. In the lower thermosphere (80-90 km) the diurnal tide forces strong easterlies in the tropics and westerlies in mid-latitudes, in apparent agreement with the observed zonal winds in this region.

The simple, one-dimensional model of the quasi-biennial oscillation of the tropical lower stratosphere originally devised by Holton and Lindzen has been investigated in some detail. It was found that the behavior of this model is very sensitive to the details of the spectrum of waves which are used to force it and to the upper boundary condition employed. In particular it is possible for the mean flow evolution in the model to be dominated by very long period ($>$ 10 years) oscillations if waves with phase speeds of 35 m/sec or greater are included.

PLANS FY80

Efforts to improve the SKYHI simulation capability will continue. Analysis of the annual mean and seasonal SKYHI experiments will intensify with emphasis on the model wave dynamics and interaction with the mean flow, as well as on a detailed comparison with observations.

2.3 PHYSICAL PROCESSES IN THE MIDDLE ATMOSPHERE

2.3.1 Radiative Transfer

A comprehensive report describing a set of algorithms for computation of CO_2 15 μm cooling rates has been accepted for publication (w). The method was described in the annual report FY78, Section 1.6.2. The bulk of transmission function tables on which the scheme rests have been recalculated several times in the interim to reflect changes in details of the spectral parameters. The version to be published will include the effects of non-Lorentzian lines.

An investigation of the effects of non-Lorentzian line shape on the CO_2 15 μm bands was begun, with two objectives: a) to assess the sensitivity of transmission functions to such effects; b) to discover the best empirical line shape by comparison with high quality laboratory data.

The comparison of line-by-line and suitable random model results shows that the latter provide a fast way of assessing the effects of altered line shape on transmitivities. It has been found that variation in line profile cutoff between 1 cm^{-1} and 30 cm^{-1} alters the total CO_2 absorption by up to 5%.

The availability of excellent laboratory spectra at a large number of pressures and path lengths has made it possible to determine an effective cutoff, ν_c beyond which line wings are negligible. The value $\nu_c = 3$ cm^{-1} fits the bulk of the data very well. With this value, calculated broad band integrated absorptions agree with the measured values to within 1/2% in most cases.

2.3.2 Ozone Chemistry

The collaborative effort with scientists from the Aeronomy Laboratory/ ERL has continued successfully. The chemical code required to calculate ozone self-consistently has now been converted to the ASC. The one-dimensional version of the chemical model has been successfully combined with the corresponding SKYHI radiative model.

PLANS FY80

The updated and improved radiative transfer algorithms will be incorporated into the SKYHI production model. A number of interacitve problems will be investigated using the combined one-dimensional radiative photochemical model.

3. EXPERIMENTAL PREDICTION

GOALS

* To develop more accurate atmospheric prediction models suitable for 30-day forecasts.

* To identify important external forcing mechanisms and additional internal processes required by models to simulate the evolution of macro-scale atmospheric disturbances over the range of several weeks to four months.

* To search for a physically based probabilistic approach for long range simulation of atmospheric variation, including the determination of appropriate initial conditions for the atmosphere, ocean, soil, and snow-ice.

* To study the mechanisms of particular atmospheric phenomena such as tropospheric blocking, orographic cyclogenesis, tropical easterly waves, and sudden warming.

NOTE:

Space discretization is an important and inevitable aspect of numerical modeling, and a shorthand notation for model spacial resolution is introduced for convenience. An N48L9 model, for example, denotes a finite difference model with N=48 grid points between pole and equator and L=9 vertical levels. Similarly, an R30L9 model denotes a spectral model with rhomboidal truncation limits at zonal (and meridional) wave number R=30 and L=9 vertical levels. The transform grid of R=30 contains 40 grid points from pole to equator.

3.1 OCEAN UPPER LAYER FORECASTS

ACTIVITIES FY80

3.1.1 Simulation of Sea Surface Temperature Variation with Mixed Layer Models

Using Gill-Turner's* (G-T) integral mixed layer model and twice-daily observed atmospheric air temperature and wind stress, an experiment was performed to predict the sea surface temperature over the Northern Hemispheric ocean for 1976 and 1977. Predictive skill exists for the first 4 months. The same case was run using the turbulent closure model of Mellor and Durbin (209), and the results were compared with those of the G-T model. The closure model requires 10 times more computer time than the integral model.

3.1.2 Adaptation of the Global Oceanic GCM

In consultation with the GFDL Ocean Group, a global dynamic ocean model is being adapted for prediction experiments. Modifications were made to the subgrid-scale turbulent transfer processes in both the vertical and horizontal directions,the exchange processes with the atmosphere, and the spatial resolution. The resulting solution possessed a considerably more active current field than the solution of the unmodified model.

PLANS FY81

The study with the turbulent closure model will be continued. Regarding the SST simulation, the relative importance of advection and up- and down-welling due to oceanic currents and the effect of heat fluxes through the surface will be examined. The performance of the adapted dynamic model will be compared with the performance of Bryan's original model. The analysis of tropical atmospheric forcing during 1976 and 1977 will be started.

3.2 SUBGRID-SCALE (SGS) PROCESSES

ACTIVITIES FY80

3.2.1 Comprehensive Experiments with Various Versions of SGS Processes

The following notation is used to describe the treatment of subgrid-scale processes and exchanges with the earth's surface in the models:

A: Basic physics of the 1965 vintage GFDL models.

E: The same as A except that the Monin-Oboukov treatment of the surface constant-flux-layer (107) and a turbulent closure scheme for the rest of the atmosphere (185) are utilized, and the dry convective adjustment scheme is omitted.

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*Gill, A.E. and J.S. Turner, 1976: A comparison of seasonal thermocline models with observation. Deep-Sea Res., 23, 391-401.

F: The same as E except that the Arakawa-Schubert** parameterization for ensemble cumulus convection is used instead of the moist convective adjustment scheme.

G: The same as E except that the moist convective adjustment is removed.

H: The same as E except that cloud-radiation interaction is included.

Model versions A, E, F and G have been integrated 30 days for two cases, January 1977 and March 1965. In each case, the SGS processes had substantial impact on many features of general circulation: tropical rainfall, the macro-scale circulation in middle and high latitudes, and in particular, the maintenance of blocking ridges. The reasons for this impact are being investigated.

A more economical method of computing the Monin-Oboukov boundary fluxes and soil heat conduction is now being used.

3.2.2 Cloud-Radiation Interaction

Utilizing the prediction model's radiation code and monthly mean distributions of observed cloudiness and water vapor for January 1977, various radiation diagnostics were computed. The sensitivity of these diagnostics to zonal mean vs. asymmetric cloudiness was examined. The clouds were reconstructed from three data sources including the voluminous Air Force Global Weather Central 3D-Nephanalysis. The asymmetric cloud distribution had a favorable impact on the computed fluxes, particularly in the Northern Hemisphere subtropics, the tropics, and the Southern (summer) Hemisphere. NOAA-4 long wave flux and reflected solar radiation data at the top of the atmosphere were used for verification.

The sensitivity of extended range predictions to zonal mean vs. asymmetric observed cloudiness and water vapor distributions is being investigated. A control integration with fixed zonal, monthly mean cloudiness and water vapor is in progress. Finally, two fully interactive cloud prediction schemes are being developed. A simple scheme analogous to that utilized by the climate group (z) has already been implemented and its validity is currently being examined.

3.2.3 Cumulus convection parameterization

A newly available version of the UCLA cumulus parameterization was tested. Although the simulation of tropical rain associated with African waves was excellent, there still exists a deficiency in the new version in that rainfall spreads erroneously into the tropical dry regions. An effort to eliminate this deficiency has been made by incorporating the downdraft process inside clouds.

**Arakawa, A. and W.H. Schubert, 1974: Interaction of cumulus cloud ensemble with the large-scale environment, Part I. J. Atmos. Sci., 31, 674-701.

PLANS FY81

The cloud-radiation interaction model will be applied to a one-month prediction experiment. A 3-D nephanalysis for the July 1977 case will be performed. Deardorff's version* of lateral nonlinear viscosity will be tested with the N48L9-E model. The examination of N48L9-F and G models will be continued.

3.3 EXTENDED RANGE PREDICTION

ACTIVITIES FY80

3.3.1 One-Month Simulation of January 1977 Event

Two successful simulations of blocking ridges have now been obtained (January 1977 and March 1965). The simulation of the January 1977 blocking event with the N48L9-E model was remarkably good for the entire month (see Figure 3). This simulation was initiated at 00GMT on January 1. In order to examine the sensitivity of these results to initial conditions, a parallel run with the same model was integrated from initial conditions at 00GMT, January 2. A very similar solution to the previous run was obtained up to day 10; however, there was substantial deviation by day 15. It is not yet clear whether this deviation is intrinsic or, possibly, the result of computer error.

The deficient performance of the R30L9 model has not been clarified. However, it was found that the incorporation of nonlinear lateral viscosity was beneficial for maintaining a large amplitude meandering flow.

3.3.2 Six One-Month January Forecasts

Preliminary tests concluded that the N48L9-E model was best in predictive performance; it was better than the N48L18-E and the N48L9-F. Before using this model for additional cases, it was revised by 1) incorporating a modified form of the economical explicit method**, 2) incorporating a new radiation code (204), 3) specifying a soil temperature distribution at 5 meter depth, and 4) using new surface roughness with significantly different values over mountains. Calculations have begun on what will be a series of six one month forecasts, using January 1 from the years 1975-1980 as initial conditions.

3.3.3 Southern Hemisphere Medium-Range Forecast Experiment

The spectral model of ANMRC (Australian Numerical Meteorology Research Centre) was used to make a 10 day global forecast, using the NMC initial condition of January 1, 1977. The results of a forecast with the R30L9-E model over the Southern Hemisphere were remarkably good for the 10 day period (perhaps the best result ever obtained), including a 5 day period of blocking over Tasmania and New Zealand.

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* Deardorff, J. W., 1973: The use of subgrid transport equations in a three-dimensional model of atmospheric turbulence. J. Fluid Engin., 429-438.

** Mesinger, F. and A. Arakawa, 1976: Garp Publication Series, No. 17, JOC, Numerical Methods Used in Atmospheric Models, pp. 53-55.

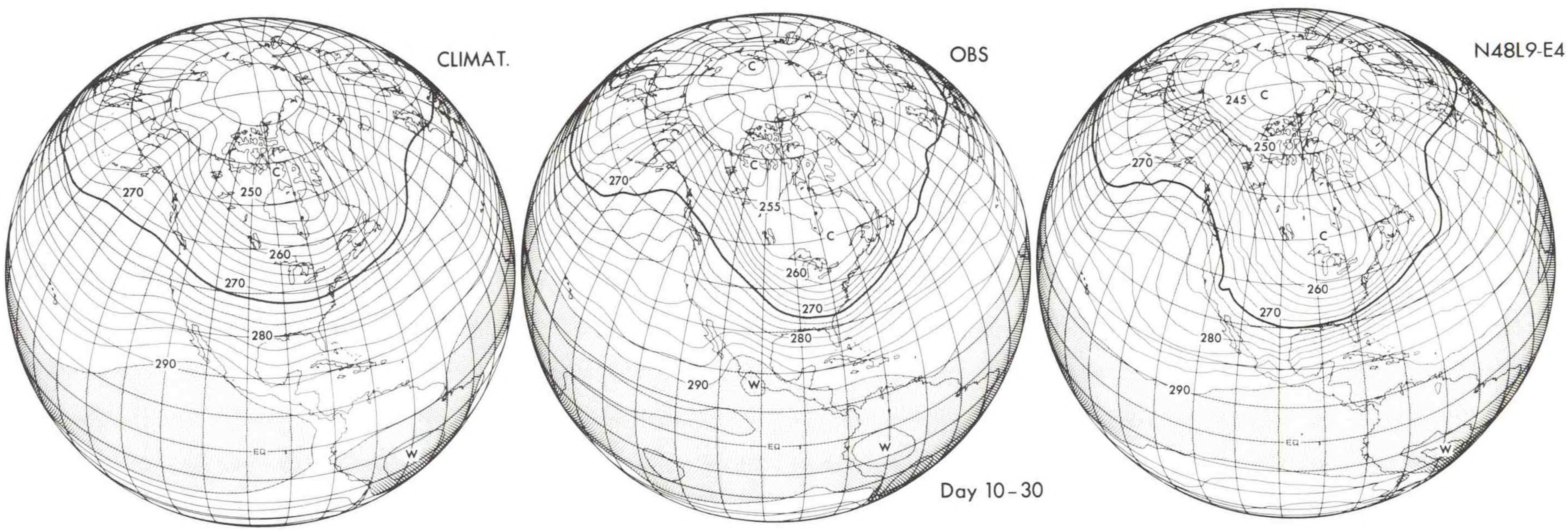


Fig. 3. The widespread record cold over the United States for January 1977 is displayed by 20 day mean temperature maps at the 850 mb level for days 10-30. Shown are the predicted temperature for the last 20 days of a one-month forecast (right) by the N48L9-E4 GCM; the observations for the same period (middle); and the January climatology (left). The units are deg. K, and the contour interval is 2.5°K. The thick contour lines are for 272.5°K, which is close to 0°C.

PLANS FY81

The energetics of the January 1977 event will be studied. The enigma of the bifurcation in the January 2, 1977 case has to be solved; if this result is representative, the impact on predictability for the one-month range will be great. The six one-month prediction case studies will be continued. The lower boundary conditions for October-December 1976 case will be investigated, with particular emphasis on soil moisture.

3.4 MODEL DEVELOPMENTS

ACTIVITIES FY80

3.4.1 HIBU Global Model

The global HIBU (Hydrological Institute, Belgrade University) N17L9 model has been constructed and a preliminary 4 day forecast attempted. E-physics is currently being incorporated into this model.

3.4.2 Spectral Model Improvement

Causes for the weakness of the spectral model are being investigated. The candidates are: the semi-implicit time differencing, the treatment of moisture and condensation, insufficient precision, the biharmonic linear (as opposed to nonlinear) lateral viscosity, and the rhomboidal (as opposed to triangular) truncation. The last possibility has been checked by the Climate Group, and has been ruled out. The benefit of nonlinear viscosity has been recognized, as mentioned above, but the effect is not large enough to explain the entire deficiency. The European Centre for Medium-Range Weather Forecasts undertook, upon the request of GFDL, a one-month forecast with GFDL's January 1, 1977 initial condition with the Centre's spectral model. It has recently been reported that the mean of the last 5 days of the forecast with the Centre's model agrees with that of GFDL. Since the Centre's forecast was made with significantly higher computer precision, precision is essentially ruled out as a cause for the weakness of the spectral model.

PLANS FY81

The vertical coordinate of the HIBU model will be modified. An I/Ø scheme will be designed to accommodate the N48L9-E HIBU model. The search for causes for the weakness of the spectral model will be continued.

3.5 FGGE PREPARATION AND IMPLEMENTATION

ACTIVITIES FY80

3.5.1 Implementation

The operational 4-dimensional analysis of FGGE data was initiated with data from 00GMT December 1, 1978. The entire month of December 1978 has been completed after experiencing several difficulties. One blow-up occurred on December 18, 1978, causing an extremely high temperature at the top level (about 42 km) over the South Pole and an extremely low temperature at high altitudes over the North Pole. Investigation revealed that three factors were apparently responsible: the insertion of moisture data, the insertion of temperature data at the top level, and an erroneous treatment of radiation-ozone interaction.

Based on these experiences, the final version of the 4-dimensional analysis system will be determined. The operational analysis will be restarted on December 29, 1978 to eliminate any startup effects in the January 1, 1979 analysis. The analysis scheme will then be frozen for the rest of the FGGE operational year, i.e., through November 30, 1979.

The final version of the 4-dimensional analysis system will include the following new components: The application of nonlinear normal mode initialization only for the extratropics (in collaboration with Mr. B. Balish, University of Maryland, and Drs. K. Puri and W. Bourke, ANMRC, Melbourne), global optimum interpolation analysis on σ -surfaces instead of p-surfaces, a new data toss-out criterion, a revised analysis of the geopotential height field, and a correction in the inclusion of surface data.

3.5.2 Efficiency of the Analysis

Recent efficiency changes to the optimum analysis program have decreased the needed computer time for that program by over 60%. This results in a net time savings of over a half hour of computer time per data day.

The merging of data tapes from as many as ten different sources of FGGE operational year data into one master tape has resulted in decreased wall clock time for the analysis system. Copies of the master tapes will be archived in the World Data Centers.

PLANS FY81

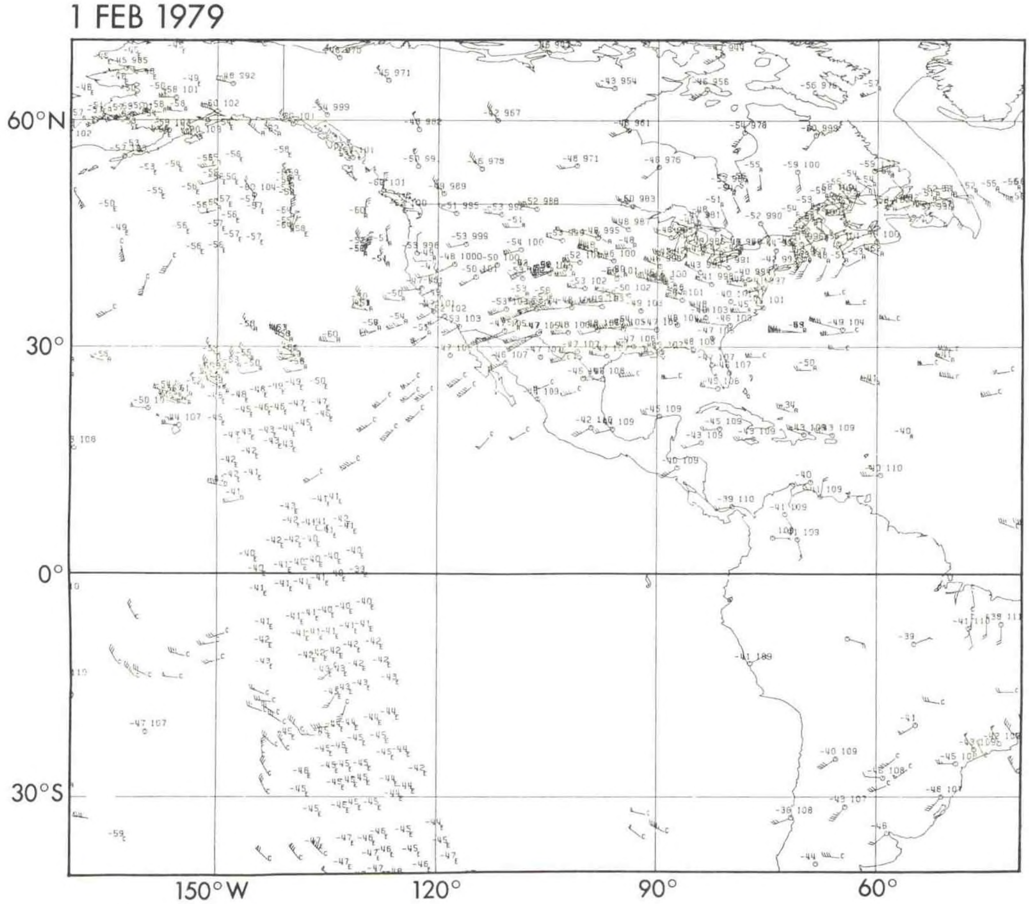
The final 4-dimensional analysis system will be applied for the rest of the FGGE period, including the Special Observing Period I (see Figure 4). Six months of FGGE data will be completed in FY81. Various analyses will be compared with analyses from the European Centre and ANMRC. A movie of the flow fields during the Special Observing Periods I and II will be produced. A paper on tests of 4-dimensional analysis will be completed. Impact tests for special tropical observational systems as well as the Southern Hemisphere ocean buoys will be conducted.

3.6 PHENOMENOLOGICAL STUDIES

ACTIVITIES FY80

3.6.1 Pacific Blocking Ridge

Choosing the example of the January 1977 blocking case, an investigation is being conducted to determine why the N48-E model was successful in simulating the maintenance of the block, and why the R30-A (bharmonic viscosity) model destroyed the blocking ridge over the Pacific.



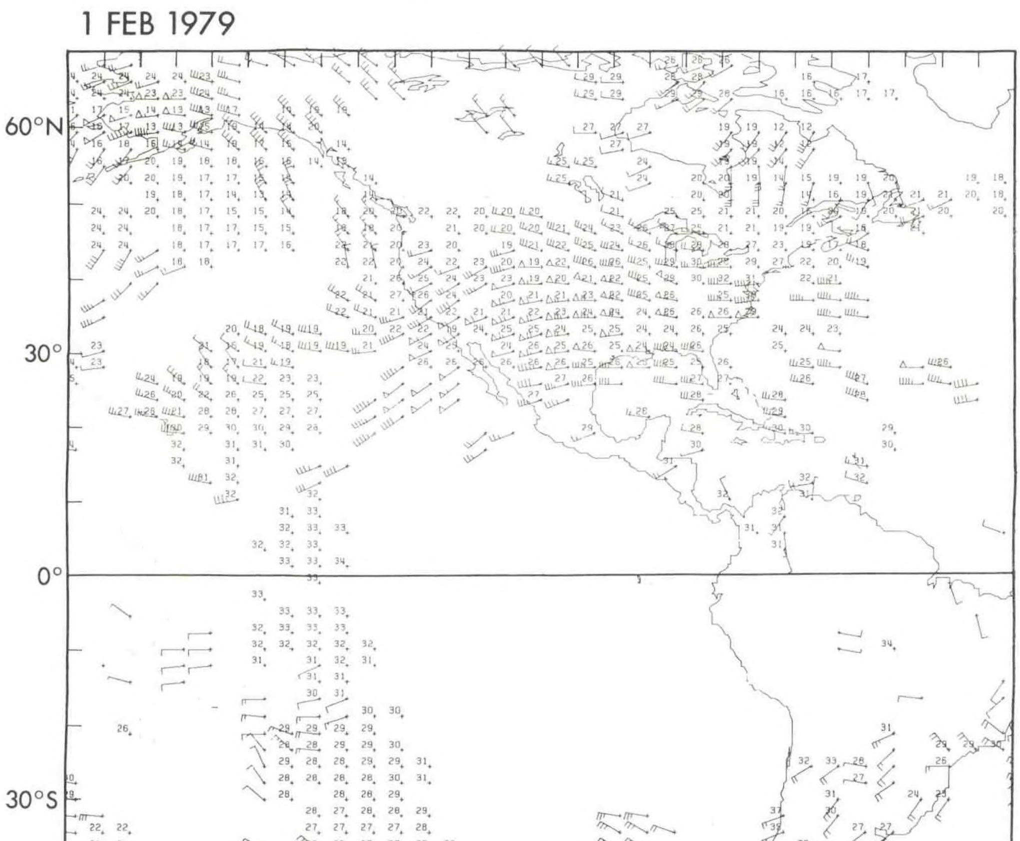


Fig. 4. The original observations (top) and the insertion data for the four-dimensional analysis determined by local optimum interpolation (bottom).

A fundamental study is also being continued to examine whether the 1977 blocking is really a consequence of resonant wave-wave interaction, and if so, to determine the resonant wavenumbers and the associated waves involved in the nonlinear interaction.

3.6.2 Africa-Atlantic Easterly Waves

Using the most recent 4-dimensional GATE (GARP Atlantic Tropical Experiment) analysis, the westward propagation of the easterly waves as well as the energetics of these waves were investigated. Nine waves revealed in the 4-dimensional analysis agree well with the subjective analysis of Sadler-Oda* in terms of their positions and speeds. Condensational heating was found to make a substantial contribution to the onset and maintenance of the easterly waves over Africa. The condensation obtained in the 4-dimensional analysis over the GATE A/B ship array was compared with the satellite infrared estimates with good correlation.

PLANS FY81

The study of the resonant wave-wave interaction associated with blocking will continue. Four cases of Genoa cyclogenesis will be simulated with the hemispheric HIBU model incorporating the effects of moisture.

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* Sadler, J. C. and L. K. Oda, 1978: The synoptic (A) scale circulations during the third phase of GATE 20 August-23 September, 1974. UHMET Report 78-02, Dept. of Meteorology, University of Hawaii, 41 pp.

4. OCEANIC CIRCULATION

Goals

* To study the large-scale response of the ocean to atmospheric forcing over a range of time scales from a few weeks to decades.

* To perform oceanic observational studies by systematically processing the large data base available for the density structure and the fields of various tracers.

* To develop detailed, three-dimensional models of the World Ocean and its regional components and interpret these in terms of a coherent hydrodynamical framework.

* To develop a capability to predict the large-scale behavior of the World Ocean in response to changing atmospheric conditions.

* To identify practical applications of oceanic models to man's marine activities.

4.1 DYNAMICS OF TROPICAL OCEANS

ACTIVITIES FY80

4.1.1 Response of Equatorial Oceans to Periodic Forcing

Variability in the tropical oceans is observed over a spectrum of frequencies and is primarily forced by the atmosphere. Results from a numerical model (ee) show that variability of the upper equatorial ocean (within 5° latitude of the equator) has the following characteristics. (i) At periods less than 10 days fluctuating currents correspond primarily to waves. (ii) At periods between 10 and 50 days wind driven equatorial jets are intense in the surface layers but in the thermocline and at greater depths variability has a small amplitude. (iii) At periods between 50 and 150 days the zonal density gradient along the equator can change significantly so that the intensity of the Equatorial Undercurrent in the thermocline is subject to large variations. Eastward phase propagation (associated with Kelvin waves) is prominent in this frequency range because the propagation of Rossby waves is impeded by the undercurrent. (iv) At periods longer than 150 days the amplitude of variability is almost independent of frequency, and oceanic fluctuations are almost in phase with the atmospheric forcing. These time scales are for a basin 5000 km wide. If the width of the basin increases, then the 150 day time scale increases. Measurements being made as part of the EPOCS program will provide a test for these results.

4.1.2 The Oceanic Response to Cross-Equatorial Winds

Winds over the eastern equatorial Atlantic and Pacific Oceans are predominantly from the south. The upwelling induced by these winds along the southeastern coasts of these basins extends far westward because of Rossby wave propagation and advection by the South Equatorial Current. A numerical model (ff) has shown that fluctuating southerly winds cause realistic sea surface temperature variations in the southeastern parts of the basin. These variations are associated primarily with a zonal (rather than cross-equatorial) redistribution of heat in that part of the ocean.

4.1.3 The Dynamics of El Niño

The term El Niño refers to the prolonged appearance of anomalously warm surface waters over the eastern equatorial Pacific Ocean. Analysis of historical data reveals that the occurrence of El Niño is correlated with a weakening of the trade winds. The oceanic response to a relaxation of the westward surface winds has therefore been studied (gg). This relaxation was found to cause a zonal redistribution of heat along the equator and hence higher sea surface temperatures in the east. The warming depends on the size of the region over which the winds relax and on the length of time, T, for which the winds relax. As T increases, the warming in the east increases until it asymptotes to a maximum value when T exceeds the adjustment time of the basin. (This is estimated to be 400 days in the case of the Pacific Ocean). Kelvin waves can be inferred to be important in the oceanic response, but whether they can be identified in oceanic measurements is questionable.

PLANS FY81

Studies of variability in low latitudes have been confined to the equatorial zone (3°N to 3°S). During FY81 the fluctuations of the tropical surface currents such as the North Equatorial Current and Countercurrent and South Equatorial Current will be studied. Recent data obtained during FGGE provide motivation for further studies of the Somali Current which was observed to behave in an intriguing manner during 1979. Finally, efforts will be made to improve the parameterization of mixing processes. At the moment, constant coefficients of vertical eddy viscosity are used even though microstructure measurements reveal considerable spatial and temporal variations in the intensity of mixing. This is a serious problem because results from models are sensitive to the value of the coefficients of eddy viscosity and diffusivity.

4.2 GEOCHEMICAL MODELING OF THE OCEAN

ACTIVITIES FY80

For determining the ocean's role in climate and climate change on a 10-50 year time scale, quantitative knowledge of water mass formation and transport processes in the ocean is essential. The tritium arising from nuclear bomb tests carried out around 1960 has entered the ocean and has now penetrated to considerable depths. The rate of penetration of tritium is one of the most reliable indicators of the ability of the ocean to take up anthropogenic CO_2 or act as a "climatic flywheel" to slow down climatic change. Using the least squares method of objective analysis, the ocean group has analyzed field observations for the North Atlantic, producing tritium maps and estimated sampling error fields. These fields will be used for evaluating models and for guidance in planning future measurement programs.

Tritium simulations begun in FY79 were completed using a robust diagnostic model of the North Atlantic circulation. The efficiency of the model permits an exploration of a wide parameter space, allowing tests of all of the important features of the model. Objective analysis indicates that by the middle of the 1970's the mean penetration depth of tritium for the entire North Atlantic was 625 m $\pm$ 20 m. The most significant finding of the model study was that models which do not include convective overturning in higher latitudes consistently underpredict the mean penetration depth.

PLANS FY81

In order to study the basic transport processes involved in tritium uptake, the major emphasis in the coming year will be on tracer studies in ocean basins of simple geometry. Objective analysis will continue for other geochemical fields such as oxygen and major nutrients.

4.3 WORLD OCEAN STUDIES

ACTIVITIES FY80

Sensitivity studies on the World Ocean model initiated in the previous fiscal year were continued in preparation for coupled ocean-atmosphere experiments in climatic response. Tests were carried out to determine the effect of seasonally varying boundary conditions on the response of a World Ocean model to a step increase in global sea surface temperature. A parallel experiment was also done in which the uptake of a passive tracer was compared with the uptake of heat (the major difference being that the heat uptake affects the buoyancy field while the passive tracer does not). For the temperature perturbations applied (less than 2°C) the overall rates of heat or tracer uptake are surprisingly alike in all cases.

PLANS FY81

A major effort will be devoted to improving the representation of the upper ocean and mixed layer in the model by increasing the number of levels in the model and improving the parameterization of the planetary boundary layer, using the experience gained in tests already carried out with the tropical ocean models (see 4.4).

4.4 OCEAN MODEL DEVELOPMENT

ACTIVITIES FY80

Research in tropical dynamics and climate demonstrates the need for developing better closure schemes for vertical mixing in the upper ocean. Effort was devoted to systematically testing existing schemes (185). The schemes were verified against the observed structure of temperature and current at the equator. All of the schemes showed an undesirable dependence on the length of time step used in the numerical integrations.

A simplified version of the ocean climate model has been developed which is core contained. This is now being used for exploratory experiments with the combined ocean-atmosphere model. A version of the World Ocean Model has been prepared for testing the effects of CO_2-buildup on climate. In this preliminary version, salinity boundary conditions are specified at the surface rather than computed from the evaporation minus precipitation fields of the joint ocean-atmosphere model.

An eddy resolving model has been prepared for the North Atlantic. Tests showed a realistic distribution of mesoscale energy, but the memory and computer time requirements are so great that the model can not be exploited until our new computer system becomes available.

PLANS FY81

A new formulation of mixing along surfaces of constant density has been designed and is ready to be incorporated in the model. It should be particularly important in the geochemical tracer work. An implicit time integration scheme for Richardson number dependent vertical mixing will be tested. The goal is to eliminate the time step dependence found in schemes already available.

5. PLANETARY CIRCULATIONS

Goals

* To discover and understand the fundamental processes controlling the circulations of the atmospheres and oceans of the planets.

5. PLANETARY CIRCULATIONS

5.1 RAPIDLY ROTATING PLANETS

ACTIVITIES FY80

Multiple experiments have been made with the GFDL spectral GCM in which rotation rate, surface properties and moist processes are varied. For Earth the calculations reveal the differences between the polar front and subtropical jets. The parameter variations also provide the first step in an evolution of the GCM from terrestrial to Jovian conditions.

For Jupiter, the calculations have produced circulations with the same characteristics as the Jovian northern hemisphere. In particular, the tropical jet and equatorial westerlies have been simulated under reasonable conditions and the existence of multiple extratropical jets confirmed.

PLANS FY81

The major unsimulated items of the Jovian circulation - the ovals and Great Red Spot - are peculiar to the southern hemisphere and may therefore be sensitive to thermodynamical details. However, attempts will be made to reproduce them with the GCM by moving closer towards the Jovian parameter state.

5.2 VENUS CIRCULATION

ACTIVITIES FY80

Recent evidence from both the Pioneer Venus mission and ground based observations suggests that the strong super-rotation of the Venusian atmosphere decreases above 70 km. Possible causes for this reduction are being investigated. A likely candidate is the forcing of the mean flow by thermally induced tides in the stratosphere.

To explore this mechanism, a one-dimensional tidal model has been constructed, allowing the calculation of tidal motions in the presence of mean flow shear, radiative forcing, and radiative damping. The Reynolds stresses from this model are used to generate a self-consistent mean flow, using the observed "four-day wind" as a lower boundary condition. Preliminary results are encouraging. For reasonable values of mean-flow viscosity, the model does yield a rapid decay of the mean flow above 75 km.

PLANS FY81

An axisymmetric model is under construction which should allow the investigation of the effects of tidal momentum fluxes in the Venusian stratosphere.

6. OBSERVATIONAL STUDIES

Goals

* To determine and evaluate the physical processes by which the atmospheric and oceanic circulations are maintained using all available observations.

* To compare results of observational studies with similar diagnostic studies of the model atmosphere and model ocean developed at GFDL and thereby develop a feedback to enhance our understanding in both areas.

6.1 ATMOSPHERIC ANALYSIS

ACTIVITIES FY80

6.1.1 The 15-Year Global Data Set, 1958-1973

The major effort of the atmospheric analysis project was once again the further preparation for publication of the upper air and surface data sets covering the 15-year period May 1958 through April 1973. Substantial progress has been made toward this goal.

Because of the huge amount of information involved, it was decided to display most of the information on microfiche (about 40, with 170 frames each), to be included in a conventional NOAA Professional Paper, of about 100 pages total length. The microfiche collection will enable an order of magnitude more information to be disseminated in a reasonably accessible form. Accessibility is very important because of the recent worldwide upsurge of interest in climate. Much work has gone into the design and organization of the microfiche. The climatological horizontal distributions over the globe of means, variances and covariances of the wind components, temperature, specific humidity and geopotential height will be shown at 11 levels in the vertical for each calendar month, season, and for the year as a whole. These maps will constitute roughly one half of the microfiche collection. In addition, the year-to-year variability will be given in the form of maps of standard deviations of monthly means. Maps of the station distributions throughout the 15 years and comparisons with standard analyses north of 20°N made by the National Meteorological Center (NMC) and other analysis centers will show the reliability and limitations of the GFDL analyses. Zonal mean conditions will be given by global cross-sections and tables of all parameters. Finally the time evolution will be exhibited with the aid of space-time sections for selected longitudes, latitudes and pressure levels. The text of the book will highlight the various results. In toto, this publication should give the most complete description of the global atmospheric climate attempted so far.

The basic analyses have already been used in several scientific papers highlighting regional momentum (tt) and vorticity (aa,kk) budgets. Important work comparing GFDL and NMC analyses has clearly shown the limitations of the analysis scheme over no-data regions, even in the Northern Hemisphere.

The 1963-1973 upper air and surface analyses have also been used to determine the space and time scales of atmospheric variability (rr) and to detect climatic signals after the short-term weather variations have been filtered out (381). Measures of the year-to-year variability are being used in the Climate Dynamics Group at GFDL.

6.1.2 The Historical Ocean Surface Ship Data

Analysis of the surface ship reports, supplemented over land with 1000 mb rawinsonde reports, has continued. The analyzed fields form an important new addition to the data set discussed under 6.1.1, and will be included in the same NOAA Professional Paper. The analyses are being extended to cover years before May 1958, so that surface variations on time-scales of decades may also be investigated in future work.

6.1.3 Diagnosis of GCM Results

With empirical orthogonal function analysis and with the aid of teleconnection analysis techniques, the time and space characteristics of a 15-year GCM data set have been investigated. Interesting similarities and differences between the real and model results have been identified (see also Section 1.3.1). In a different study, regional climatological features of a GCM developed earlier at GFDL have been found to compare very well with observations as analyzed at NMC.

PLANS FY81

The preparation of the NOAA Professional Paper describing the global climate during the 1958-1973 period will have first priority. Additional local budget studies will be performed to determine our present-day ability to understand the mechanics of the mean climate and its variability based on conventional rawinsonde data. On the other hand, the FGGE data set will be used to show what can be done on a regional scale based on an unusually extensive data set, including all available instrumental records for that period. FGGE data will also provide a unique opportunity to study global diurnal variability using analyses at six times of the day made by the Experimental Prediction Group at GFDL.

6.2 OCEANIC ANALYSES

ACTIVITIES FY80

6.2.1 Global Analysis of Oceanic Data

Steady progress has been made in the preparation of an oceanographic atlas, to be published as a NOAA Professional Paper. As in the case of the atmospheric publication, most of the global fields of temperature, salinity, density and oxygen at different depths will be displayed on microfiches. Vertical cross-sections at selected latitudes and longitudes will be included. The atlas will also contain maps of derived variables of special interest, such as mixed-layer depth, thermocline depth, depth of oxygen minimum and geopotential thickness.

These analyses have resulted in new estimates of the global seasonal heat storage, making feasible a study of the energy budget in the Southern Hemisphere. The analyses are also being used extensively in the Ocean Circulation Group at GFDL, especially for geochemical modeling.

PLANS FY81

First priority will be given to the preparation of the Oceanographic Atlas for publication. In cooperation with colleagues at Colorado State

University, a study of the role of the oceans in carrying heat poleward will be extended to the Southern Hemisphere. Also the feasibility of regional energy studies for each ocean separately will be studied in depth. Such pilot projects are timely in view of the plans for national and international projects to monitor the heat balance of the North Atlantic Ocean during the latter part of the 1980's.

7. HURRICANE DYNAMICS

Goals

* To understand the genesis, development and decay of tropical depressions by investigating the thermo-hydrodynamical processes using numerical simulation models.

* To study small-scale features of hurricane systems, such as the collective role of deep convection, the exchange of physical quantities at the lower boundary and the formation of organized spiral bands.

7. HURRICANE DYNAMICS

7.1 GENESIS OF TROPICAL STORMS

ACTIVITIES FY80

Extensive analysis of the numerical simulation of tropical storm genesis has been continued. The numerical model used is the same as the one employed in the previous year, an eleven-level primitive equation model in channel geometry. In a control experiment, the formation of a tropical storm, starting from a simple shallow easterly wave and evolving through a tropical depression stage, was successfully simulated (Fig. 5). In this experiment a warm core at 300 to 500 mb levels and a divergent anticyclonic flow at the upper levels were not specified as pre-existing conditions but appeared as a consequence of the storm genesis. In order to understand the mechanisms of vortex intensification and of warm core formation, budget analyses of vorticity and heat were performed at a time within the depression stage. A paper describing the simulation and analyses is being prepared. Numerical experiments were also carried out to investigate the effects of environmental flow conditions on storm genesis. The results indicate that the forced evolution of the flow above the storm is very much dependent on the initial condition of the mean flow and that the resultant upper flow has a large influence on the subsequent status of the underlying disturbance. Comparative analysis of the energy budget in these experiments is in progress. Experiments have also been conducted with different specified sea surface temperatures. A threshold value of sea surface temperature required for a disturbance to grow seems to exist.

PLANS FY81

The analysis of numerical results from the simulation experiments performed in the current year will continue. A series of experiments is planned using the real basic field at three different longitudes in the Atlantic during three different phases of GATE. This study will supplement and hopefully validate the simulation results obtained so far. It will also serve as a guide in the exploration of the model's capability for the prediction of tropical storm formation.

7.2 NESTED-MESH MODEL

ACTIVITIES FY80

A detailed description of a movable nested-mesh model was completed (s). Using a quadruply nested model, the simulation of a hurricane eye was attempted. Starting from an axisymmetric flow field, a strong vortex having a persistent eye was obtained and analysis of its structure is under way. An effort to formulate a general boundary condition for the outermost domain of a nested-mesh model has been continued. A feasible scheme which can handle both an open, free boundary and a specified or forced boundary is being investigated. Special attention is being paid to the dynamic balance between mass and momentum fields near the boundary.

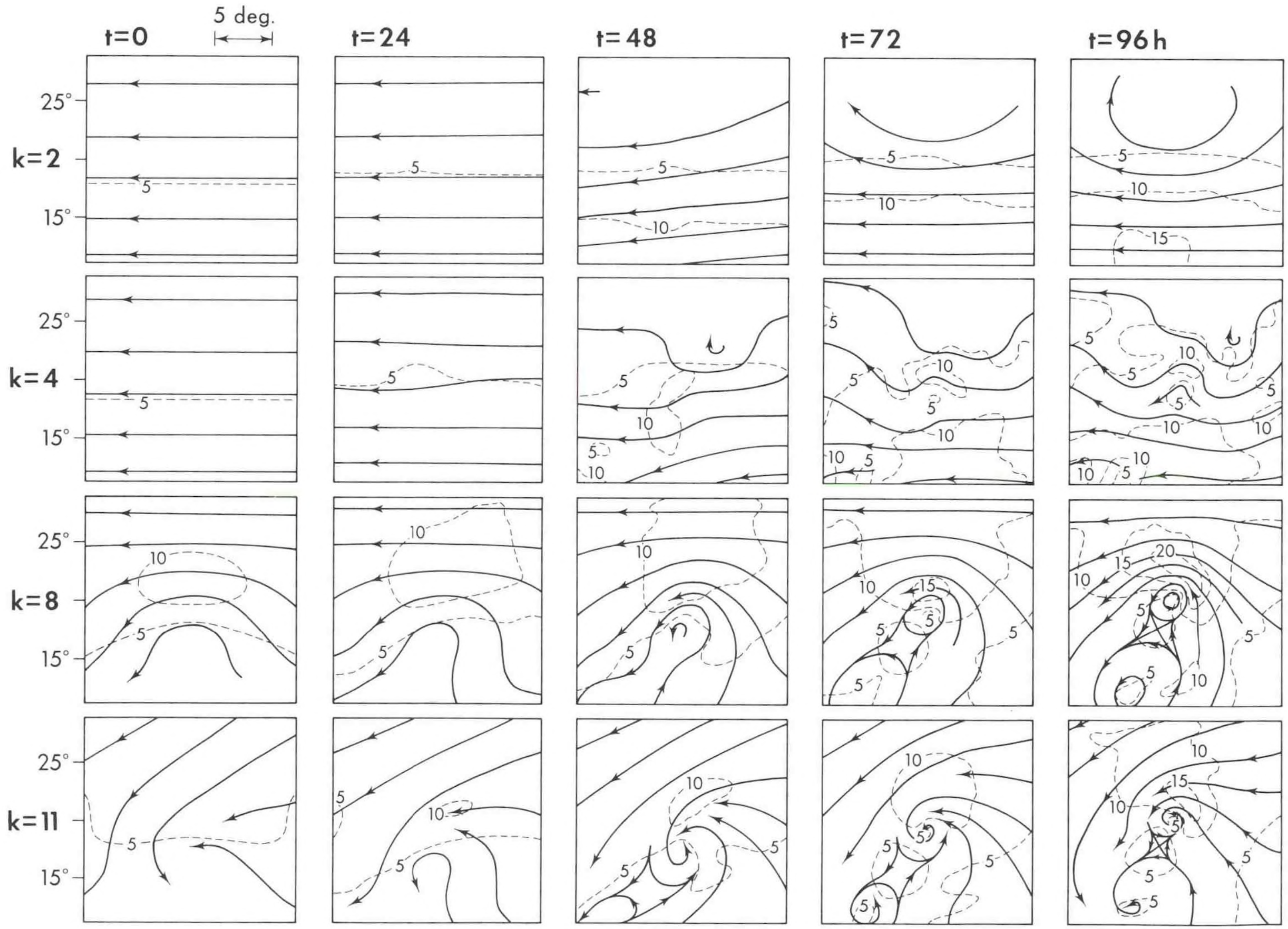

Fig. 5. Time sequence of streamlines (solid lines) and isotachs (dashed lines) at four levels showing the genesis of a tropical storm by an atmospheric model. k=2 refers to a level at ∿ 120 mb, k=4 at ∿ 335 mb, k=8 at ∿ 895 mb, and k=11 at ∿ 990 mb; t is the number of hours after the initial analysis. The isotachs are in units of m/s.

PLANS FY81

Analysis of the simulated hurricane eye, including an analysis of the maintenance mechanism for the indirect eye circulation, will be pursued further. A continuous effort will be made to establish a general treatment of the boundary condition for a limited domain integration. Depending on the success in improving the treatment of open boundaries, the phenomenon of hurricane landfall may be reexamined by adopting an environmental condition which is more realistic than the simple one used in a previous study (293).

8. MESOSCALE DYNAMICS

Goals

* To produce accurate numerical simulations of mesoscale processes in order to understand what role synoptic scale parameters play in their generation and evolution.

* To understand the internal gravity waves (generation, interaction and breakdown) that are strongly connected with the diffusive processes in the atmosphere and ocean.

8. MESOSCALE DYNAMICS

ACTIVITIES FY80

8.1 THE DYNAMICS OF A COLD FRONT

8.1.1 Frontogenetic and Frontolytic Processes

The numerical integration of an observed cold front and its associated convection system (355) for a period of 48 hours has been analyzed in great detail so as to address a number of questions that remain unsolved. Many investigations have been published which deal with frontal structure and evolution; most of these works have concentrated on problems of frontogenesis in very simplified fields. Although these investigations give an accurate explanation of frontal formation, they do not provide a complete picture of the circulation within a fully developed front after frontogenesis has occurred. The present numerical frontal solution gives a clue as to the most important terms in the vorticity and potential temperature equations which produce the intense gradients characteristic of frontal regions. In addition, it indicates the leading terms which may be the cause of frontolytic processes. These terms are associated with the vertical velocity field which most of the quasi-geostrophic or semi-geostrophic systems are unable to reproduce.

PLANS FY81

Mesoscale feedback to the synoptic scale will be investigated further. The observational period of April 10-14 from SESAME 79 contains a cyclonic intensification in the north-central United States which led to frontal occlusion. This case will be simulated numerically, and then sensitivity studies will be performed in which environmental parameters such as the moisture content of the atmosphere will be varied to determine the factors controlling the occlusion process.

8.1.2 Mesoscale Cold Front Disturbances

It has long been realized that fronts are a source of many extra-tropical mesoscale disturbances ranging from rain bands to the more intense squall lines. A study was performed to determine the effects of turbulent subgrid-scale parameterization intensities and the initial moisture field on frontal dynamics and convective instability. The control for this study was a solution which used low viscosity values and which was initialized with the observed moisture field. An analysis of the differences between the various solutions clearly indicated the role of subgrid-scale turbulent parameterization and moisture in determining the scale and intensity of the deep convection associated with the frontal lifting and also in producing internal gravity waves. The detailed structure of the frontal jet, the potential temperature, the cross-stream circulation, and the associated cloud distribution is seen in Fig. 6.

PLANS FY81

The three-dimensional mesoscale model which was employed to study the evolution of a moist cold front will be focused on an investigation of the Wichita Falls severe storm episode of April 10, 1979 (SESAME).

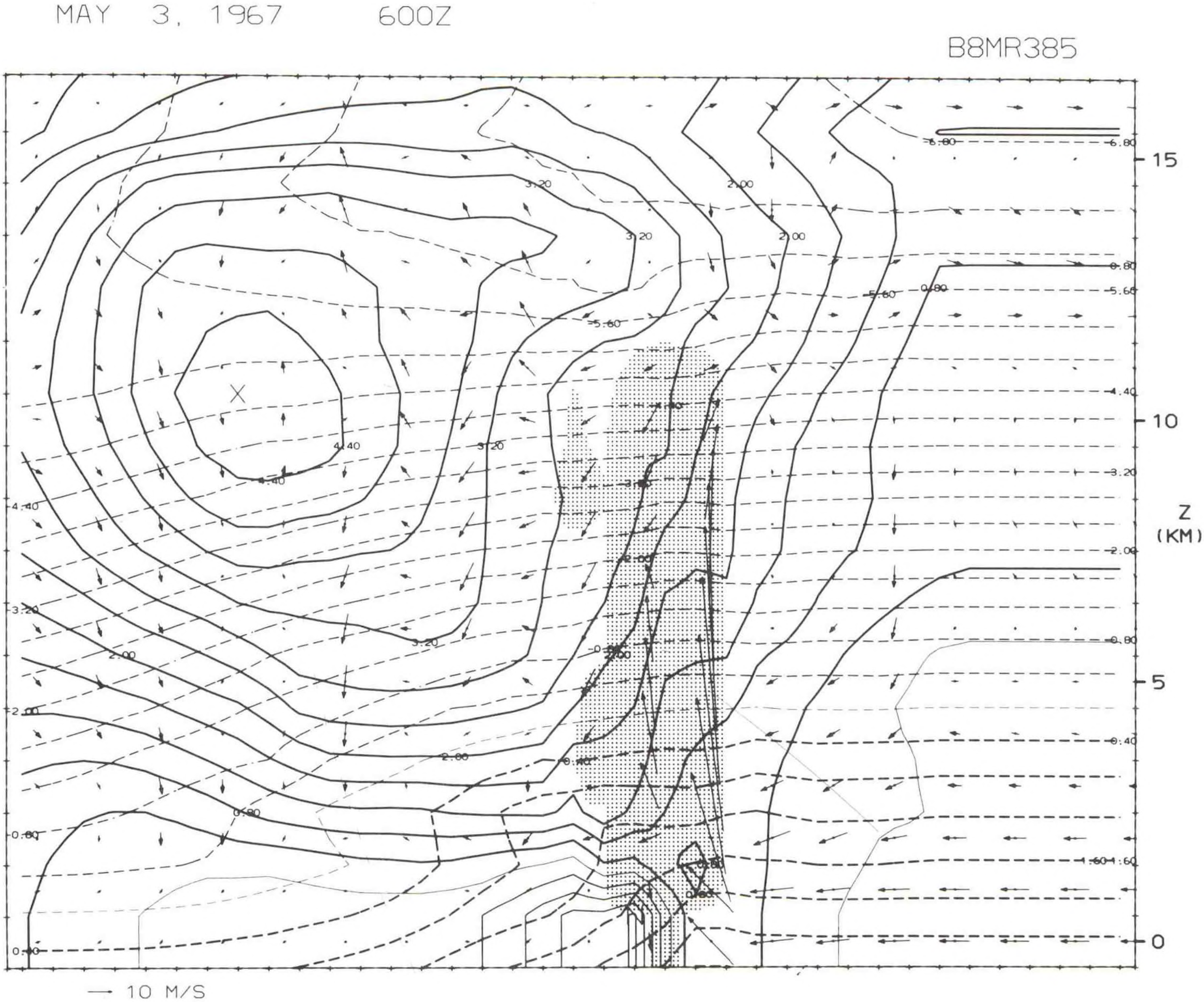

Fig. 6. Vertical cross-section perpendicular to a surface cold front. The wind component, v, normal to the cross-section is denoted by solid contours (contour interval Δv = 4 m/s). The dashed contours indicate potential temperature θ ($\Delta\theta$ = 4°C). Vectors designate the direction and magnitude of the cross-stream winds in the plane of the cross-section with the frontal translation speed removed (Δu_{front} = 4 m/s). Stippling denotes the location of cloud water. The total horizontal extent of the cross-section is 2275 km with tick marks (grid points) every 61.5 km.

8.2 THE LAND-SEA BREEZE CIRCULATION

The well-known sea-breeze circulation forced by the diurnal heat contrast between land and sea was studied in a two-part paper in preparation. The interactions between the forced sea-breeze circulation and the trapeze instability were investigated by means of linear and nonlinear models.

Results of such models show that the mesoscale waves associated with trapeze instability can be easily triggered by the sea-breeze circulation and can spread well inland but that little wave activity is detectable over the ocean. Waves obtained in this study compare very well with cloud bands over west Africa and South America.

8.3 THE QUASI-HYDROSTATIC SYSTEM

A new set of equations has been developed in which the simplicity and efficiency of the hydrostatic system is retained (mm). The new system of "quasi-hydrostatic" equations performs extremely well in the simulation of deep convection in mesoscale models, without requiring the great computational time which a non-hydrostatic system demands. As an example, a two-dimensional model with 5 km horizontal grid size takes eight times longer to run in a non-hydrostatic calculation than in a quasi-hydrostatic model with the same resolution.

8.4 GUST FRONT DYNAMICS

SESAME 79 provided a unique data set for detailed studies of severe downdrafts and gust fronts, as well as for the generation and evolution of tornadic frontal activity. A preliminary theoretical study with simplified gust front models has been initiated to determine possible areas of maximum instability where the generation of vortex centers can be expected.

PLANS FY81

These studies will be corroborated with analyses of observations and 3-D numerical simulations.

8.5 LEE MESO-CYCLOGENESIS

It is well-known that air flow over mountains produces mesoscale disturbances and generates vorticity centers of different scales. One of the aims of ALPEX in 1981 is to obtain observations of the lee cyclogenesis produced by the Alps. Preliminary studies by the mesoscale group of satellite pictures over the Andes mountains show lee meso-cyclogenesis. We are attempting to determine the relationship between wave scales and environmental conditions associated with such events. A simple laboratory experiment is now being performed to investigate such orographic effects.

PLANS FY81

A continuation of this study is anticipated for the coming year.

8.6 DIURNAL TIDE

The effect of the atmospheric boundary layer and wave-wave interactions in the diurnal tide are presently being investigated. It has been found that considerable energy may be transferred from the tide to other global waves. Observations indicate the existence of stratospheric waves that may be related to this suggested mechanism.

PLANS FY81

Completion of this study is expected in the coming year.

9. CONVECTION AND TURBULENCE

Goals

* To develop and improve three-dimensional numerical models capable of simulating dry and moist thermal convection in the atmosphere.

* To develop numerical models capable of simulating turbulence in homogenous and stratified fluids by simulating the large turbulent eddies directly and by testing various parameterizations of the subgrid-scale flow.

* To perform laboratory measurements and analysis of turbulence in various media to aid our understanding of its fundamental mechanisms.

* To formulate and test against observation various turbulence closure hypotheses applicable to the diabatic planetary boundary layer.

* To formulate and to test against observations a coastal ocean model which has a detailed surface layer and bottom boundary layer.

9.1 CONVECTION

ACTIVITIES FY80

Several important modifications were made in the moist convection numerical model during the past year. The model now has the capability to include a large-scale time-invariant convergence. The effect of this convergence is neglected in the momentum equations but is represented by source terms in the heat and water vapor equations. The surface boundary conditions are now more realistic, appropriate to a neutral surface mixed layer. Finally, the subgrid-scale turbulence parameterization has been changed in the gravitationally stable cloud-free atmosphere. Vertical mixing in this region has been modified to be much smaller than the horizontal mixing in order to represent the vertical stability. Thus the present model has much less artificial mixing of momentum, temperature and water vapor in the vertical.

The moist model with the large-scale convergence was first applied to the simulation of trade wind cumuli. The results were not much different from those of an earlier study (280). In spite of the convergence and the use of random initial data for thermal forcing, the clouds were transient and tended to dry out from below, contrary to the observed data discussed in (280).

Much more positive results were obtained when the large-scale convergence was included in the simulation of deep moist convection. In a preliminary calculation, the maximum convergence was 3x10sec-1 and a weak vertical wind shear was present, typical of tropical conditions. Several transient convective cells formed, precipitated significant amounts of rain, and decayed. A gust front formed ahead of the second cell and new transient cells formed at the leading edge of the gust front, apparently forced by the local lifting of the moist surface air. This realistic type of formation of successive transient cells had not been attained with the present model before the inclusion of the large-scale convergence.

One paper (362), dealing with various approximations to the thermodynamic equation, was published during the current year.

PLANS FY81

The above calculations of deep moist convection will be continued using a vertical sounding of temperature and water vapor somewhat more appropriate to the tropics than the present one. Calculations with no vertical wind shear will be carried out in order to evaluate the importance of shear as well as convergence in the present simulations. It is hoped that the data thus obtained will give new insight into the role of convection in such atmospheric phenomena as cloud clusters and easterly waves. The formulation of the moist model and preliminary results will be submitted for publication.

A planned modification of the moist model is to include the ice phase in the bulk cloud physics. The ice phase will increase the amount of latent heat released and could significantly affect the intensity and depth of the convection.

In all of these studies, a primary objective is to determine how moist convection acts to transfer water vapor, heat and momentum in the vertical as well as to account for precipitation and evaporation at the surface. A long-term goal is to use the knowledge gained from convection modeling for improving cumulus-scale parameterizations in mesoscale and larger-scale numerical models.

9.2 ATMOSPHERIC AND OCEANIC BOUNDARY LAYERS

ACTIVITIES FY80

Work has continued on the extension of the Mellor-Yamada turbulent closure model (185) to include condensation physics (261) and radiative transfer, with particular regard for the interaction between the radiation field, both solar and infrared, and clouds. The effects of clouds on the radiative fluxes are parameterized in terms of their liquid water content.

PLANS FY81

This model will be utilized to address a number of questions related to the effects of condensation and radiation on boundary layers as well as on mesoscale and sub-mesoscale circulations. An example is the investigation of the importance of cloud-top infrared cooling on a moist boundary layer.

9.3 OCEAN COASTAL DYNAMICS MODEL

ACTIVITIES FY80

The two-dimensional ocean coastal dynamics model (0) has been used to study tidal responses in Long Island Sound and Newark Bay. Meaningful results have been obtained only when the flows near the open boundaries are nearly linear. Also, by treating part of the pressure gradient terms in the momentum equations implicitly, the maximum time-step resulting in a stable integration has been increased by a factor of 1.8, increasing the computational efficiency of the model.

A three-dimensional version of the model has been constructed, and has been applied to study the mixing due to internal waves on continental margins.

PLANS FY81

The model (both two- and three-dimensional) will be used to study tidal response and sediment transport in New York Harbor. Detailed comparisons with field data will be made. Open boundary conditions at the Sandy Hook - Rockaway point transect are expected to present a major problem due to their strongly nonlinear character.

APPENDICES

APPENDIX A

GFDL Staff Members

and

Affiliated Personnel

during

Fiscal Year 1980

* Affiliation Terminated Prior to September 30, 1980

Joseph Smagorinsky, Director	FTP
Rosemary Kelly-Champ, Secretary	FTP
Isidoro Orlanski, Deputy Director	FTP
Howard M. Frazier, Assistant Director	FTP
Janice M. Lizura, Secretary	FTP*
Annette Chandler, Secretary	FTT
Vacancy, Secretary	FTP

CENTRALIZED SUPPORT SERVICES

Administrative and Technical Support

Fraulino, Philip	Librarian	PTP
Pensyl, Ornella	Librarian	PTP*
Preece-Canfield, Rebecca	Librarian	PTT*
Shaffer, Daryl	Administrative Officer	FTP
Byrne, James	Jr. Technician	FTP
Conner, John	Sr. Technician	FTP
D'Amico, Elaine	Administrative Clerk	FTP
Pope, Ingrid	Secretary	FTP
Tunison, Philip	Sr. Technician	FTP
Ellis, William	Sr. Technician	FTP
Zadworney, Michael	Jr. Technician	FTP
Williams, Betty	Editorial Assistant	FTP
Kennedy, Joyce	Editorial Assistant	FTP

Computer Support

Welsh, James	Sr. Computer Sys. Ana.	FTP
Baker, Philip	Computer Sys. Analyst	FTP
Lewis, Lawrence	Computer Sys. Analyst	FTP
Newman, James	Computer Sys. Analyst	FTP*
Vacancy	Computer Sys. Analyst	FTP
Reek, Thomas	Computer Sys. Analyst	FTP*
Vacancy	Computer Sys. Analyst	FTP
Uveges, Frank	Sr. Computer Technician	FTP
Conover Leonard	Sr. Computer Technician	FTP
Brandbergh, Gerald	Computer Technician	FTP
Cordwell, Clara	Computer Technician	FTP
King, Lois	Computer Aide	PTT*
Miller, Almore	Computer Technician	FTP
Mitman, Mark	Computer Aide	PTT*
Franckowiak, Helen	Keypunch Operator	FTP*
Heinbuch, Ernest	Sr. Computer Technician	FTP
Deuringer, Howard	Computer Technician	FTP
Hand, Joseph	Computer Technician	FTP
Kreuger, Mark	Computer Technician	FTP
Schwartz, Henry	Sr. Computer Technician	FTP*
Shearn, William	Sr. Computer Technician	FTP
Douglis, Frederick	Computer Aide	PTT*
Henne, Ronald	Computer Technician	FTP
Hopps, Frank	Computer Technician	FTP
King, John	Computer Technician	FTP
Napoleon, Mark	Computer Aide	FTT*
Smith, Robert	Computer Technician	FTP
Taylor, Thomas	Computer Technician	FTP

CLIMATE DYNAMICS

Manabe, Syukuro	Sr. Research Scientist	FTP
Bowman, Kenneth	Student	PU
Fels, Stephen	Research Scientist	FTP
Crisp, David	Student	PU
Hamilton, Kevin	Student	PU
Schwarzkopf, M. Daniel	Research Associate	FTP
Hahn, Douglas	Sr. Research Associate	FTP
Daniel, Donahue	Research Associate	FTP
Dimmick, Lanny	Senior Technician	FTP
Green, Edwin	Research Associate	FTP*
Hayashi, Yoshikazu	Research Scientist	FTP
Golder, Donald	Research Associate	FTP
Held, Isaac	Research Scientist	FTP
Linder, David	Research Associate	FTP
Nigam, Sumant	Student	PU
Sardeshmukh, Prashant	Student	PU
Holloway, J. Leith	Sr. Research Associate	FTP
Keshavamurty, R.N.	Visiting Scientist	PU
Spelman, Michael	Sr. Research Associate	FTP
Stouffer, Ronald	Research Associate	FTP
Pege, Deborah	Junior Fellow	PTT
Wetherald, Richard	Sr. Research Associate	FTP

MIDDLE ATMOSPHERE DYNAMICS AND CHEMISTRY

Mahlman, Jerry	Sr. Research Scientist	FTP
Andrews, David	Visiting Scientist	PU *
Hsu, Chih-Ping Flossie	Visiting Scientist	PU
Levy, Hiram II	Research Scientist	FTP
Moxim, Walter	Sr. Research Associate	FTP
Sinclair, Russell	Research Associate	FTP
Narvaez, Carmen	Junior Fellow	PTT

EXPERIMENTAL PREDICTION

Miyakoda, Kikuro	Sr. Research Scientist	FTP
Chao, Chi-Ping	Visiting Scientist	PU
Gordon, Charles	Research Scientist	FTP
Hovanec, Russell	Research Associate	FTP
Stern, William	Research Associate	FTP
Dilliplane, Steven	Junior Fellow	PTT
Kinter, James	Student	PU
Rosati, Anthony	Sr. Research Associate	FTP
Boland, Frederick	Research Associate	FTP
McFarland, Margaret	Junior Fellow	PTT
Sirutis, Joseph	Research Associate	FTP
Sheldon, John	Research Associate	FTP
Strickler, Robert	Sr. Research Associate	FTP
Chludzinski, Julius	Research Associate	FTP*
Terpstra, Theodore	Research Associate	FTP
Jobson, Charles T.	Research Associate	FTP
Ploshay, Jeffrey	Research Associate	FTP
White, Robert	Jr. Technician	FTP
Umscheid, Ludwig	Sr. Research Associate	FTP
Caverly, Richard	Research Associate	FTP
Davis, William	Research Associate	FTP*

OCEANIC CIRCULATION

Bryan, Kirk	Sr. Research Scientist	FTP
Cox, Michael	Sr. Research Associate	FTP
Komro, Frederick	Research Associate	FTP
Delecluse, Pascale	Visiting Scientist	PU
Hellerman, Solomon	Research Associate	FTP
Jackson, Martha	Sr. Technician	FTP
MacAyeal, Douglas	Student	PU
Philander, Samuel G.	Research Scientist	FTP
Carton, James	Student	PU
Pacanowski, Ronald	Research Associate	FTP
Puzo, James	Junior Fellow	PTT
Seigel, Anne	Research Associate	FTP
Yoon, H.	Visiting Scientist	PU
Rooth, Claes	Visiting Scientist	PU *
Sarmiento, Jorge	Visiting Scientist	PU

PLANETARY CIRCULATIONS

Williams, Gareth	Sr. Research Scientist	FTP
Vacancy	Research Associate	FTP

OBSERVATIONAL STUDIES

Oort, Abraham	Sr. Research Scientist	FTP
Holopainen, Eero	Visiting Scientist	PU *
Lau, Ngar-Cheung	Visiting Scientist	PU
Levitus, Sydney	Research Associate	FTP
Maher, Mary Ann	Junior Fellow	PTT
Rosenstein, Melvin	Sr. Technician	FTP
Stefanick, Michael	Student	PU *

HURRICANE DYNAMICS

Kurihara, Yoshio	Sr. Research Scientist	FTP
Bender, Morris	Research Associate	FTP
Tuleya, Robert	Sr. Research Associate	FTP

MESOSCALE DYNAMICS

Orlanski, Isidoro	Sr. Research Scientist	FTP
Chen, Wen-Dar	Student	PU
Garaffo, Zulema	Student	PU
Moore, G. W. Kent	Student	PU
Polinsky, Larry	Research Associate	FTP
Ross, Bruce	Sr. Research Associate	FTP
Shaginaw, Richard	Research Associate	FTP

CONVECTION AND TURBULENCE

Lipps, Frank	Research Scientist	FTP
Hemler, Richard	Research Associate	FTP
Mellor, George	Professor	PU
Blumberg, Alan	Visiting Scientist	PU *
Oey, Lie-Yauw	Visiting Scientist	PU

GFD PROGRAM

Dahlen, F. A.	Professor	PU
Eldridge, Dawn	Secretary	PU
Favata, Phyllis	Secretary	PU*
Olsen, Esther	Secretary	PU
Rajkovic, Borivoje	Student	PU
Wahr, John	Visiting Scientist	PU

TEXAS INSTRUMENTS

Williams, Michael	Site Manager	TI
Bates, Craig	Maintenance Engineer	TI
Battersby, Batt	Maintenance Engineer	TI
Bagshaw, Mark	Maintenance Engineer	TI
Caldwell, Lee	Maintenance Engineer	TI
Devlin, Thelma	Secretary	TI
Fedor, John	Maintenance Engineer	TI
Iasello, Anthony	Maintenance Engineer	TI
Lindquist, Charles	Software Support	TI
Smisloff, Michael	Software Support	TI
Smith, Mark	Maintenance Engineer	TI
Troup, John	Maintenance Engineer	TI
Zimbars, Rodney	Maintenance Engineer	TI

PERSONNEL SUMMARY

September 30, 1980

FTP - Full Time Permanent (GFDL)	84
Vacancies for FTP Positions (GFDL)	4
PTP - Part Time Permanent (GFDL)	1
FTT - Full Time Temporary (GFDL)	1
Junior Fellows (GFDL)	6
Visiting Scientists (PU)	9
Students (PU)	12
Professors (PU)	2
Secretaries (PU)	2
Texas Instruments Advanced Scientific Computer (ASC) Maintenance (TI)	13
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APPENDIX B

GFDL

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HAMILTON, Kevin	(375),(380),(v),(hh),(nn)
HANTEL, Michael	(219),(223)
HARTMANN, Dennis, L.	(171-A),(206-A),(237),(241)
HAYASHI, Yoshikazu	(147),(165),(218),(260),(267),(292),(320), (336),(338),(353-A),(365),(377),(384),(pp)
HELD, Isaac M.	(161-A),(204-A),(242),(243),(294),(319), (352),(369),(bb)
HELD, Joann L.	(207)
HELLERMAN, Solomon	(39),(55),(g)
HEMBREE, G. Daniel	(4),(58),(72),(85),(109),(139),(180), (282),(300)
HEMLER, Richard B.	(362)
HIBLER, W. D., III	(271),(281),(340),(345),(383)
HICKIE, Bryan P. B.	(d)
HIRSCHMAN, Alan D.	(136)
HOLLAND, William R.	(62),(121),(136),(142),(210),(211),(214)

HOLLOWAY, J. Leith, Jr.	(3), (32), (53), (58), (87), (92), (93), (100), (108), (143), (163), (177), (195), (360)
HOLOPAINEN, Eero	(aa), (kk), (tt)
HOSKINS, B. J.	(159-A), (192-A), (217-A)
HUNT, Barrie G.	(35), (37), (63), (64), (70)
KUNG, Ernest C.	(27), (36), (41), (54)
KURIHARA, Yoshio	(29), (30), (53), (65), (96), (123), (141), (156), (172), (179), (189), (193), (230), (231), (286), (293), (327), (354), (s)
LAU, Ngar-Cheung	(337), (344), (357), (368), (tt)
LEE, D. H.	(227)
LEVITUS, Sydney	(268), (285), (299)
LEVY, Hiram, II	(323), (367), (379), (dd), (ii)
LEWIS, Lawrence	(332)
LILLY, Douglas K.	(6), (12), (15), (16a), (18), (24), (28)
LIN, Liang-Bee	(178-B), (210), (211)
LIPPS, Frank B.	(38), (86), (103), (105), (134), (151), (229), (234), (264), (280), (362), (ss)
LUSEN, Ronald	(227)
MAHLMAN, Jerry D.	(133), (149), (150), (153), (176), (239), (244), (246), (263) (308), (323), (358), (367), (379), (j), (k), (t), (u), (dd), (ii)
MANABE, Syukuro	(13), (14), (26), (32), (33), (49), (50), (51), (58), (63), (64), (67), (70), (76), (79), (80), (87), (92), (93), (97), (98), (100), (108), (110), (117-A), (125), (133), (143), (162), (163), (177), (190), (191), (192), (195), (198), (206), (216), (244), (247), (278), (347), (355), (357), (360), (360-C), (361), (i), (n), (y), (z)
MATSUNO. Taroh	(117)
McFARLAND, Margaret	(ii)
MECHOSO, Carlos, R.	(342),
MELLOR, George L.	(159-A), (185), (203), (209), (217), (261), (268), (284), (311), (333), (334), (341), (356), (371), (e), (f), (0)
MESINGER, Fedor	(q)
MIYAKODA, Kikuro	(20), (60), (72), (85), (89), (91), (107), (109), (119), (120), (122), (132), (139), (154), (158), (166), (180), (181), (220), (227), (276), (291), (295), (l), (m), (ll), (oo)

MOLLER, Fritz (10),(11),(13),(14)

MOXIM, W. J. (239),(308),(323),(367),(379),(j)

MOYER, R. W. (60),(122)

NAPPO, C. J. (109)

OORT, Abraham H. (73),(77),(83),(90),(95),(106),(115),(118),(126),(145),(148),(168),(169),(171),(174),(175),(188),(197),(232),(245),(279),(285),(287),(290),(299),(360A),(aa),(kk),(tt)

ORLANSKI, Isidoro (61),((82),(84),(114),(130),(146),(159),(160),(173),(188-A),(200),(201),(224),(236),(249),(277),(288),(296),(301),(355),(374),(h),(mm)

PACANOSWKI, Ronald C. (191),(350),(364),(372),(ee),(ff)

PIEXOTO, Jose P. (171),(174),(232)

PHILANDER, S. G. H. (144),(157),(235),(255),(270),(289),(310),(324),(329),(348),(349),(364),(370),(372),(r),(ee),(ff),(gg)

PIACSEK, Steve A. (101)

POLINSKY, L. J. (173),(188-A),(288)

PRATTE, F. (227)

RASMUSSON, Eugene M. (40),(52),(57),(66),(90),(104),(115),(140)

RINTEL, Lionel (48),(59)

RIPÁ, Pedro (298),(305),(a)

ROBINSON, John B. (152),(184)

ROOTH, Claes G. (366)

ROSATI, Anthony (276),(l),(m)

ROSS, Bruce B. (160),(173),(188-A),(277),(296),(301),(355),(374)

ROSSOW, William B. (257),(259),(304),(313),(326),(363)

ROTUNNO, Richard (238),(275)

ROWNTREE, Peter R. (127)

SANGSTER, Wayne E (7),(58)

SARMIENTO, Jorge L. (321),(366),(382),(x)

SCHEMM, Charles	(177-C),(229)
SCHOPF, Paul	(274)
SCHWARZKOPF, M. Daniel	(204),(k),(w)
SEMTNER, Albert	(155-A)
SHELDON, John	(11)
SHUKLA, J.	(194),(248),(250)
SHULMAN, Irving	(139)
SIMMONDS, Ian	(233),(251),(307)
SINCLAIR, Russell W.	(263),(k),(u)
SIRUTIS, J.	(227),(295),(ll)
SMAGORINSKY, Joseph	(1),(2),(5),(8),(9),(17),(22),(23),(25),(32),(33),(42),(43),(44),(49),(58),(72),(74),(87),(91),(99),(112),(138),(183),(272),(314),(315),(330),(360-B),(373),(b),(qq)
SOMERVILLE, Richard	(105),(111),(151)
SPELMAN, Michael J.	(143),(190),(347)
STAMBLER, H.	(122)
STEFANICK, Michael	(381),(rr)
STEGEN, Gilbert R.	(178),(186),(193-A),(202),(207)
STERN, Bill	(180-A)
STONE, Hugh M.	(67),(87),(92)
STOUFFER, Ronald J.	(360),(i),(y)
STRICKLER, Robert F.	(26),(33),(58),(72),(85),(91),(109),(122),(131),(139),(291),(oo)
SUAREZ, Max J.	(161-A),(242),(243),(294),(352)
SUN, Wen-Yih	(378)
TALAGRAND, Oliver	(119),(120)
TANG,D. H. Edward	(225)
TERPSTRA, Theodore B.	(162)
TRIPOLI, Gregory	(231),(327)
TULEYA, Robert E.	(172),(179),(193),(286),(293)
UMSCHEID, Ludwig, Jr.	(132),(158),(227),(265),(266)

WETHERALD, Richard T. (50),(125),(192),(216),(351),(n),(z),(jj)

WILLEBRAND, Jurgen (318),(372)

WILLIAMS, Gareth (31),(46),(47),(71),(75),(84),(101),(116),(124),(129),(152),(167),(184),(205),(215),(302),(304)(326),(335),(343),(353)

YAMADA, Tetsuji (128-A),(137-A),(182),(185),(199),(217),(226),(283),(284),(356)

APPENDIX C

Computational Support

APPENDIX C

Computational Support

During FY80 there have been two principal activities concerning computational support for the Laboratory. The new DICOMED microfilm recorder has been installed to replace the old and ailing Datagraphix 4020; and the RFP for a new computer system to replace the TI ASC has been issued.

The DICOMED D148C microfilm recorder was delivered in December, 1979. This machine offers significantly greater resolution than did the 4020. It accepts data either in the 4020 format or in a native-mode format that exploits the full resolution. Acceptance testing was not started until February, because of difficulties with the 7-track tape drive used for input of tapes written for the 4020. The acceptance test was completed in March 1980, and the performance of the sytem has been quite reliable since then.

The 4020 was turned off in March, and dismantled in May, 1980. The transfer of software and operations to the DICOMED has been smooth, and the hoped for increased turnaround for users has been realized. Users received three microfilm outputs per day. More than 95% of film generation is in the native mode of the DICOMED with only a few frames each day generated in the old 4020 format, so users are generally enjoying the advantages of the greater capability of the DICOMED system.

After several years of gestation, the RFP for a new, large computer system to replace the TI 4-pipe ASC was issued in April, 1980. Responses were due August 14, 1980. Evaluation will be essentially complete by the end of FY80, and it should be possible to sign a contract early in FY81. Although the only mandatory delivery requirement is in FY82, there are incentives for vendors to deliver equipment in FY81.

The RFP provides for evaluating vendors by how much computing power they can deliver before September 30, 1989, provided that they stay within the Laboratory's budget for computing resources. Computing power is measured by a suite of benchmark programs that simulate two basic types of workload: daytime, quick turnaround work, and overnight, long production. The vendors are given the total amount budgeted by the Laboratory for each Fiscal Year through FY89, which limits their ability to bid system components.

TABLE C-1: COMPUTER AND MICROFILM USAGE

Month	ASC CPU Hours	Microfilm Frames
Oct. 79	552	56,185
Nov. 79	428	52,536
Dec. 79	463	48,209
Jan. 80	489	69,324
Feb. 80	531	74,643
Mar. 80	525	72,418
Apr. 80	536	74,632
May 80	524	56,906
Jun. 80	488	80,872
Jul. 80	497	77,393
Aug. 80	*	*
Sep. 80	*	*

(* = Data unavailable)

TABLE C-2: AVERAGE MONTHLY COMPUTER USAGE FOR PAST YEARS

Fiscal Year	CPU Hours per Month
FY79	513
FY78	497
FY77	523
FY76	499

APPENDIX D

Seminars given at GFDL

During Fiscal Year 1980

Seminars not included in FY 79 Report

September 5, 1979	"CO_2 Sensitivity in a Coupled Atmosphere-Mixed Layer Ocean Model" by Mr. Ronald Stouffer, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
September 12, 1979	"Quasi-Geostrophic Turbulence Driven by a Mean Temperature Gradient" by Dr. Isaac Held, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
September 19, 1979	"Cyclogenesis in the Gulf of Genoa" by Mr. R. F. Strickler, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
September 26, 1979	"Thermohaline Transport Problems in the Ocean" by Dr. Claes G. H. Rooth, Geophysical Fluid Dynamics Program, Princeton, New Jersey

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October 3, 1979	"FGGE Four-Dimensional Analysis System at GFDL - Part I" by Dr. Kikuro Miyakoda, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
October 3, 1979	"Amplitudes, Scales and Phases in Free and Themodynamically Forced Large-Scale Waves" by Dr. Ragnar Fjørtoft, Det Norske Meteorologisk Institutt, Blindern, Oslo, Norway
October 10, 1979	"The Three-Dimensional Structure of Monthly Anomalies Appearing in a 15-Year Simulation of a GFDL Spectral General Circulation Model" by Dr. Ngar-Cheung Lau, Geophysical Fluid Dynamics Program, Princeton, New Jersey
October 12, 1979	"FGGE Four-Dimensional Analysis System at GFDL - Part II" by Dr. Kikuro Miyakoda and Mr. Theodore Teprstra, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
October 18, 1979	"Performance of United Kingdom Meteorological Office 5-Level Model, and its Application to the CO_2-Climate Problem" by Dr. J. Mitchell, United Kingdom Meteorological Office, England
October 23, 1979	"A Simulation of the Bomb Produced Titium Distribution in the North Atlantic" by Dr. Jorge Sarmiento, Geophysical Fluid Dynamics Program, Princeton, New Jersey
October 25, 1979	"The Ins and Outs of the Langmuir Circulation in the Ocean and in the Laboratory" by Professor Allen J. Faller, University of Maryland, Institute for Fluid Dynamics and Applied Mathematics, College Park, Maryland

October 31, 1979	"Variability of Equatorial Oceans" by Dr. George Philander and Mr. Ronald C. Pacanowski, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
November 2, 1979	"1980's - Decade for Ocean Prediction" by Professor Russell L. Elsberry, Naval Postgraduate School, Department of Meteorology, Monterey, California
November 7, 1979	"A Comparison of Spectral and Grid Model Forecasts" by Dr. Tony Gordon and Mr. William Stern, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
November 8, 1979	"CO_2 in Climate - Transient Response versus Equilibrium Solution" by Dr. Stephen H. Schneider, National Center for Atmospheric Research, Boulder, Colorado
November 14, 1979	"Wave-Energy, Wave-Action, and Other Diagnostic Tools for the Study of Atmospheric Waves" by Dr. David G. Andrews, Geophysical Fluid Dynamics Program, Princeton, New Jersey
November 16, 1979	"The Poleward Heat Flux in the North Atlantic Ocean" by Ms. Mindy Hall, Woods Hole Oceanographic Institute, Woods Hole, Mass.
November 19, 1979	"Surface Frontogenesis in an Amplifying Eady Wave - Analytic and Numerical Solutions" by Dr. Daniel Keyser, Pennsylvania State University, Meteorology Department, University Park, Pennsylvania
November 21, 1979	"Some Aspects of the Long-Term Mean Budgets of Vorticity and Zonal Momentum in the Atmosphere" by Dr. E. O. Holopainen, Geophysical Fluid Dynamics Program, Princeton, New Jersey
November 26, 1979	"Radiative Transfer in Clouds for Climate Studies" by Dr. Graeme Stephens, Commonwealth Scientific & Industrial Research Organization, Victoria, Australia and Colorado State University
November 27, 1979	"Multi-Dimensional Interpolation with Noisy Data" by Professor Wesley Wilson, Wave Propagation Laboratory, National Oceanic and Atmospheric Administration, Boulder, Colorado
November 29, 1979	"The Reversal of the Somali Current During April-May 1979" by Dr. Ants Leetmaa, Physical Oceanography Laboratory, National Oceanic and Atmospheric Administration, Miami, Florida
November 30, 1979	"The Structure of a Middle-Latitude Squall Line" by Dr. Yoshio Ogura, Laboratory for Atmospheric Research, University of Illinois, Urbana, Illinois

December 5, 1979	"A Method of Estimating Space-Time Spectra From Polar-Orbiting Satellite Data" by Dr. Yoshikazu Hayashi, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
December 7, 1979	"Tidal Calculations Using the Finite Element Method" by Dr. C. Provost, University of Grenoble, France
December 12, 1979	"Heat Transfer and Ocean Circulation" by J.A.T. Bye, Flinders University, Melbourne, Australia
December 19, 1979	"Active and Break Monsoon and Multiple Equilibria in the Tropical Atmosphere" by Dr. B. N. Goswami, Massachusetts Institute of Technology, Department of Meteorology, Cambridge, Mass.
January 4, 1980	"Seasonal Response of the Equatorial Atlantic Ocean" by Dr. Eli Katz, Lamont-Doherty Geological Observatory, Columbia University, New York
January 10, 1980	"The Evolution of Meteorological Satellites" by Mr. Abe Schnapf, RCA Space Center, Princeton, New Jersey
January 23, 1980	"Variations of the Oceanic Thermal Inertia" by Dr. J. Miller, Rutgers University, New Brunswick, New Jersey
January 31, 1980	"Normal-mode Initialization at the National Meteorological Center" by Dr. David Parrish, National Meteorological Center, National Oceanic and Atmospheric Administration, Wash., DC
February 6, 1980	"Atmospheric Chemistry Research in the Department of Chemical Engineering" by Professors Ron Andres and J. Calo, Chemical Engineering Department, Princeton University, Princeton, New Jersey
February 7, 1980	"Beta Dispersion of Rossby Waves" by Dr. Paul Schnopf, NASA Goddard Space Flight Center, Greenbelt, Maryland
February 11, 1980	"Studying the Dynamics of the Ocean on Climate Time and Space Scales Using Inverse Modeling Techniques" by Professor Klaus Hasselmann, Max-Planck-Institut for Meteorologie, Hamburg, Germany
February 12, 1980	"Vorticity Dynamics of the Tornado's Near Environment" by Dr. Richard Rotunno, CIRES, University of Colorado, Boulder, Colorado
February 21, 1980	"Tropical Storm Development from Easterly Waves: Theory and Practice" by Dr. Lloyd Shapiro, National Hurricane and Experimental Meteorological Laboratory, Coral Gables, Florida
February 22, 1980	"Modeling a Variable Thickness Sea Ice Cover" by Dr. William Hibler, III, USA Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire

February 28, 1980	"Numerical Simulations of Rotational Convective Storms" by Dr. Joseph B. Klemp, National Center for Atmospheric Research, Boulder, Colorado
March 6, 1980	"Turbulent Mixing in Stratified Fluids" by Dr. Lakshmi Kantha, Dynalysis of Princeton, Princeton, New Jersey
March 7, 1980	"Venusian Stratospheric Circulation" by Dr. Stephen B. Fels, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
March 17, 1980	"The ECMWF Forecasting System and Results from Operational Forecasting" by Dr. Adrian Simmons, European Centre for Medium Range Weather Forecasts, Berkshire, England
March 18, 1980	"Results of Long-Term Integration with the Operational ECMWF Model" by Dr. Michael Tiedtke, European Centre for Medium Range Weather Forecasts, Berkshire, England
March 25, 1980	"A Linear Model for Predicting Storm Propagation" by Mr. Adrian Marroquin, New Mexico Tech (New Mexico Institute of Mining and Technology) Socorro, New Mexico
April 4, 1980	"Space-Time Spectral Analysis of the GLAS GCM" by Dr. David Straus, Goddard Laboratory for Atmospheric Sciences, Greenbelt, Maryland
April 11, 1980	"Response of the Tropical Atmosphere to Sea Surface Anomalies Over the Equatorial Pacific" by Dr. R. N. Keshavamurty, Geophysical Fluid Dynamics Program, Princeton, New Jersey
April 18, 1980	"Equatorial Wind Accelerations in SKYHI" by Dr. Jerry D. Mahlman and Mr. Russell Sinclair, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
April 18, 1980	"Low Order Model with Orographic Forcing on the Sphere" by Dr. Erland Källén, European Centre for Medium Range Weather Forecasts, Berkshire, England
April 21, 1980	"The Effects of Long Planetary Waves on the Regions of Cyclogenesis" by Dr. J. S. Frederiksen, Commonwealth Scientific and Industrial Research Organization, Australia
April 25, 1980	"Four-Dimensional Analysis During GATE Phase III" by Mr. John Sheldon, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
April 29, 1980	"Planetary Wave Coupling Between the Troposphere and the Middle Atmosphere as a Possible Sun-Weather Mechanism" by Dr. Marvin A. Geller, Rosenstiel School of Marine and Atmospheric Science, Miami, Florida
May 1, 1980	"Response of the Equatorial Ocean to Anomalous Waves" by Dr. David Anderson, Department of Physics, Clarendon Laboratory, University of Oxford, England

May 2, 1980	"Stratospheric Sudden Warning: The Role of Wave-Wave Interactions" by Dr. Chih-Ping Flossie Hsu, Geophysical Fluid Dynamics Program, Princeton, New Jersey
May 8, 1980	"Mean Flows Generated by a Progressing Water Wave Packet" by Dr. Roger Grimshaw, Department of Mathematics, University of Melbourne, Australia and Department of Mathematics, Massachusetts Institute of Technology, Cambridge, Mass.
May 9, 1980	"Zonal-Vertical Propagation of a Planetary Wave Packet in a Steady State" by Dr. Yoshikazu Hayashi, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
May 15, 1980	"Atmospheric Brightness Temperature Spectra at High Global Wavenumbers Utilizing Satellite Microwave Measurements" by Professor John L. Stanford, Goddard Laboratory for Atmospheric Sciences, Greenbelt, Maryland
May 22, 1980	"Mechanics of Mountain Building" by Professor John Suppe, Department of Geological and Geophysical Sciences, Princeton University, Princeton, New Jersey
June 5, 1980	"Large Scale Ocean Response to Surface Temperature Perturbation" by Dr. Claes G. H. Rooth, Geophysical Fluid Dynamics Program, Princeton, New Jersey
June 6, 1980	"Modeling the Quasi-Biennial Oscillation" by Mr. Kevin Hamilton, Geophysical Fluid Dynamics Program, Princeton, New Jersey
June 13, 1980	"Momentum Fluxes in Unstable Quasi-Geostrophic Waves" by Dr. Isaac Held, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
June 16, 1980	"Oceanic Fronts" by Dr. Pierre Welander, Department of Oceanography, University of Washington, Seattle, Wash.
June 24, 1980	"Role of Mesoscale Eddies in the Momentum and Kinetic Energy Balance of the Kuroshio Extension" by Dr. Hideo-Nishida. Japanese Maritime Safety Agency, Japan (presently at Scripps Institute of Oceanography)
June 27, 1980	"Long-term Variations in Stratospheric Ozone: Relationship to Meteorological Variables" by Professor Peter Bloomfield, Statistics Department, Princeton University
July 11, 1980	"Are Atmospheric Tides Important for the General Circulation of the Stratosphere, Mesosphere or Lower Thermosphere?" by Mr. Kevin Hamilton, Geophysical Fluid Dynamics Program, Princeton, New Jersey

July 18, 1980	"Eliassen-Palm Fluxes as Diagnostics of Wave Mean-Flow Interaction in the SKYHI Model" by Dr. David Andrews, Geophysical Fluid Dynamics Program, Princeton, New Jersey
July 25, 1980	"Saltfinger Convection and the Potential Vorticity Budget in Subtropical Pycnocline" by Dr. Claes G. H. Rooth, Geophysical Fluid Dynamics Program, Princeton, New Jersey
September 2, 1980	"Aspects of Barotropic Flow: Wave-turbulence Interaction, Intermittency, and Predictability" by Dr. Robert Sadourny, Centre National de la Recherche Scientifique, Labatoire de Meteorologie Dynamique, Paris, France

APPENDIX E

Talks, Seminars and Papers Presented Outside GFDL

During Fiscal Year 1979

FY-80

TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1979 through September 30, 1980

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
*September 12, 1979	Dr. Gareth P. Williams "Parametric Variability of Quasi-Geostrophic Circulations on Earth and Jupiter"	European Geophysical Society Vienna, Austria
*September 27, 1979	Dr. Gareth P. Williams "Blocking and Jet Multiplicity"	RMS Blocking Workshop Imperial College London, United Kingdom
October 2, 1979	Mr. Russell D. Hovanec "The Mean Upper Tropospheric Jet Streak; Associated Low Level Jet and Static Stability for Spring Season Colorado Cyclones"	The Eleventh Conference of Severe Local Storms Kansas City, Missouri
October 2, 1979	Dr. Yoshio Kurihara "Use of a Movable Nested-Mesh in the Numerical Modeling of the Atmosphere"	International Symposium "Ill-Posed Problems: Theory and Practice" University of Delaware Newark, Delaware
October 2, 1979	Dr. Bruce B. Ross "3-D Simulation of a Frontal Squall Line: Sensitivity Studies"	The Eleventh Conference of Severe Local Storms Kansas City, Missouri
October 15, 1979	Dr. Ngar-Cheung Lau "The Structure and Transport Properties of Transient Disturbances in the Northern Hemisphere Wintertime Circulation"	Department of Meteorology University of Wisconsin Madison, Wisconsin

*Not included in FY-79 Report.

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TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1979 through September 30, 1980

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
October 16, 1979	Mr. Douglas Hahn "Simulation of Atmospheric Variability"	Climate Diagnostics Workshop University of Wisconsin Madison, Wisconsin
October 16, 1979	Dr. Isaac Held "Linear Equilibrium Climatic Responses to Orbital Parameter Variations"	Symposium on Empirical and Model Assisted Diagnosis of Climate and Climate Change Tbilisi, USSR
October 18, 1979	Dr. Ngar-Cheung Lau "The Three-Dimensional Structure of Monthly Anomalies Appearing in a 15-Year Simulation of a GFDL General Circulation Model"	Fourth Annual Climate Diagnostics Workshop Madison, Wisconsin
October 18, 1979	Dr. Jerry D. Mahlman "On the Proposed Discontinuation of Various Stratospheric Monitoring Efforts"	Presented to the Climate Research Board of the National Research Council Washington, D.C.
October 24, 1979	Mr. Robert Tuleya 1) "Initialization of Tropical Vortices Utilizing a Nested Model" 2) "Parameterization of Diabatic Heating in Tropical Cyclone Models"	Tropical Cyclone Initialization Workshop National Meteorological Center Camp Springs, Maryland
October 30, 1979	Mr. Ronald J. Stouffer "A CO_2 Sensitivity Study with a Mathematical Model of the Global Climate"	WMO Meeting on CO_2 Research in U.S.A. Environmental Research Laboratory Boulder, Colorado

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TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1979 through September 30, 1980

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
November 1, 1979	Dr. Kirk Bryan "Joint Ocean-Atmosphere Models - Some Recent Results"	U.S. GARP Meeting on Ocean Models for Climate Research NCAR Boulder, Colorado
November 2, 1979	Dr. Gareth P. Williams "The Jovian Quasi-Geostrophic Response"	Rotating Fluids Workshop University College London, United Kingdom
November 9, 1979	Dr. Ngar-Cheung Lau "The Structure and Transport Properties of Transient Disturbances in the Northern Hemisphere Wintertime Circulation"	NASA/Goddard Institute for Space Studies New York, New York
November 12, 1979	Dr. Ngar-Cheung Lau "The Structure and Transport Properties of Transient Disturbances in the Northern Hemisphere Wintertime Circulation"	Department of Atmospheric Sciences State University of New York Albany, New York
November 15, 1979	Dr. Ngar-Cheung Lau "The Structure and Transport Properties of Transient Disturbances in the Northern Hemisphere Wintertime Circulation"	Department of Meteorology Florida State University Tallahassee, Florida
November 16, 1979	Dr. Charles T. Gordon "Extended Range Experimental Prediction of the January 1977 Winter Event"	University of Wisconsin Madison, Wisconsin

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TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1979 through September 30, 1980

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
November 16, 1979	Dr. Isidoro Orlanski "Equilibrium Spectra for I.G.W., Numerical Experiments"	Harvard University Cambridge, Massachusetts
November 16, 1979	Dr. Gareth P. Williams "Comparison of the Meteorologies of Earth and Jupiter"	Reading University Reading, United Kingdom
November 23, 1979	Dr. Gareth P. Williams "Connection Between the Meteorologies of Earth and Jupiter"	Exeter University Exeter, United Kingdom
November 29, 1979	Dr. Joseph Smagorinsky "Carbon Dioxide and Climate: A Continuing Story"	Inaugurative Meeting of the Meteorological Society of New Zealand Wellington, New Zealand
November 30, 1979	Dr. Gareth P. Williams "Climate Variability on Earth and Jupiter"	Cambridge University Cambridge, United Kingdom
December 3, 1979	Dr. Kikuro Miyakoda 1) "Simulation of 1976/77 Winter Event with One-Month Integration of Various GC Models" 2) "FGGE 4-Dimensional Analysis System at GFDL"	XVII General Assembly of IUGG Canberra, Australia
December 3, 1979	Dr. Isidoro Orlanski "Energy Transfer Among Internal Gravity Modes: Weak and Strong Interactions"	XVII General Assembly of IUGG Canberra, Australia

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TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1979 through September 30, 1980

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
December 3, 1979	Dr. Abraham H. Oort "Observed Variability in the Atmosphere"	Institute for Space Studies New York, New York
December 3, 1979	Dr. George Philander 1) "The Equatorial Undercurrent Revisited" 2) "Initial Results from EPOCS"	XVII General Assembly of IUGG Canberra, Australia
December 4, 1979	Mr. Jeffrey J. Ploshay "A Description of the FGGE Data Processing System at GFDL"	National Meteorological Center Development Division Camp Springs, Maryland
December 5, 1979	Dr. Jerry D. Mahlman 1) "Three-Dimensional Tracer Structure and Behavior as Simulated in Two Ozone Precursor Experiments" 2) "On the Applicability of Large-Scale Atmospheric Models in Sun-Weather Relationships"	XVII General Assembly of IUGG Canberra, Australia
December 6, 1979	3) "Recent Results from the GFDL Troposphere-Stratosphere-Mesosphere General Circulation Model" 4) "Coupling of Atmospheric Observations with Comprehensive Numerical Models"	
December 18, 1979	Dr. Kikuro Miyakoda 1) "The Variation of Sea Surface Temperature in 1[illegible]6 and 1977, Part I. The Data Analysis" 2) "P[illegible]t II, The Characteristics of Spatial and Temporal Variability"	Australian/New Zealand GARP Symposium Melbourne, Australia

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TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1979 through September 30, 1980

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
January 22, 1980	Dr. Syukuro Manabe "Will Increased CO_2 Production Influence Climate"	Quaternary Research Center University of Washington Seattle, Washington
January 30, 1980	Dr. Hiram Levy, II "Influence of Solar Variability on Atmospheric Chemistry"	Annual Meeting of the American Meteorological Society Los Angeles, California
February 4, 1980	Dr. George Philander "On El Nino"	EPOCS Meeting Boulder, Colorado
February 6, 1980	Dr. Ngar-Cheung Lau "The Structure and Transport Properties of Transient Disturbances in the Northern Hemisphere Wintertime Circulation"	NASA/Goddard Laboratory for Atmospheric Science Greenbelt, Maryland
February 7, 1980	Dr. Ngar-Cheung Lau "The Three-Dimensional Structure of Monthly Anomalies Appearing in a 15-Year Simulation of a GFDL General Circulation Model"	Department of Meteorology and Physical Oceanography Rutgers University New Brunswick, New Jersey
February 11, 1980	Dr. Joseph Smagorinsky 1) "Simulation Capab ility of General Circulation Models" 2) "Monthly Numerical Prediction"	Workshop on Drought Forecasting for Northeast Brazil São José Dos Campos-SP, Brazil

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DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
March 9, 1980	Dr. Joseph Smagorinsky 1) "An Experiment in 30-Day Prediction: January 1977" 2) "Carbon Dioxide and Climate" 3) "Natural Variability of Climate Simulations"	Course on Climatic Variations: Facts and Causes International School of Climatology Erice, Sicily
March 13, 1980	Dr. Isaac Held "What Determines the Meridional Extent of the Hadley Cell"	Florida State University Tallahassee, Florida
March 14, 1980	Dr. Kirk Bryan "A Model of the Southern Ocean Circulation"	Harvard University Center for Earth & Planetary Physics Boston, Massachusetts
March 14, 1980	Dr. Isidoro Orlanski "Cross Stream Circulation in Atmospheric Fronts"	Laboratory of Atmospheric Research University of Illinois Champaign, Illinois
March 25, 1980	Dr. Abraham H. Oort "Atmosphere, Oceans and the Rotation of the Earth"	The New York Academy of Sciences New York, New York
April 14, 1980	Dr. Kikuro Miyakoda "One-Month Simulation of a Great Blocking Event in January 1977"	Institute for Space Studies Goddard Space Flight Center New York, New York

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April 21, 1980	Dr. Isaac Held "Heat Fluxes in a Turbulent Quasi-Geostrophic Flow"	Harvard University Cambridge, Massachusetts
April 23, 1980	Dr. Ngar-Cheung Lau "A Diagnostic Study of the Local Sources and Sinks of Momentum, Kinetic Energy, Vorticity and Heat in the Observed Northern Hemisphere Wintertime Circulation"	European Centre for Medium Range Weather Forecasts Reading, England
April 30, 1980	Mr. Michael D. Cox "A Numerical Stability Analysis of Equatorial Mean Flows"	Equatorial Theoretical Panel Meeting Tallahassee, Florida
April 30, 1980	Dr. George Philander 1) "On El Nino" 2) "The Oceanic Response to Large-Scale Atmospheric Disturbances"	INDEX Meeting Florida State University Tallahassee, Florida
May 9, 1980	Dr. Jerry D. Mahlman "Relationship of Atmospheric Observations to Comprehensive Numerical Models"	Aeronomy Laboratory/NOAA Boulder, Colorado
May 13, 1980	Dr. Stephen B. Fels "Tidal Motions in Venusian Stratosphere"	NASA/Goddard Space Flight Center Institute for Space Studies New York, New York
May 16, 1980	Dr. Abraham H. Oort "The Role of the Oceans in the Earth's Heat Balance"	Applied Physics Laboratory John Hopkins University Laurel, Maryland

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June 16, 1980	Dr. Kirk Bryan "Modelling and Monitoring Strategy"	North Atlantic Pilot Ocean Monitoring Study NAPOMS Meeting Institute of Oceanographic Science Wormley, England
June 24, 1980	Dr. Syukuro Manabe "Climatic Effect of an Increase in the CO_2 Concentration in the Atmosphere"	JASON Study Meeting on CO_2 La Jolla, California
June 24, 1980	Dr. George Philander "Response of Equatorial Oceans to Periodic Forcing"	North Carolina State University Department of Oceanography Raleigh, North Carolina
July 7, 1980	Dr. Ngar-Cheung Lau "The Influence of Orography on the Northern Hemisphere Wintertime Circulation as Identified by Two Long-Term Integrations of a General Circulation Model"	Joint Institute for the Study of Atmosphere and Ocean University of Washington Seattle, Washington
July 8, 1980	Dr. Isaac Held "Quasi-Geostrophic Turbulence and Baroclinic Eddy Heat Fluxes"	Joint Institute for the Study of the Atmosphere and Ocean University of Washington Seattle, Washington
July 9, 1980	Dr. Tony Gordon "Sensitivity of Radiation Diagnostics to Zonal Mean vs. Zonally Assymmetric Cloud and Water Vapor Distributions"	Penn State University University Park, Pennsylvania

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July 15, 1980	Dr. Abraham H. Oort "Oceanic Heat Transport"	Colorado State University Fort Collins, Colorado
July 28, 1980	Dr. Jerry D. Mahlman "Modeling the Middle Atmosphere: Progress and Problems"	International Symposium on Middle Atmospheric Dynamics Transport University of Illinois at Urbana Urbana, Illinois
July 28, 1980	Dr. Abraham H. Oort "Ocean Heat Transport"	Florida State University Tallahassee, Florida
July 29, 1980	Dr. Stephen B. Fels "Stratospheric Sensitivity to Perturbations in Ozone and Carbon Dioxide: Radiative and Dynamical Response"	International Symposium on Middle Atmosphere Dynamics and Transport Urbana, Illinois
July 29, 1980	Dr. C. F. Hsu "Air Parcel Motions During a Simulated Sudden Stratospheric Warming"	International Symposium on Middle Atmosphere Dynamics and Transport Urbana, Illinois
July 30, 1980	Mr. Kevin Hamilton 1) "The Holton-Lindzen Model of the Quasi-Biennial Oscillation in the Presence of Several Waves" 2) "Effects of Atmospheric Tides on the General Circulation of the Stratosphere, Mesosphere and Lower Thermosphere"	MAP Symposium on Middle Atmosphere Dynamics and Transport Urbana, Illinois

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August 4, 1980	Dr. Hiram Levy "A Three-Dimensional Numerical Model of Atmospheric N_2O"	International O_3 Symposium Boulder, Colorado
August 11, 1980	Mr. Daniel Schwarzkopf "Non-Lorentzian and Weak Line Effects on CO_2 15μm Transmissivities"	International Radiation Symposium Fort Collins, Colorado
August 11, 1980	Mr. Richard Wetherald "A Simulation of Cloud Cover with a Global General Circulation Model (IRS)"	1980 International Radiation Symposium Colorado State University Fort Collins, Colorado
August 12, 1980	Dr. Kikuro Miyakoda "One-Month Weather Prediction Experiment"	United Kingdom Meteorological Office Bracknell, England
August 15, 1980	Dr. Kikuro Miyakoda 1) "Simulation of the Blocking Event in January 1977" 2) "Prediction Experiment of the Sea Surface Temperature with an Integral and a Turbulent Closure Mixed Layer Model" 3) "The 4-Dimensional Analysis of the GATE Data Set"	European Centre for Medium-Range Weather Forecasts Reading, England
August 26, 1980	"Prediction Experiment of the Sea Surface Temperature with an Integral and a Turbulent Closure Mixed Layer Model"	University of Belgrade Belgrade, Yugoslavia
September 2, 1980	"One-Month Weather Prediction Experiment"	World Meteorological Organization Geneva, Switzerland

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September 17, 1980	Dr. George Philander "Physics of the Upper Tropical Ocean"	GATE Meeting: WMO/ICSU Kiev, USSR