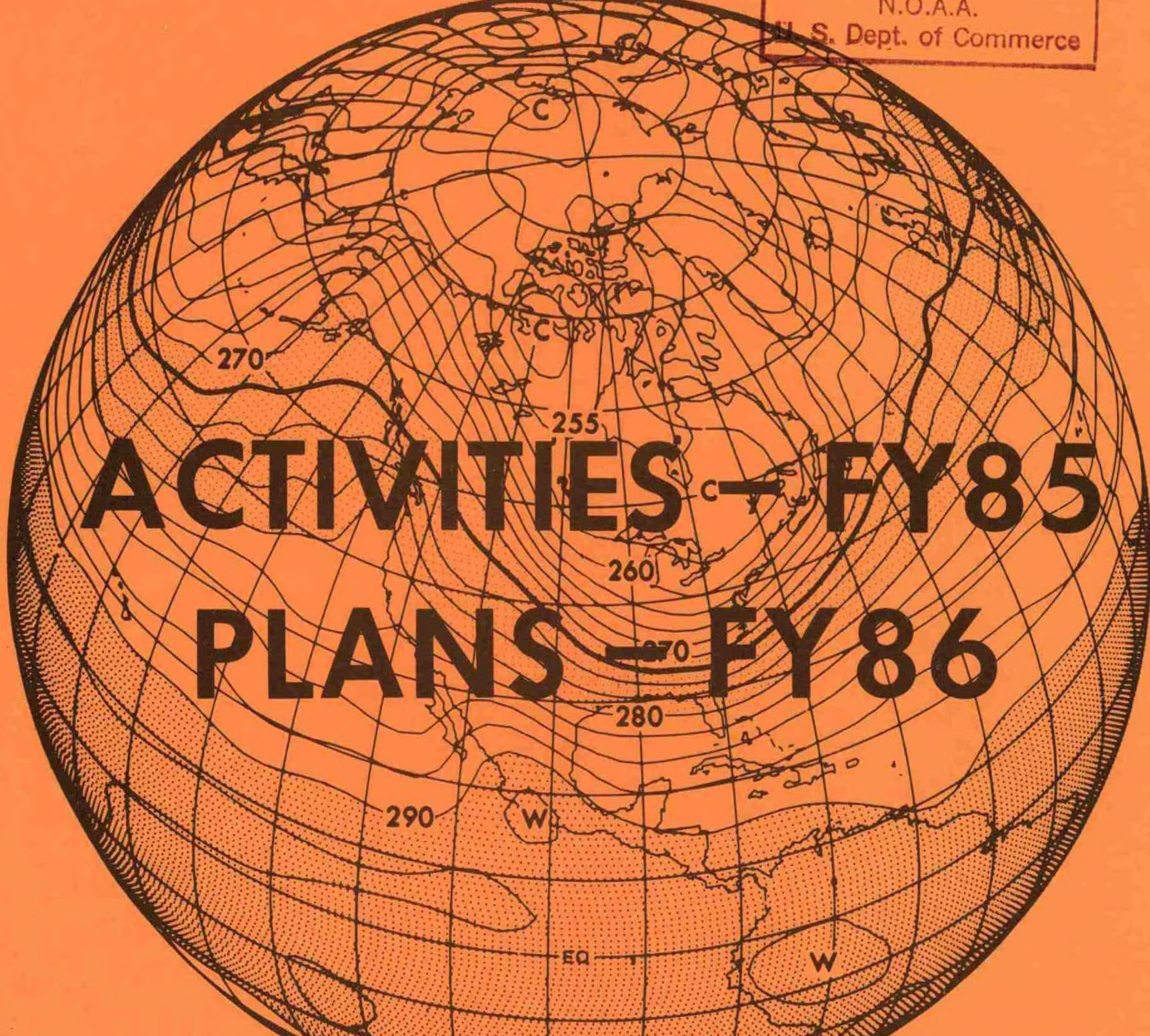
GEOPHYSICAL FLUID DYNAMICS LABORATORY



ACTIVITIES — FY85
PLANS — FY86

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories

GEOPHYSICAL FLUID DYNAMICS LABORATORY

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September 1985

Geophysical Fluid Dynamics Laboratory
Princeton, New Jersey

UNITED STATES DEPARTMENT OF COMMERCE

Malcolm Baldrige, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Environmental Research Laboratories

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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.

It has been prepared within GFDL and its distribution is primarily limited to GFDL members, to interested offices of the National Oceanic and Atmospheric Administration, and to other relevant government agencies and national organizations.

The organization of the document encompasses an overview, project activities and plans for the current and next fiscal years and appendices. The overview covers highlights of the five major research areas that correspond to NOAA's mission in oceanography and meteorology: Weather Service; Climate; Atmospheric Quality; Marine Quality; Ocean Service. These are five of the NOAA categories (bins) for research activities. The body of the text describes 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; and Convection and Turbulence. These categories, which correspond to the internal organization of research groups are different from the NOAA bins 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 1985; a bibliography of relatively recent 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 FY86; a listing of seminars presented at GFDL during Fiscal Year 1985; a list of seminars and talks presented during Fiscal Year 1985 by GFDL staff members and affiliates at other locations.

Although the specific names of individuals are not generally given in the overview, 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 or the names listed in the body of the text.

The 1985 Annual Report was co-edited by Ngar-Cheung Lau and Betty M. Williams.

September 1985

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AN OVERVIEW

SCOPE OF THE LABORATORY'S WORK

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

The goal is to expand the scientific understanding of these 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 experiment 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.

The following sections of the Annual Report describe the GFDL contribution to five major research areas that correspond to NOAA's mission in oceanography and meteorology.

HIGHLIGHTS OF FY85

and

IMMEDIATE OBJECTIVES

In this section, some research highlights are listed that may be of interest to those persons less concerned with the details of GFDL research. Selected are items that may be of special significance or interest to a wider audience.

Items in this section are placed in the NOAA emphasis categories of Weather Service, Climate, Atmospheric Quality, Marine Quality, and Ocean Service. These categories are organized rather differently than the GFDL research project areas presented in the main body of the report. References to more detailed discussions are given in parentheses.

I. WEATHER SERVICE

GOALS

During the past two decades synoptic-scale weather forecasts have improved considerably because of the development of numerical models that include more of the physical processes of the atmosphere, that have high spatial resolution, and that parameterize turbulent processes more accurately. Successful forecasts for periods up to a few days are now possible, and the limits of atmospheric predictability have been extended to several weeks; however, quantitative precipitation forecasts remain elusive. For smaller spatial scales, there has been considerable progress in determining the mechanisms that generate severe storms, in explaining how mesoscale phenomena interact with the large-scale flow, and in simulating the genesis, growth, and decay of hurricanes.

This success in the extension of atmospheric predictability encourages us to pose more challenging questions. Can the weather be predicted on time-scales of months? Are mesoscale weather systems and regional scale precipitation patterns predictable, and if so, is the accuracy dependent on the prediction of the ambient synoptic flow? Research to develop mathematical models for improved weather prediction will also contribute to the understanding of such fundamental meteorological phenomena as fronts, hurricanes, severe storms, and tropospheric blocking.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY85)

* An extended series of 30-day forecasts using numerical models have been completed for evaluating the feasibility of long-range prediction. The score statistics for 8 January cases show an encouraging degree of predictive skill for the time averaged flow in the 20-30 day range. To attain useable skill levels, however, it has been necessary to subtract the model's known climatic bias from the forecasts. This study marks the first quantitative demonstration of predictive skill by numerical models in the monthly forecast range (3.5)[1]

* A new National Meteorological Center (NMC) spectral medium range forecasting model has been developed by including the GFDL subgrid scale physics package. In quasi-operational runs launched during January, 1985, the useful forecast range has been extended from about 4.5 days to about 6 days. This represents a breakthrough in forecast accuracy, as compared to the existing operational model. This has now become the NMC operational model (3.6).

* An analytical theory of the distribution of eddy fluxes along storm tracks has been developed. The theory is based on baroclinic instability of zonally varying flows, and reproduces many of the features in the observations (3.2.1).

[1] Section number in this report

* It has been shown that the response of a baroclinic atmosphere to a pulsating localized forcing consists of a baroclinic wavetrain which amplifies with distance downstream of the source, in addition to the more familiar equivalent-barotropic Rossby wavetrains. The amplification rate is appreciable even at quite low frequencies. This spatial instability has implications for the nature of low frequency atmospheric variability (3.2.1).

* The effects of mountainous islands on the behavior of tropical cyclones were investigated. Three regions of high tropical cyclone frequency were selected: Caribbean Sea region, Taiwan, and Luzon, Philippines. Results show that the storm's track and speed can be significantly affected by island mountains. The intensity change upstream of islands can be caused by the advection of relatively dry air from the land. These and other results suggest that inclusion of detailed topography and accurate treatment of boundary layer processes are important for the prediction of tropical cyclones (7.1.1).

* A forecast study of the genesis of Hurricane David, 1979, is in progress. The analysis shows that latent heat release is a necessary process even at the storm genesis stage. The distribution of computed rainfall intensity compared favorably with the cloud satellite imagery. Also, the movement of the model storm for 72 hours was in fairly good agreement with the observed track. These preliminary results provide encouragement for further exploration of the forecasting skill of the hurricane model (7.1.2).

* A study of the evolution of mesoscale disturbances on a mean baroclinic state has demonstrated the importance of localized surface heating in producing the rapid development of short baroclinic waves. These waves have a depth on the order of the boundary layer and horizontal scales of a few hundred kilometers. In the presence of moisture, the waves will explosively develop into an intense meso-cyclone due to latent heat release (8.1.1).

* Successful prediction of the Presidents' Day snowstorm (18-20 February 1979) has been made using the limited-area (HIBU) model nested in a global spectral model. Starting from coarse initial conditions, a mesoscale disturbance developed with the aid of strong surface sensible and latent heating. This disturbance rapidly intensified through latent heat release. Varying the initial and boundary conditions had only minor effects on the model solutions. However, a higher model resolution was required in order to produce accurate forecasts of the storm's structure, intensity, and position (8.2).

* The stability analysis of a linear representation of a convectively unstable cloud region and its stably-stratified, subcloud layer indicates some of the parameters which determine the structure of low-level updrafts associated with convective systems. A simple relationship has been found between the vertical convergence field and characteristics of the stable lower layer which allows one to predict whether a single (vertical) or dual (upshear sloping) updraft will occur in the subcloud layer (8.3.1).

* Four-hour numerical simulations have been carried out for a north-south squall line observed on May 22, 1976, in west-central Oklahoma. In this calculation a line of precipitation extended in a nearly unbroken form across the 32 km north-south domain of the model. The propagation speed of the line,

the surface cooling behind the gust front and the point values of precipitation were in reasonable agreement with the observed values. In all simulations a significant down-gradient vertical momentum flux was found in regions with strong shear in the zonal wind component. This preliminary result suggests that GCM parameterizations of moist convection should include the effect of vertical momentum transfer (9.1.1).

SOME PLANS FOR FY86

* A variety of approaches in the wave amplification and cyclogenesis problem will be carried out using analytical and numerical techniques.

* Numerical models will be under continual development to improve forecasting of the large scale, the mesoscale, hurricanes, and squall lines, with emphasis on improved parameterizations.

* Diagnostic analysis will be employed to improve understanding of these shorter range processes.

II. CLIMATE

GOALS

The purpose of climate related research at GFDL is twofold: to describe, explain and simulate climate variability on time-scales from seasons to millennia; and to evaluate the climatic impact of human activities such as the release of CO_2 and other gases in the atmosphere. The phenomena that are studied include: large-scale wave disturbances, and their role in the general circulation of the atmosphere; the seasonal cycle, which must be defined before departures from the seasonal cycle (interannual variability) can be understood; interannual variability associated with phenomena such as the Southern Oscillation-El Niño; very long-term variability associated with the ice ages; and the meteorologies of various planets, the study of which enhanced our perspective on terrestrial meteorology and climate. To achieve these goals, both observational and theoretical studies are necessary. Available observations are analyzed to determine the physical processes by which the circulations of the oceans and atmospheres are maintained. Mathematical models are constructed to study and simulate the ocean, the atmosphere, the coupled ocean, atmosphere and cryosphere system, and various planetary atmospheres.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY85)

* The geographical distribution of soil moisture change in response to an increase of atmospheric CO_2 has been investigated by use of an atmospheric GCM coupled with a simple model of the mixed-layer ocean. The results of this study indicate that, during summer, soil moisture is expected to be reduced over extensive regions of the North American and Eurasian continents in middle and high latitudes (1.1.1).

* The climate of the last glacial maximum was simulated using two versions of a coupled atmosphere-mixed layer ocean model with fixed and predicted cloud cover. In both versions, the reduced glacial CO_2 concentration as inferred from ice core measurements was incorporated. A comparison of these

experiments with a variety of paleoclimatic data indicates reasonably good agreement in simulating the ice age cooling over both oceans and continents, suggesting that these models may be used with increased confidence (1.2.1).

* The atmosphere-mixed layer ocean model has been used to study the individual contributions of expanded continental ice, reduced atmospheric CO_2, and vegetation-induced changes in land albedo to the maintenance of the cold climate of the last glacial maximum. The expanded continental ice sheets are found to make the largest contribution to the ice age cooling on a global basis, with the reduced CO_2 making an important additional contribution, especially in the Southern Hemisphere (1.2.2).

* Linear simulations of the interannual variability produced by a GCM suggest that anomalous transient eddy fluxes are of greater importance than anomalous heating or orographic forcing in generating the anomalous extratropical stationary waves in El Nino years. These results reveal that the transient disturbances portray a much more dominant role in atmospheric interannual variability than has heretofore been speculated (1.3.2).

* Space-time spectral analysis of a spectral GCM indicates that the tropical 40-day oscillations are qualitatively well simulated, although the simulated amplitude is somewhat smaller than that based on FGGE IIIb data (1.4.1). Further statistical analyses indicate that this tropical phenomenon is linked to circulation features in the wintertime extratropics, as well as to the summer monsoon over South Asia (6.1.4).

* Experiments using a GCM with a zonally uniform surface indicates that wave-wave energy transfer is an important source of energy for transient ultralong waves in their growing stage, whereas this transfer plays a less important role in their mature stage (1.4.2).

* A global coupled ocean-atmosphere model with realistic topography and annual mean insolation has been time integrated to an equilibrium solution. The simulation of the coupled system by this model is found to be substantially superior to a previous simulation by a model with relatively lower resolution and higher subgrid scale viscosity (1.6.1).

* The new experimental 1° latitude version of the SKYHI troposphere-stratosphere-mesosphere general circulation model has achieved some important advances in simulation capability in all regions of the atmosphere. These advances have allowed planning for future applications in climate and in atmospheric chemistry. The most notable improvements include: stratosphere winter polar cold bias, tropospheric jet stream location, tropical zonal winds, surface pressure, eddy kinetic energy and planetary wave amplitudes, cyclone dynamics, tropical tropopause temperatures, the mesoscale energy spectrum, and interaction between gravity-wave and planetary scales (2.2.2 and 2.2.3).

* The first large-scale modeling attempt to evaluate directly the effect of gravity waves on planetary scale flows has been completed. Using a 3° latitude version of the SKYHI model, the analysis shows that gravity waves moving with phase speeds similar to the large scale flow are strongly absorbed in the lower stratosphere. The remaining waves propagate to the upper stratosphere and lower mesosphere where they are absorbed mainly by turbulent

dissipation. This absorption acts to produce strong decelerations of both easterly and westerly flows, in addition to providing a strong damping on the planetary waves. Preliminary testing with the 1° latitude SKYHI model indicates even stronger effects, suggesting that these effects are even stronger in the actual atmosphere (2.2.4).

* A coupled ocean-atmospheric model indicates a new feedback mechanism in the response of the climate system to an increase of greenhouse gases. For large perturbations from equilibrium, a climate warming produces a partial collapse of the ocean's thermohaline circulation. This allows the ocean to sequester more heat than would be possible for a normal circulation, augmenting the delaying effect of the ocean on climate response to a CO_2-induced warming (4.3).

* An equation capable of describing all scales of geostrophic motion and the interactions between such motions in high and low latitudes has been obtained. This formulation has proven useful for defining and describing oceanic and Jovian eddies and currents on planetary, intermediate and synoptic scales (5.1.1).

* Solitary coherent vortices resembling Jupiter's great Red Spot have been simulated for periods in excess of a century and some of the factors controlling their genesis have been isolated. These factors include the inhomogeneity of the initial perturbation, the width and criticality of the shear zone, and the history of the interactions (5.1.1).

* On the basis of the observed semi-diurnal tidal radiances, the presence of a strong midlatitude jet at about 75 km in the Venus atmosphere was deduced from theoretical considerations for the first time. This is very significant because it is impossible to observe the mean wind structure of Venus directly using existing instruments (5.2).

* Global computations of the observed divergence of water vapor show that the strongest source of water vapor is located over the eastern Arabian Sea during the summer months. The evaporation over this region (with maximum values of up to 100 cm/month) must be a very important source of water vapor for the Indian monsoon, probably exceeding the supply of Southern Hemisphere water vapor carried toward India by the Somali jet system (6.1.2).

SOME PLANS FOR FY86

* Detailed analyses of important budgets for an earth warmed by a greenhouse gas and an earth during the ice age will be underway.

* Model development will continue in a number of climatically important areas. These include: a coupled atmosphere-ocean system, the stratosphere, higher computational resolution, radiative transfer, subscale closure, and sources of remaining climatic biases in the various models.

* Many diagnostic and theoretical analyses will be undertaken on transient and standing flows as well as their interaction. Diagnostic analysis will continue with emphasis on global dynamical climatology, as well as an increased emphasis on regional problems such as those of the southern hemisphere, polar regions, southeast Asia and the central Pacific.

* The GFDL work on details of ocean climate will continue.

III. ATMOSPHERIC QUALITY

GOALS

The main goal of atmospheric quality research at GFDL is to understand the formation, transport, and chemistry of atmospheric trace constituents on regional and global scales. Such understanding requires judicious combinations of theoretical models and specialized observations. The understanding gained will be applied toward evaluating the sensitivity of the atmospheric chemical system to human activities.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY85)

* A series of model experiments which explore the global impact of the North American combustion sources of reactive nitrogen (NO_x) have been completed. This problem is of special concern because of its possible impact on the chemistry of ozone in the "unpolluted" troposphere, in addition to its well recognized role in the "acid rain" problem. Preliminary conclusions from this work suggest that about 50% of the combustion source returns directly to the source region as dry deposition, 25% returns through rainout, and about 25% is exported to more remote regions (2.1.2).

* For the first time, a two-dimensional (2-D) tracer transport model has been constructed that successfully reproduces zonally averaged results from its "parent" 3-D transport model. The transport coefficients and meridional circulations are derived from the 3-D model in a completely self consistent manner. These data sets were then used to assemble a 2-D model capable of running completely independent of the 3-D model. This process has provided fundamental new insights into the transport mechanisms acting in the 3-D model. A number of 2-D model comparisons with the 3-D model yield generally excellent results. This methodology is already being widely used throughout the chemical modeling community (2.1.4).

* The vertical mixing of passive tracers initially confined to the boundary layer has been examined. Calculations with a moist convection model have been carried out for a fully insoluble tracer and an infinitely soluble tracer. Present results indicate that significant amounts of the insoluble tracer can be advected into the upper troposphere due to the convection, whereas rainout of the soluble tracer prevents all but a small fraction of this tracer from reaching the upper atmosphere. Also, there is an indication that much more insoluble tracer is advected above the 6 km level due to line convection than by isolated cells (9.1.3).

SOME PLANS FOR FY86

* Work will continue on the regional/global transport, chemistry, and removal of chemically and climatically important trace gases. A self-determined ozone chemistry will be inserted into the SKYHI GCM.

* Moist chemical removal parameterization processes will be developed for use in convective and large scale models.

IV. MARINE QUALITY

GOALS

Research at GFDL related to the quality of the marine environment has as its objectives the simulation of oceanic conditions in coastal zones and in estuaries, the modeling of the dispersion of geochemical tracers (tritium, radon...) in the world oceans, and the modeling of the oceanic carbon cycle and trace metal geochemistry. For regional coastal studies two and three-dimensional models of estuaries such as the Hudson-Raritan and Delaware Estuaries are being developed. The response of coastal zones to transient atmospheric storms, and the nature of upwelling processes which are of great importance to fisheries, are being studied by means of a variety of models. Basin and global ocean circulation models are being developed for the study of the carbon cycle and trace metal cycling.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY85)

* The important role of persistent salinity anomalies in generating asymmetric interhemispheric ocean flows in the presence of symmetric forcing about the equator was demonstrated in a sector ocean general circulation model. This result is part of an ongoing study to understand what factors control the deep ocean circulation, how this might be affected by climate changes, and how ocean circulation changes will affect the carbon cycle (4.2).

* A seasonally driven model of the Atlantic Ocean developed for tracer studies shows a dramatic change in oceanic heat transport associated with the cycle of the North Equatorial Countercurrent. The model is being used to study the role of seasonality in thermocline and deep ocean ventilation (4.2).

* Studies of oceanic nutrient measurements have demonstrated the importance of diapycnal mixing processes in the Equatorial region and beneath the Mediterranean Sea salt tongue. The observations are being analyzed in order to develop a data base for the development of carbon cycle models (4.2).

* An observational and numerical modeling study of the Delaware Estuary has been launched in collaboration with NOS scientists. It was found that most but not all of the sea level variability due to winds can be calculated, even though the alongshore extent of the model shelf is limited (4.5).

SOME PLANS FOR FY86

* An effort will be initiated to incorporate biological effects in a coupled carbon cycle/ocean GCM.

* A wide range of analyses of ocean tracer data relative to ocean dynamical structure will continue.

V. OCEAN SERVICE

GOALS

A variety of models that can be used for the prediction of oceanic conditions are being developed at GFDL. The simpler models are capable of predicting relatively few parameters. For example, one-dimensional models of the turbulent surface layer of the ocean predict the sea surface temperature and heat content of the upper ocean. More complex three-dimensional models are being developed to study phenomena such as the time dependent development of Gulf Stream meanders and rings, the generation of the Somali Current after onset of the southwest monsoons, the response of coastal zones to atmospheric storms, and the development of sea surface temperature anomalies such as those observed in the tropical Pacific Ocean during El Niño-Southern Oscillation phenomena.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY85)

* A simple coupled ocean-atmosphere model indicates that El Nino conditions - high sea surface temperatures over the entire tropical Pacific Ocean, and weak trade winds - cannot persist indefinitely because the coupled system is unstable in this state. Perturbations will amplify and will restore horizontal sea surface temperature gradients, and intense tradewinds (4.1.1).

* A model of an idealized subtropical gyre circulation with steady external boundary conditions exhibits large scale, internally generated pulsations in the gyre structure on the time scale of years. These pulsations are accompanied by complex changes in the intensity and spatial distribution of convection and ventilation. Unexplained multi-year time dependence observed in ocean and climate systems may be related to this model simulated phenomenon (4.3).

SOME PLANS FOR FY86

* Detailed analysis of the behavior of ocean models will be underway with special emphasis on the new higher resolution models.

* Work will continue on ocean model development with emphasis on ice dynamics, turbulent closure, and isopycnal coordinates.

* Detailed comparisons of estuary model behavior against observations will be carried out.

PROJECT ACTIVITIES FY85

PROJECT PLANS FY86

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 and elucidate the physical and dynamical mechanisms which maintain climate and cause its variation.

* To evaluate the impact of human activities on climate.

1.1 CO_2 AND CLIMATE

K. Bryan M. J. Spelman
S. Manabe R. T. Wetherald

1.1.1 Hydrologic Response

ACTIVITIES FY85

In the past, investigations have been conducted on the change of the hydrologic cycle in response to an increase of atmospheric CO_2 concentration (393,473,at). Until recently, the main emphasis of these investigations has been placed on analyzing the seasonal change of zonal mean soil moisture. An effort is now being made to evaluate the geographical distributions of the change of soil moisture in response to an increase of atmospheric CO_2.

The model used for this research effort is an atmospheric general circulation model coupled with a static mixed layer ocean model. It has a global computational domain, seasonally varying insolation and predicted cloudiness. The response of the model climate to an increase of CO_2 concentration is evaluated by comparing two quasi-equilibrium climates which emerge from 40-year integrations of the model with normal and an above normal amounts of CO_2. To distinguish the CO_2-induced change from the large natural fluctuation of the model hydrology, it is necessary to time-average the results over a very long time period i.e., the last 10 year period of each 40-year integration.

Fig. 1.1a shows the geographical distribution of the change of soil moisture during the June-July-August period in response to a doubling of the CO_2 concentration in the model atmosphere. This figure indicates a CO_2-induced summer reduction of soil moisture over extensive regions of North America and Eurasia in middle and high latitudes. The present result is consistent with previous findings of zonal mean summer dryness. An analysis of the soil moisture budget indicates that the summer dryness results from the earlier initiation of the spring-to-summer reduction of soil moisture. This is caused by (1) an earlier termination of the spring snowmelt season due to CO_2-induced warming, and (2) an earlier termination of the spring rainy period due to a poleward shift of the middle latitude rainbelt. In addition, the summer dryness is enhanced further by the positive feedback process involving cloud cover and insolation over the land surface.

A Student's t-test is performed in order to evaluate the statistical significance of the geographical distribution of the changes shown in Fig. 1.1a. The results of this test are shown in Fig. 1.1b. This figure indicates that the areas of CO_2-induced summer dryness over North America and Eurasia are statistically significant at the 90% or higher confidence level. In contrast, most of the soil moisture changes in tropical latitudes and in the Southern Hemisphere are not statistically significant.

These results were obtained from a GCM with predicted cloud cover. However two other sets of numerical experiments were also conducted by use of

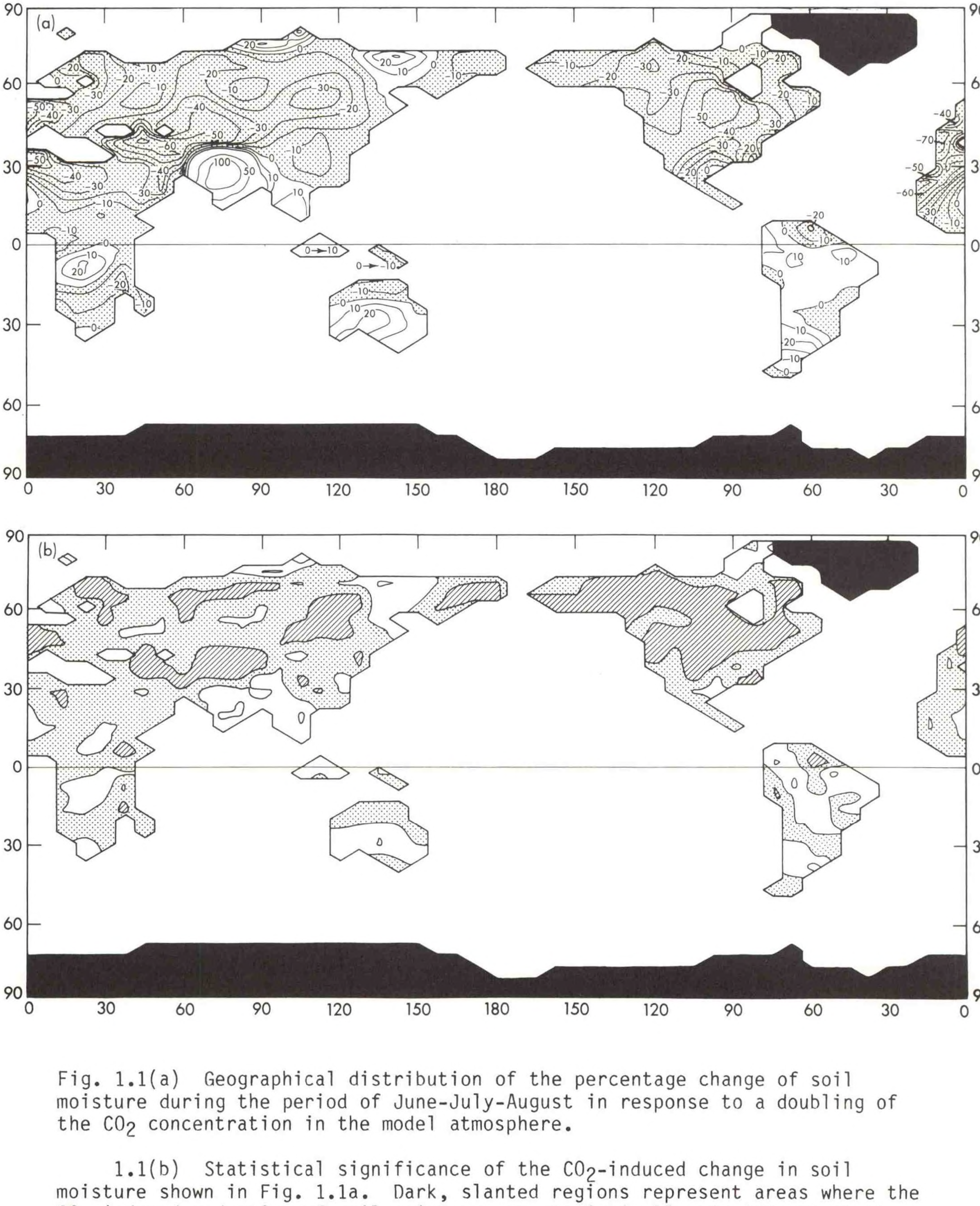

Fig. 1.1(a) Geographical distribution of the percentage change of soil moisture during the period of June-July-August in response to a doubling of the CO_2 concentration in the model atmosphere.

1.1(b) Statistical significance of the CO_2-induced change in soil moisture shown in Fig. 1.1a. Dark, slanted regions represent areas where the CO_2-induced reduction of soil moisture are statistically significant at the 90% or higher confidence level.

a model with a prescribed distribution of cloud cover; one for a doubling and the other for a quadrupling of CO_2. Preliminary analysis indicates that similar patterns of soil moisture reduction during the July-July-August period are obtained over North America and Eurasia from these experiments.

PLANS FY86

The detailed analysis of heat- and water balance will be conducted for four continental regions where soil moisture is reduced during summer in response to an increase of the CO_2 concentration in the atmosphere.

1.1.2 Cloud Feedback and Climate Sensitivity

ACTIVITIES FY85

The influence of cloud cover upon the sensitivity of climate has been the subject of many investigations. Unfortunately, it has been extremely difficult to acquire a coherent understanding of this subject because of the apparent contradiction among the results obtained from these studies. Therefore, an attempt has been made to review the results from several climate sensitivity experiments which have been conducted both in and outside of GFDL during the past several years. As the first step, the scope of this review has been limited to the change of cloud cover which occurs in response to an increase of either the solar constant or CO_2 concentration in the atmosphere. Detailed results from this review are available in (cp).

From this review, it has been found that the zonal mean profiles of the CO_2-induced changes of cloud cover from several experiments recently performed at GFDL, the Goddard Institute for Space Studies and the National Center for Atmospheric Research are qualitatively similar to the profile obtained from the earlier GFDL study (420). This earlier study utilized a simple GCM with a limited computational domain and idealized geography. For example, in all of the experiments, cloud cover decreased in the moist, convectively active regions such as the tropical and middle latitude rainbelts. On the other hand, it increased in the stable region near the model surface in high latitudes. In addition, cloud also increased in the lower model stratosphere. These features are evident in Fig. 1.2, which shows the zonal mean distribution of CO_2-induced cloud change in a GFDL model. The similarity among the results from a wide variety of models encourages one to explore further the physical mechanism responsible for the CO_2-induced cloud changes identified here.

PLANS FY86

According to the results from the numerical experiments recently conducted at GFDL, the sensitivity of the global model climate is significantly enhanced by the cloud feedback process. These results differ from the earlier findings of Wetherald and Manabe (420) which were obtained from a model with annual mean insolation and idealized geography. An extensive analysis will be conducted to determine the physical mechanisms responsible for the enhancement of the global model sensitivity by the cloud feedback process.

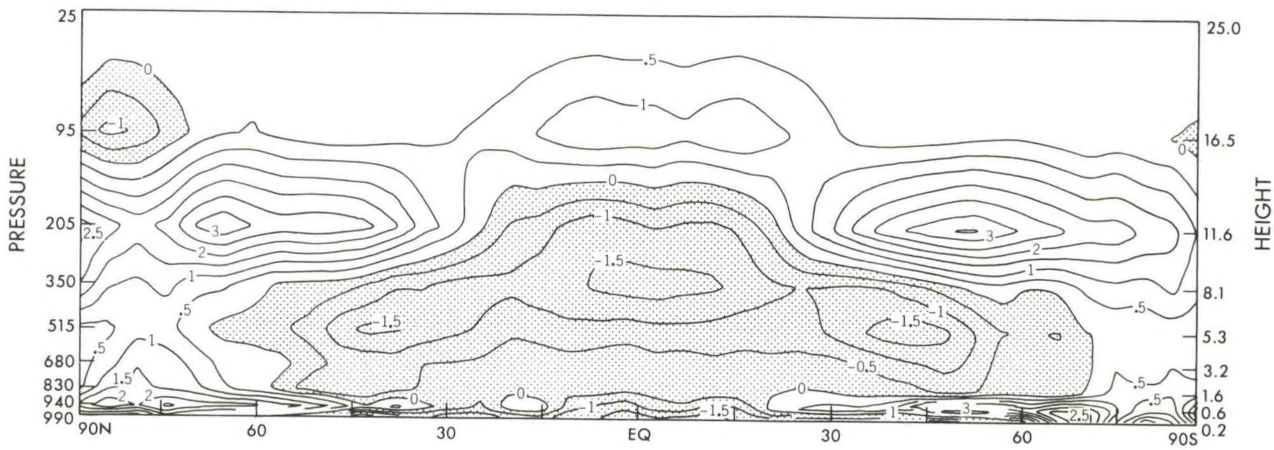

Fig. 1.2 Latitude-height distribution of the zonal mean change of cloud amount of a GFDL global model in response to a doubling of the CO_2 concentration in the atmosphere. The model consists of an atmospheric GCM and a simple mixed layer ocean. It has realistic geography and a seasonal variation of insolation. Results represent annual averages taken over 10 seasonal cycles. Units are in percent.

1.1.3 CO_2 and Paleoclimate

ACTIVITIES FY85

The preliminary results from this study were already discussed in the report of the preceding fiscal year. The study investigates the climatic effect of large changes of the CO_2 concentration in the atmosphere by use of a general circulation model of the coupled ocean-atmosphere system. In collaboration with the ocean circulation group of the laboratory, it was continued throughout this fiscal year.

Recent results from a computer model of the geochemical cycle suggest that the atmospheric concentration of carbon dioxide at the beginning of the Tertiary epoch was several-fold higher than the modern concentration (Berner et al., 1983).* On the other hand, the chemical analysis of air bubbles trapped in the Antarctic and Greenland ice sheets indicates that the atmospheric concentration was approximately 2/3 of the modern concentration at the last glacial maximum (Neftel et al., 1983).** To evaluate the climatic impact of such a large alteration in the CO_2-concentration, a series of climatic equilibria have been obtained for cases with 1/2, $1/\sqrt{2}$, 1, 2, 4 and 8 times the present CO_2 concentration in the atmosphere. As a simplification, the model has an annual mean insolation and an idealized geography.

The experiments indicate that the climatic change of the Cenozoic era as determined from the geologic record could be explained in terms of changes in atmospheric CO_2 concentration, although other causes cannot be eliminated.

The climate of one half normal CO_2 is markedly different from the normal and high CO_2 cases. Sea ice extends to middle latitudes and the thermohaline circulation in the model ocean loses its intensity and is largely confined to a limited area between the sea ice margin and the equator. The poleward heat transport by ocean currents is very small in high latitudes, thus markedly reducing the surface air temperature there. A similar weakening of thermohaline circulation, which enhances the positive albedo feedback effect of sea ice, may have played a key role in reducing surface air temperatures over the North Atlantic during the last glacial maximum. For further details, see (da).

PLANS FY86

It is desirable to conduct a similar study by use of a coupled ocean-atmospheric model with realistic geography. The development of a coupled

* Berner, R.A., A.C. Lasaga and R.A. Garrels, 1983: The carbonate-silicate geochemical cycle and its effect on atmospheric carbon dioxide over the past 100 million years. American Journal of Sciences, 283, 641-683.

** Neftel, A., H. Oeschger, B. Stauffer, and R. Zumbrunn, 1983: Ice core sample measurements give atmospheric CO_2 content during the past 40,000 yrs., Nature, 295, 220-222.

model, which is capable of simulating the observed behavior of the ocean and atmosphere, is in progress as described in Section 1.5.

1.2 ICE AGE CLIMATE

A. J. Broccoli   S. Manabe

ACTIVITIES FY85

1.2.1 Simulation of an Ice Age Climate

During the past year, an experiment was completed in which the climate of the last glacial maximum (i.e., ~18,000 years ago) was simulated using two versions of an atmosphere-mixed layer ocean model. The two versions differ in their treatment of cloud cover, with one version using a fixed cloud distribution and the other using a simple parameterization to predict clouds. These two models have been used previously to study CO_2-induced climate change, yielding significantly different results. In response to the doubling of atmospheric CO_2, the area mean surface air temperature of the variable cloud model increases by about 4°C, which is almost twice as large at the 2.3°C warming of the fixed cloud model. For the simulations of the last glacial maximum (LGM) climate, the surface air temperature of the variable cloud model is also more sensitive, yielding a cooling of 4.7°C as compared with the 3.5°C cooling produced by the fixed cloud model.

To simulate the LGM climate, both models were given the distributions of continental ice and surface albedo of the ice age along with the reduced glacial CO_2 concentration. In an effort to determine which of the two versions of the model is more realistic in its simulation of the LGM climate, the model results were compared with a variety of paleoclimatic data. Fig. 1.3 compares the geographical distribution of the LGM reduction in sea surface temperature (SST) from each of the models with paleoclimatic estimates assembled by the CLIMAP project* from microfossils in deep-sea sediments. Both models produce changes in SST that are similar to the CLIMAP estimates. Comparisons with paleotemperature data from the continents also indicate reasonably good agreement between the models and estimates of the LGM climate. However, it is difficult to determine which version of the model is more realistic in simulating the LGM climate because of uncertainties in the paleoclimatic data and the relatively small differences between the fixed and variable cloud results. Nevertheless, the similarity of the results from both models to the estimates of the LGM climate suggests that the models may be regarded with increased confidence in studies of the climate sensitivity (cu).

1.2.2 Factors Contributing to Ice Age Climate

The same atmosphere-mixed layer ocean model used to simulate the ice age climate was also used to study the individual contributions of expanded continental ice, reduced atmospheric CO_2, and vegetation-induced changes in

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* CLIMAP Project Members, 1981: Seasonal reconstruction of the earth's surface at the last glacial maximum. Geol. Soc. Am. Map Chart Ser., MC-36.

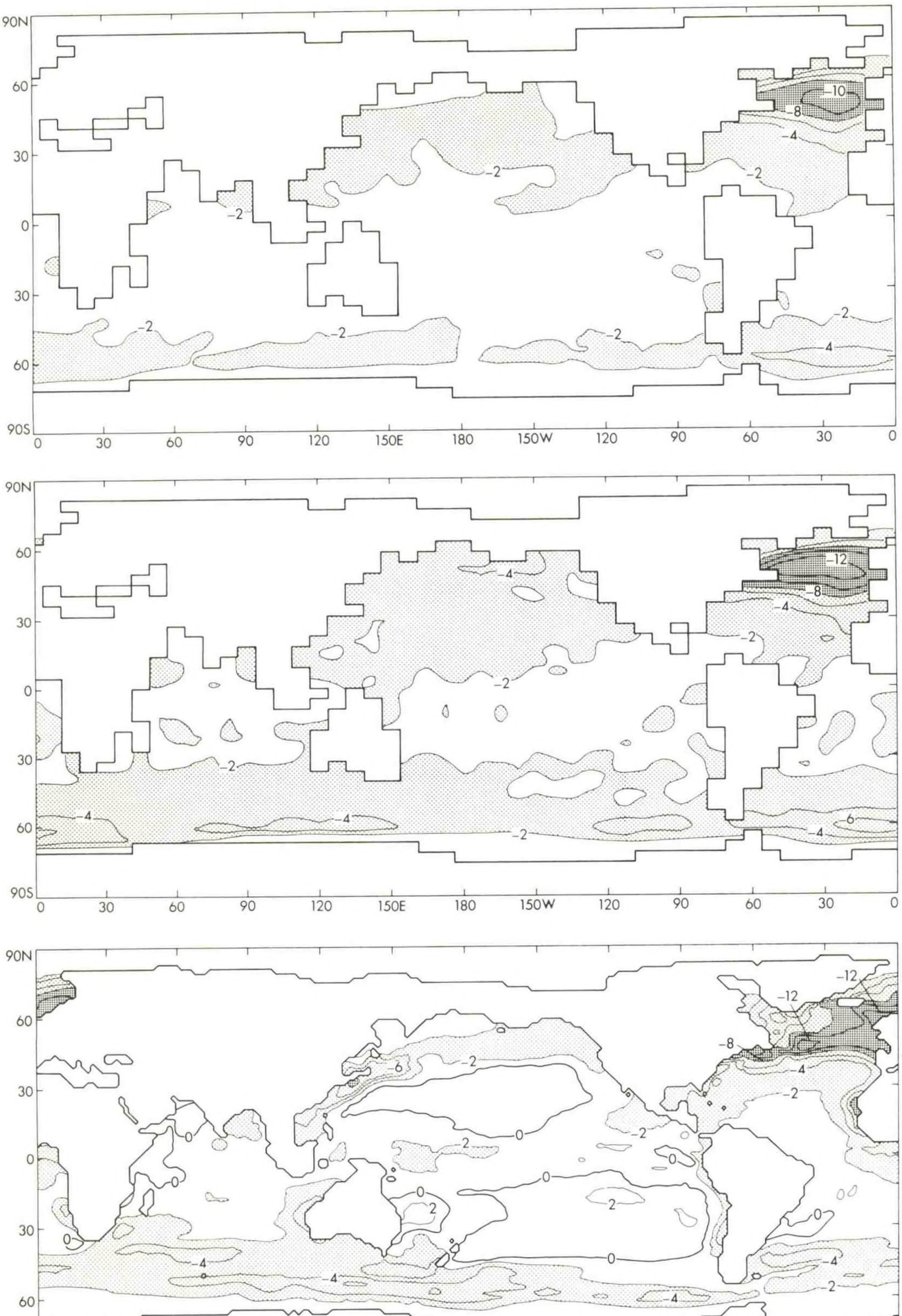

Fig. 1.3 Geographical distribution of sea surface temperature differences between the last glacial maximum and the present (degrees K). Top: fixed cloud model. Center: variable cloud model. Bottom: CLIMAP estimates.

land albedo to the maintenance of the cold climate of the last glacial maximum. A series of GCM experiments were run, with each experiment incorporating these changes in boundary conditions singly or in combination. The response of the model to a particular change in boundary conditions can be examined by comparing runs with and without that change.

A measure of the thermal response of the model to the various changes can be obtained by examining differences in surface air temperature. On a global basis, the expanded continental ice sheets make the largest contribution to the LGM cooling, with the effect of the reduction of atmospheric CO_2 being about two-thirds as large. The changes in land albedo have a relatively small effect on a global scale, although this factor may be quite important locally. As found in an earlier study (616), the ice sheet effect is much larger in the Northern Hemisphere where most of the increase in continental ice is found, with only a small influence on Southern Hemisphere temperature. The thermal response to reduced CO_2 is about the same in each hemisphere. In the Southern Hemisphere, the CO_2 reduction is the most important contributor to the LGM cooling, consistent with the hypothesis that a reduction in atmospheric CO_2 triggered by Northern hemisphere glaciation may be responsible for Southern Hemisphere cooling during glacial periods.

Analysis of the changes in atmospheric circulation associated with each of the changes in ice age boundary conditions are currently underway.

PLANS FY86

A more detailed analysis of the LGM simulation experiment is planned, including an evaluation of changes in hydrology and atmospheric circulation.

The changes in atmospheric circulation associated with each of the ice age boundary conditions will be analyzed.

1.3 STATIONARY EDDIES

I. M. Held	D. Neelin
I. S. Kang	R. Panetta
S. Lyons	R. Pierrehumbert

ACTIVITIES FY85

The comparison of stationary eddies produced by GCM's with those predicted by simpler linear and nonlinear models has evolved on four separate fronts:

1) modeling the climatological stationary eddies in Northern Hemisphere winter, using a linear primitive-equation model on the sphere;

2) modeling the interannual variability of the wintertime stationary eddies, using the same linear model as in 1);

3) modeling the low-level flow and the precipitation field in the tropics using a linear model on an equatorial beta-plane, given sea surface temperatures; and

4) modeling the tropical upper tropospheric streamfunction in NH summer, given the upper tropospheric divergence, using linear and nonlinear barotropic models on the sphere.

In each case, the GCM is treated as a surrogate atmosphere that provides the three-dimensional heating fields, transient eddy fluxes, etc., that make detailed analyses of this sort possible. From the failure or success of various idealized models in simulating a GCM, we evaluate the validity of the assumptions underlying these models. To the extent that a linear model is successful, one can decompose the total stationary flow field into parts forced by different orographic features, thermal sources, or transient eddy fluxes.

1.3.1 Climatological Stationary Eddies in NH Winter

Work is nearing completion on the simulation with linear models of the climatological wintertime stationary eddies produced by two GCM's: a "no-mountain" model with a flat lower boundary, and a "mountain" model with realistic orography. The simulation of the "no mountain" model is useful for evaluating the treatment of the critical-latitude singularity in such linear models, and for determining the relative importance of extratropical and tropical thermal forcing, without the complicating presence of the large orographically forced waves. The linear model underestimates the amplitude of the extratropical stationary eddies in the upper troposphere of the "no-mountain" model by 25-50%. Orographic forcing dominates in the "mountain" model in the extratropical middle and upper troposphere, and in these regions the linear model predicts the correct amplitudes for the stationary eddies. At low levels, the response to orography and to transient eddy fluxes are of comparable importance, with the direct response to heating playing a surprisingly secondary role outside of the tropics. The low level results for the "mountain" model are summarized in Figure 1.4.

1.3.2 Interannual Variability of Stationary Eddies in NH Winter

An identical linear model has been used to simulate the departures from climatology of the seasonal-mean flow field in individual winters of an extended GCM integration. This integration was performed with sea-surface temperatures prescribed over the Pacific Ocean as observed in a 15-year period encompassing four El Niño episodes (see Section 6.2.2). The linear model is able to capture a large fraction of the anomalous stationary wave pattern, particularly in the middle and upper troposphere in low and subtropical latitudes. Surprisingly, both the direct response to anomalous tropical thermal forcing and anomalous orographic forcing are of minor importance; the dominant term is the forcing by anomalous fluxes of heat and momentum by transient eddies. This is true even for the enhanced subtropical jet in the central Pacific in El Niño years, a feature that is generally thought of as directly forced by tropical heating. Since this extension of the jet over the Pacific is consistently produced by the GCM in El Niño years, and since the linear model consistently shows it to be forced by anomalous transient fluxes, it is clear that these transient fluxes must be responding to the sea-surface temperature anomalies. The mechanism by which this occurs remains to be clarified.

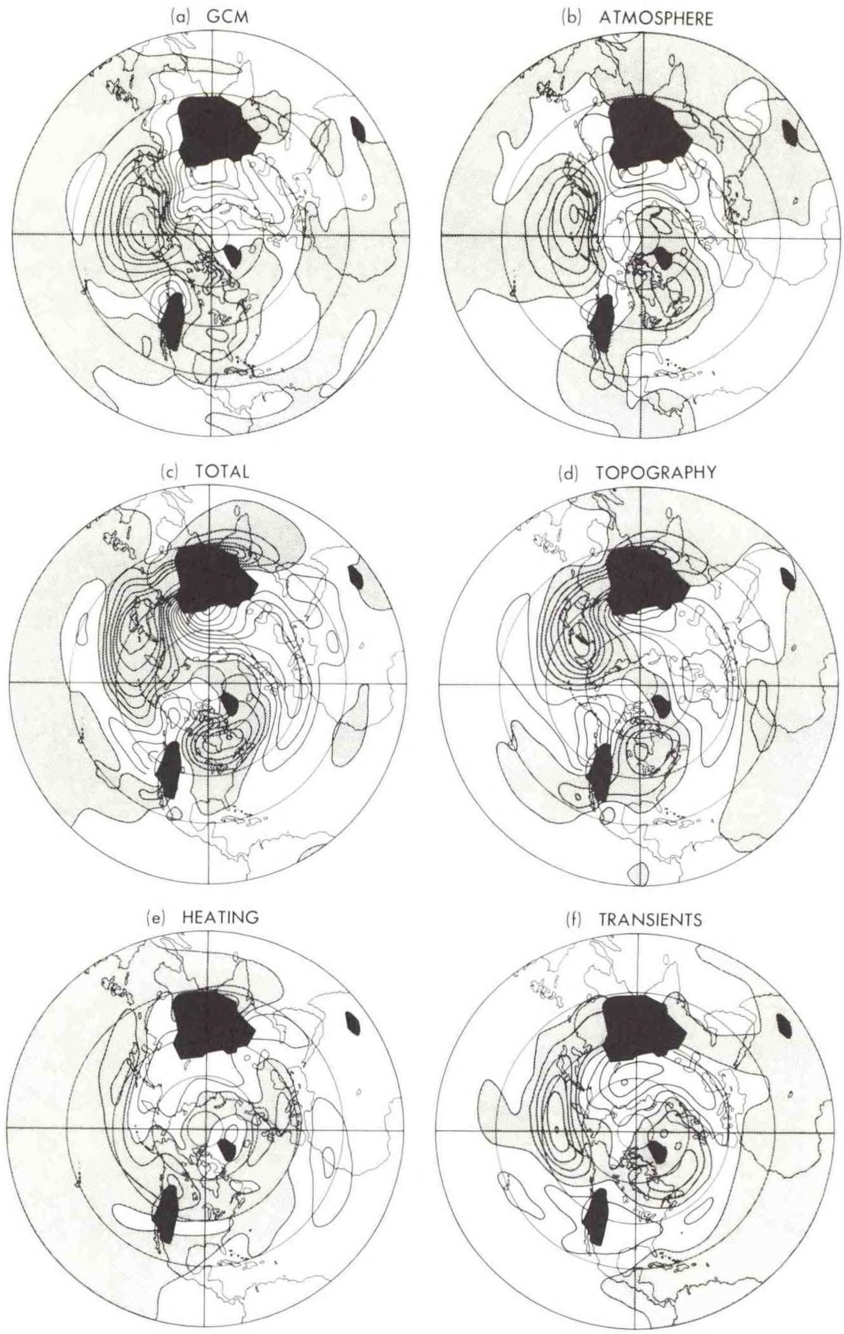

Fig. 1.4 The stationary eddy geopotential at 900 mb in the Northern Hemisphere during winter (DJF):

a) simulated by low resolution spectral GCM;
b) observed in the atmosphere (data from Oort (599));
c) linear response to topography plus diabatic heating plus transient eddy flux convergences;
d) linear response to topography only;
e) heating only;
f) transients only.

The contour interval is 20 m. Negative values are shaded.

1.3.3 Lower Tropospheric Flow in the Tropics

The construction of idealized models of the low-level flow in the tropics suitable for coupling to a variety of ocean models for studies of the El Niño Southern Oscillation phenomenon has proceeded in two complimentary directions. First the ability of linear viscous models similar to those used by other investigators to simulate the GCM's tropical surface stress distribution, given the low-level divergence or the precipitation field has been verified. The results are encouraging, both for simulation of the climatological seasonal cycle and for simulation of the anomalous flow in El-Niño years. A difficulty that has been discovered is the underestimation of the cross-equatorial flow in such models. Modifications that may remove this deficiency are under investigation. Secondly, a novel approach has been developed which predicts the low-level divergence field in the tropics, given the sea surface temperature distribution. The approach is based on the vertically integrated moist static energy equation and provides intuitively appealing explanations for the close relationship between precipitation and sea-surface temperature and for the concept of a "critical temperature" required for sustained deep convective activity in the tropics.

1.3.4 Climatological Upper Tropospheric Flow in the Tropics in Northern Summer

Models of the stationary flow in the tropical upper troposphere are inherently more complex than those for the lower troposphere because the flow is more nonlinear and quasi-horizontal mixing by large-scale transients is more important. We have found that a nonlinear barotropic model, forced by the GCM's upper tropospheric divergence, provides a remarkably good simulation of the GCM's time-averaged streamfunction during northern summer, including the correct position and strength of the Tibetan high. The result is insensitive to the dissipative parameterization used, and remains useful even when the model is sufficiently inviscid that substantial eddy activity is generated. Useful results can be obtained with linear models only if very strong dissipation is included that crudely mimics the effects of nonlinearity, and only if the advection of vorticity by the divergent component of the flow is retained.

PLANS FY86

Work will continue on the simulation of the seasonal cycle of the GCM's stationary eddies and the interannual variability of these eddies with a variety of linear and nonlinear models. Topics to be stressed in the coming year include -- the seasonal cycle of the stationary wave field forced by the Tibetan plateau, the importance of transient forcing for the extratropical low-level flow, the moist static energy budget in the GCM and its importance for the tropical time mean flow, and the key (and, at present, mysterious) role played by transients in determining the reponse of the GCM to El Niño lower boundary conditions.

1.4 TRANSIENT EDDIES

D. G. Golder   Y. Hayashi

ACTIVITIES FY85

1.4.1 Low Frequency Waves in the Tropics

In order to study the low frequency atmospheric oscillations in the tropics, a space-time spectral analysis has been made of data from a GFDL model and two sets of FGGE analyses, one processed at GFDL and another at ECMWF (European Centre for Medium Range Weather Forecasts). A spectral peak of the zonal wind component at wavenumber 1 and 45-day period with eastward phase velocity was found in the model data and the two sets of FGGE data between May and September. The amplitude of the spectral peak of the model data is about 1/2 that of the GFDL- and ECMWF FGGE data. Nevertheless, this result demonstrates that this low frequency oscillation occurs, to some extent, even in the absence of air-sea interactions, since the model's sea surface temperature has a prescribed climatological seasonal variation.

1.4.2 Growth of Extratropical Waves

In order to study how extratropical transient waves grow from small perturbations, experiments have been conducted using a general circulation model with a zonally uniform surface by adding initial perturbations after the model has reached its steady state under the constraint of zonal symmetry. The model has been time integrated by either including all the zonal wavenumbers or selecting some wavenumbers. It was found that, in the presence of all the wavenumbers, ultralong (wavenumber 1-3) waves and cyclone-scale (wavenumber 4-9) waves grow as fast as short scale (wavenumber 10-21) waves, whereas ultralong waves do not grow as fast in the absence of wave-wave interactions. This result is consistent with the finding that wave-wave energy transfer plays an important role in ultralong waves in their growing stage, whereas this energy transfer plays a less important role in their mature stage.

PLANS FY86

The studies of the tropical and extratropical transient waves simulated by the spectral general circulation models will continue, particularly with regard to the role of condensational heating on their growth and maintenance.

1.5 WAVE-MEAN FLOW INTERACTION

D. G. Golder   I. M. Held
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ACTIVITIES FY85

1.5.1 Interaction between Rossby Waves and the Hadley Cell

The study of the maintenance of the subtropical jet by competition between poleward flow in the Hadley cell and drag generated by decaying Rossby waves has continued. A number of high resolution barotropic calculations of the dispersion and decay of localized disturbances to a shear flow on a sphere have been analyzed in an attempt to clarify when linear theory can be used to predict the resulting drag on the zonal mean flow, and when nonlinearity cannot be neglected. Semi-quantitative arguments have been developed to delineate the range of parameters for which linear theory is adequate. Analysis of the linear problem has also led to new results on the orthogonality of modes on shear flows (cl). The concept of "pseudo-momentum" conservation is particularly useful in this regard. It proves to be meaningless to ask how much "energy" resides in a mode (when more than one mode is present), but one can ask how much pseudo-momentum resides in a particular mode. Furthermore, the modal decomposition of the pseudomomentum proves to be central to an understanding of conditions under which linear theory for the mean flow modification breaks down.

1.5.2 Interaction between Transient Waves and the Tropospheric Jet

In order to study the effect of tropospheric transient waves on the zonal flow, experiments have been conducted by eliminating waves from a spectral general circulation model with a zonally uniform ocean surface. It was found that, in the absence of transient waves, the tropospheric jet was shifted equatorward and increased in magnitude in a perpetual January condition, while the jet is increased *in situ* in a perpetual March condition. These results are not satisfactorily explained by the eddy momentum flux convergence or the Eliassen-Palm flux divergence alone without taking into account the effects of eddies on mean damping as suggested in recent theoretical studies (ax,ay).

PLANS FY86

Work will continue on the analysis of linear and nonlinear barotropic decay of disturbances on the sphere. The incorporation of both linear and nonlinear models of Rossby wave drag into Hadley cell models of the sort summarized recently in (671) will be actively pursued.

The study of the effect of tropospheric transient waves on the zonal mean flow will continue, particularly with regard to the sensitivity of the results with different ground and ocean surface conditions.

The conventional and transformed energy cycles of zonal mean and eddies will be re-examined and their physical interpretations will be discussed.

1.6 MODEL DEVELOPMENT

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M. D. Schwarzkopf
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R. J. Stouffer

1.6.1 The Coupled Ocean-Atmosphere Model

ACTIVITIES FY85

For the comprehensive study of climate change, it is essential to have a general circulation model of the coupled ocean-atmosphere system which is capable of simulating the observed behavior of the earth's climate. Unfortunately, the thermal and dynamical structures of both the ocean and atmosphere as simulated by current models are far from satisfactory.

The previous GFDL report described the results from a coupled ocean-atmosphere model with a limited-sector computational domain and idealized geography. It shows how the simulation of the coupled system improves when the resolution is increased and the subgrid scale viscosity is reduced. During this fiscal year, a similar study has been conducted by use of a global coupled model with realistic geography and annual mean insolation.

Two versions of the global model are constructed. The second version has twice as high computational grid resolution and eight times smaller subgrid scale viscosity as the first one. (See Table 1 for the computational resolutions of the two versions of the model.) From the comparison of the simulations between the high- and low-resolution versions of the model, it was found that the high-resolution model is superior to the low-resolution model in simulating the observed state of the coupled ocean-atmosphere system. For example, in the high-resolution model the temperature of the deep water is lower and much more realistic than the low-resolution model due to the enhanced formation of Antarctic bottom water. The polar fronts at the ocean surface are better defined. The Hadley cell and trade winds in the high-resolution model atmosphere are more intense than those in the low-resolution model. The equatorial minimum in sea surface temperature in the eastern Pacific Ocean of the high-resolution model is sharper and more realistic than the corresponding minimum in the low-resolution model. For an assessment of the performance of the high-resolution model, refer to Figs. 1.5a and 1.5b which compare the distribution of the model ocean temperature with that of the observed temperature.

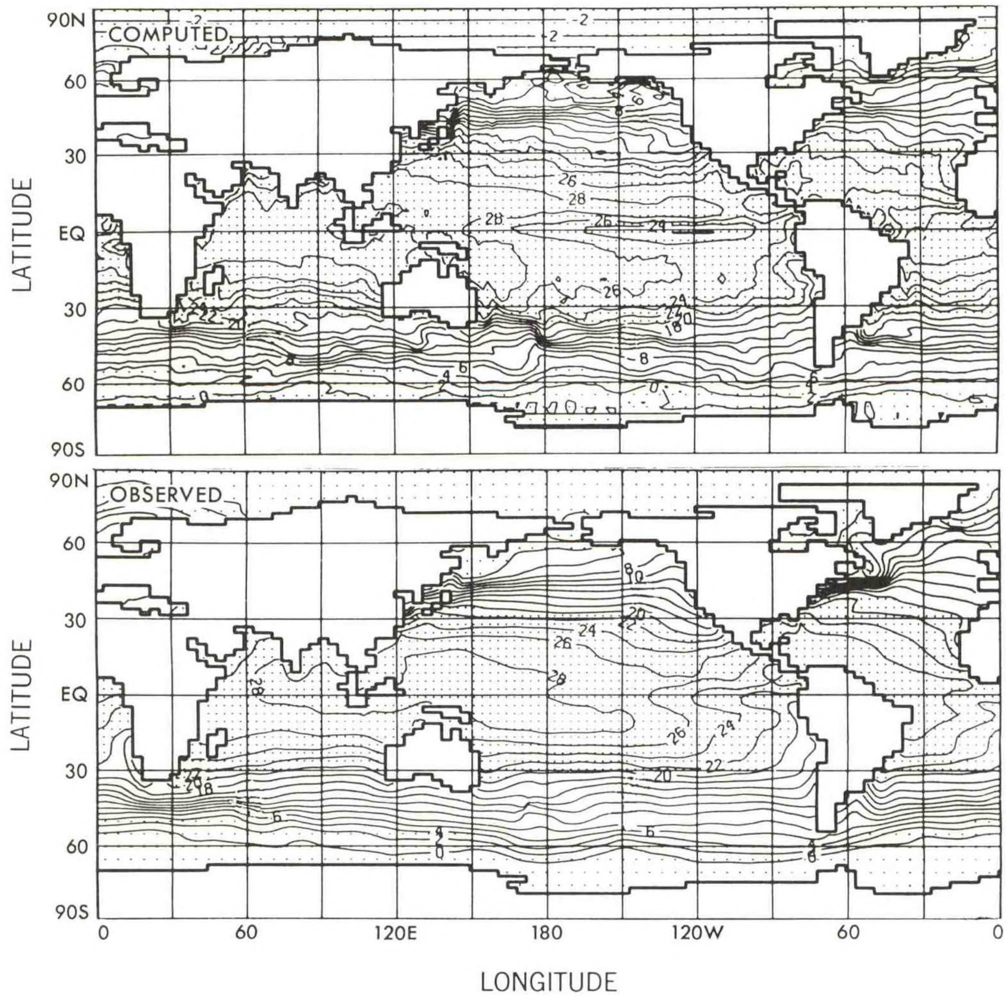

Fig. 1.5(a) Top: the distribution of sea surface temperature (°C) from the higher resolution version of the GFDL coupled ocean-atmosphere model. Bottom: the observed distribution of sea surface temperature (°C) compiled by Levitus (528). Contour interval is 2°C. Dense stipling indicates the region where temperature is above 20°C and coarse stipling indicates the region where temperature is below 4°C.

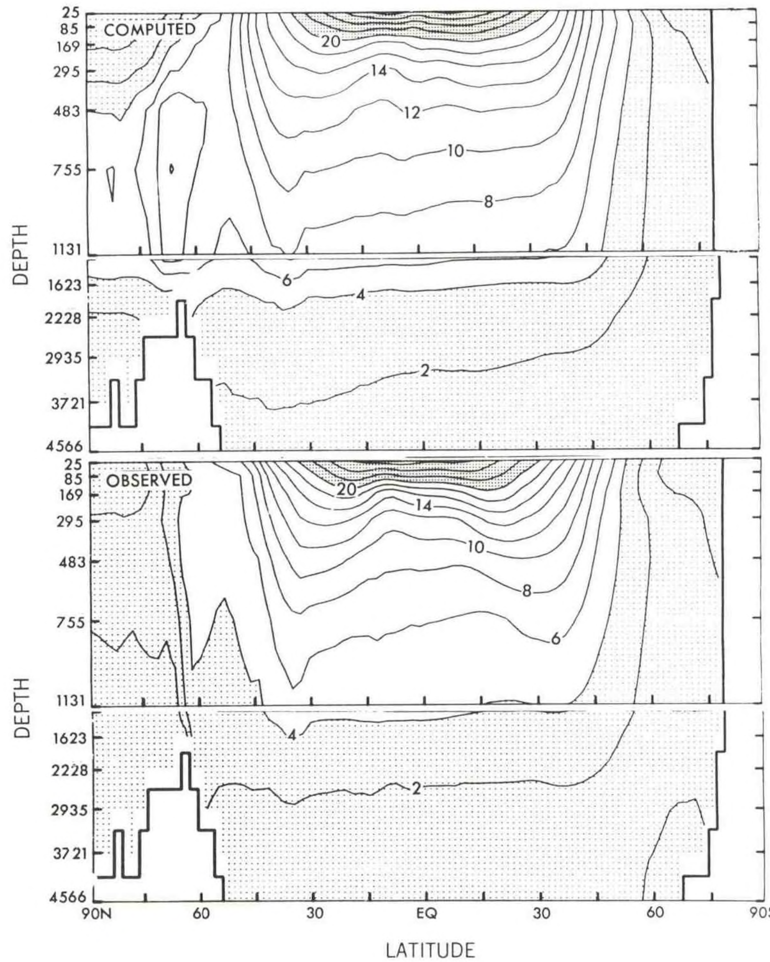

Fig. 1.5(b) Top: zonal mean ocean temperature (°C) from the higher resolution version of the coupled ocean-atmosphere model. Bottom: observed zonal mean ocean temperature (°C) compiled by Levitus (528). Contours are drawn in every 2°C. Dense stipling indicates the layer where temperature is above 20°C and coarse stipling indicates the layer where temperature is below 4°C.

Table 1. Computational Resolution of Two Versions of the Model.

	Low-Resolution Version	High-Resolution Version
Atmospheric Component (spectral truncation)	rhomboidal 15	rhomboidal 30
Oceanic Component (finite difference grid size)	3.8 deg long. by 4.4 deg lat.	1.9 deg long. by 2.2 deg lat.

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Despite the significant improvement in the performance of the high resolution version of the coupled ocean-atmosphere model, the simulated climate of the model has many unrealistic features. For example, the surface westerly winds in middle latitudes of the Northern Hemisphere are more zonal and more intense than observed. The surface waters of the North Atlantic and equatorial oceans have lower salinity compared to observed values. The intensity of the thermohaline circulation of the North Atlantic is too weak. A major effort will be made to improve the model.

1.6.2 Improvement of Atmospheric GCM

ACTIVITIES FY85

It has been noted that, as the computational resolution of a spectral GCM increases, the surface flow in middle latitudes of the Northern Hemisphere in winter becomes more zonal and less realistic. To resolve this difficulty, it has been suggested to increase the height of the mountains thereby incorporating the effect of subgrid scale terrain upon the large scale circulation in the model atmosphere ("envelope" mountain technique). An attempt was made to test this hypothesis by use of a global spectral GCM with rhomboidal 30 truncation of the spherical harmonics. The first version of the model has the normal orography. The second version has the envelope orography which is higher than the normal by one standard derivation of the height of subgrid scale terrain. By comparing the results from half year integrations of these two versions of the model, the impact of the "envelope"-mountain technique upon the model climate was evaluated. It was found that the shift from the normal to the envelope orography has very little effect upon the time mean distributions of sea level pressure and accordingly, that of surface flow.

PLANS FY86

Continuous effort will be made to remove the bias of a spectral GCM of the atmosphere which produces an excessive surface westerly wind in middle latitudes during winter. For example, the influence of gravity wave drag upon the zonal components of the flow in the model atmosphere will be evaluated.

1.6.3 Radiative Transfer Model Intercomparison Study

ACTIVITIES FY85

GFDL is a leading participant in the WMO-DOE International Comparison of Radiation Codes in Climate Models (ICRCCM). The purpose of this study is to provide a forum for a careful intercomparison of radiative transfer algorithms used in climate models, and to encourage the production of high-accuracy "line-by-line" bench-mark cooling rates, against which other codes can be tested. Line-by-line calculations make no mathematical approximations in the solution of the radiative transfer equations, performing monochromatic calculations at $\sim 10^6$ frequencies per case. Discrepancies between these calculations and observations therefore indicate problems in the underlying physics or spectroscopy utilized.

To this end, some 37 standard cases were proposed for intercomparison. A set of six analytical functions which provide excellent fits to the standard temperature profiles constructed at the Air Force Geophysics Laboratory were used to eliminate discontinuities in the lapse rate (df).

For each case, transmission functions, fluxes, and cooling rates have been generated for 10 cm^{-1} wavenumber intervals on a vertical grid with 108 layers between 0 and 95 km. These quantities have been archived, and will provide a valuable data set against which various more highly parameterized schemes used in GCM's can be tested. The computational labor involved in carrying out the full suite of these calculations is very large, and GFDL is one of the institutions with the required facilities.

A preliminary report describing the first phase of the study has been issued by the World Meteorological Organization.* In those cases where comparisons with other groups have been possible, the agreement is very satisfactory. An example of this is seen in Table 2, which tabulates the fluxes in the atmosphere with CO_2 as an only absorber. It will be noted that the agreement between various models is always very good; for the change in net flux at the tropopause due to doubling CO_2, the results are within 0.4 W/m^2 of each other. The agreement for the contributions to the fluxes from the line spectra of H_2O and O_3 is also excellent.

The chief remaining difficulty in the calculation of clear-sky IR fluxes relates to a correct specification of the shape of the wings of very distant

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*Luther, F. M., 1984: The intercomparison of radiation codes in climate models (ICRCCM): Long wave clear sky calculations. World Climate Program Report, 93. World Meteorological Organization, Geneva, Switzerland.

Table 2. Line-by-line flux calculations (W/m^2) for CO_2 only.

Source	UF_s	DF_s	NF_s	NF_{trop}	UF_t
Isothermal, 300 K, 300 ppmv CO_2					
GISS	459.22	93.04	366.18	403.09	459.22
GFDL	459.22	93.19	366.02	403.13	459.22
Isothermal, 300 K, 600 ppmv CO_2					
GISS	459.22	103.37	355.85	394.34	459.22
GFDL	459.22	103.62	355.60	394.39	459.22
Isothermal, 250 K, 300 ppmv CO_2					
GISS	221.45	40.88	180.57	196.64	221.45
GFDL	221.45	40.66	180.79	196.83	221.45
LMD	221.45	41.31	180.14	197.57	221.45
Isothermal, 250 K, 600 ppmv CO_2					
GFDL	221.45	44.55	176.90	193.13	221.45
LMD	221.45	44.82	176.63	193.97	221.45
Midlatitude Summer, 300 ppmv CO_2					
GISS	423.57	75.36	348.21	371.49	384.33
GFDL	423.57	75.38	348.19	371.96	384.54
LMD	423.57	76.38	347.19	371.04	383.52
Midlatitude Summer, 600 ppmv CO_2					
GISS	423.57	83.50	340.07	364.61	380.05
GFDL	423.57	83.60	339.97	365.10	380.27
LMD	423.57	84.20	339.37	364.45	397.51

Here, UF_s, DF_s and NF_s are upward, downward and net fluxes of terrestrial radiation at the earth's surface, respectively. NF_{trop} is the net flux of terrestrial radiation at the tropopause, and UF_t is the upward flux of terrestrial radiation at the top of the atmosphere. GISS and LMD stand for the Goddard Institute for Space Studies, New York, N.Y., and Laboratoire de Meteorologie Dynamique, Paris, France, respectively.

spectral lines, and the behavior of the foreign and self-broadened continuum. Variation in the effective cutoff of H_2O line-wings from 5 to ∞ cm^{-1} can produce changes in the surface IR flux of > 10 w/m^2. A similar situation plagues the CO_2 problem, where the lines are very sub-Lorentzian. Since there exists no reliable theory for such effects, comparison with laboratory data is the only possible way to reduce these uncertainties. A comprehensive study of this sort is currently well under way. Results indicate that excellent agreement with laboratory CO_2 data is obtained from the line-by-line model, and suggests strongly that calculated CO_2 cooling rates are accurate to much better than 10% below 70 km. Early indications from the water comparisons suggest that accuracies of ~10% throughout most of the atmosphere can also be expected.

PLANS FY86

Comprehensive intercomparisons of the calculated and laboratory absorptances will be carried out and used to place definitive bounds on the accuracy of atmospheric IR calculations. The archived data set from the 37 ICRCCM cases will be used to evaluate the accuracy of more highly parameterized models.

2. MIDDLE ATMOSPHERE DYNAMICS AND CHEMISTRY

Goals

* To understand the interactive three-dimensional radiative-chemical-dynamical structure of the middle atmosphere (10-100km), 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 TRACE CONSTITUENT STUDIES

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ACTIVITIES FY85

2.1.1 Atmospheric N_2O Experiments

All work has been completed on the series of experiments designed to test the sensitivity of stratospheric N_2O to various photodestruction efficiencies. As an outgrowth of these experiments, theories have been developed that help to explain various aspects of the climatologies of long lived trace gases. These include the global horizontal averaged (1-D) behavior, the meridional equilibrium slopes, and transient variability.

In each case the role of chemical processes in modifying the trace gas structures is clarified. Details are available in (cz).

2.1.2 Reactive Nitrogen in the Troposphere

The preliminary experiments to examine the global role of the North American combustion nitrogen source were re-designed to provide a more realistic simulation of chemical conversion and deposition. Upper and lower bounds for wet removal were determined from separate photochemical calculations of the conversion rate of NO_x to HNO_3. Similar calculations were used to determine the upper and lower limits for dry removal. With a more realistic description of wet removal, it is clear that the controlling process is the chemical conversion of NO_x to HNO_3, not the wet deposition of HNO_3.

The model's wet deposition data in the source region are now being compared with multiple-year deposition measurements in North America as well as with a station sensitive to long-range transport, Bermuda. Preliminary conclusions are that deposition in the source regions and the northeastern United States in particular is dominated by dry deposition (which currently cannot be measured). Approximately 50% of the combustion nitrogen source returns to the source region as dry deposition, 25% returns as wet deposition and 25% is exported, both over the Atlantic and the subtropical and tropical Pacific.

2.1.3 Multiple Tracer Experiments: Radon-222/Lead-210

As a first test of our recently developed multiple tracer global chemical transport model (GCTM), we chose to study Radon-222 and Lead-210. This pair, with their very simple "chemistry" of radioactive decay, allows us to isolate two key physical processes in the model: turbulent transport from the surface to the "free troposphere", and wet removal.

By comparing the model's wintertime Radon-222 profiles with available observations, transport out of the boundary layer during conditions of large-scale stability was found to be too weak. Previous studies of the model's simulation of ozone in the boundary layer (639) had suggested the problem. Accordingly, a shear-dependent boundary layer vertical diffusion was added to the model's moist Richardson-dependent vertical diffusion to give better agreement with the observed Radon profiles. This extra vertical diffusion is now part of the standard model.

Work was also begun on clarifying the roles of large-scale and subgrid-scale processes in the model transport. Preliminary results show that vertical transport between the bottom two model layers is dominated by subgrid-scale vertical diffusion, but that the resolved motions rapidly take over in the higher levels.

2.1.4 Development of a 2-D Transport Model

Work has been underway to evaluate the feasibility of deriving a 2-D transport model self-consistently from the GFDL 3-D transport model. This was accomplished by assuming a flux-gradient relationship and then, given gradient and flux statistics from two independent (and contrived) 3-D model tracer experiments, deriving the transport coefficients by inversion of this relationship. Given the meridional circulation from the GCM, the antisymmetric and symmetric parts of the coefficient tensor determine the advective and diffusive contributions to the net meridional transport in the 2-D model. The effective 2-D transport circulation thus defined differs substantially from the well known Lagrangian-mean and "residual" circulations; in fact, it provides the simplest representation of the model 2-D circulation.

The 2-D diffusion coefficients so derived exhibit a complex, but coherent structure. Strong lateral mixing is found in the mid-latitude lower troposphere, the tropical upper troposphere and the subtropical winter stratosphere. This latter region is associated with the recently identified stratospheric "surf zone" of breaking planetary waves.

The validity of this theoretical formulation has been tested through construction of a self-consistent 2-D model, using the derived coefficients. Comparison experiments show that the 2-D model reproduces well the zonally averaged tracer evolution in the 3-D transport model. This research strongly indicates that a viable theoretical framework has been formulated that allows self-consistent 2-D transport models to be designed and utilized.

2.1.5 Observational Analysis of Long-Lived Trace Gases

A dynamically oriented observational analysis has been completed on N_2O, $CFCl_3$, and CF_2Cl_2 data from a limited Aeronomy Laboratory balloon network. A rough meridional-height climatology has been established. The analysis shows that N_2O and CF_2Cl_2 appear close to a "slow-chemistry" limit (cz) in which their distribution is determined by an approximate balance between lateral wave-induced mixing and vertical advection by the meridional (diabatic) circulation. The more chemically active $CFCl_3$ exhibits flatter mixing ratio surfaces, indicating a very important role of chemical destruction in determining its meridional structure.

An attempt was made to isolate the seasonal cycle in mixing ratio at Laramie, Wyoming, the station with the most data. By comparing the spring variance with the annual variance, as well as using the structure from the GFDL N_2O studies (2.1.1), an estimate was made of the additional data that would have been required to resolve the annual cycle of the trace gases at Laramie.

PLANS FY86

To clarify the role of various U.S. source regions in the acid deposition in the northeastern United States, the combustion nitrogen model will be run with all sources shut off except for northestern United States and eastern Canada. The resulting deposition (both wet and dry) will be compared with the deposition for the full source case.

Work on Radon-222/Lead-210 will continue with emphasis on the wet deposition of Lead-210 and on a more detailed study of resolved and subgrid transport processes in the model.

A new collaboration with Professor William Chameides of the Georgia Institute of Technology will begin on investigation of wet removal processes, both rainout and washout. Also, a new collaboration has begun with Dr. John Merrill of the University of Rhode Island to study the simulation of transport from Asian dust storms.

Final work on the observational analysis of balloon N_2O, CF_2Cl_2, and $CFCl_3$ data will be completed.

2.2 MODELS OF THE TROPOSPHERE-STRATOSPHERE-MESOSPHERE

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D. G. Golder
D. S. Graves
Y. Hayashi
C. Kranz
S. Miyahara
M. D. Schwarzkopf
L. J. Umscheid

ACTIVITIES FY85

2.2.1 Model Improvements

Over the year a number of improvements have been completed on the troposphere-stratosphere-mesosphere (SKYHI) GCM. The model's execution speed has been increased by about 20% and a number of changes have been made to increase the accuracy of the advection and diffusion algorithms.

A very high resolution version (1° latitude by 1.2° longitude, N90) has been developed and is in the early stages of integration. In addition, preparations to include an active, self-consistent ozone photochemistry code are in a mature stage.

2.2.2 Higher Resolution Seasonal Cycle Experiments

The seasonal cycle of the middle atmosphere is being investigated with 3° latitude (N30) and 1° latitude (N90) versions of the 40-level SKYHI GCM. The N90 version is an experimental exploration of the biases that may result purely from an inadequate computational resolution.

Although it is almost prohibitively expensive to run, the N90 model has been integrated for over 2-1/2 months (October to mid-December). Early indications are that a number of model simulation improvements have been achieved. These include: polar cold bias (see 2.2.3), gravity wave, mean-flow interaction (see 2.2.4), tropospheric jet stream location, tropical zonal winds, surface pressure, eddy kinetic energy, planetary wave breaking, polar night jet stream, mesospheric temperatures, midlatitude cyclone dynamics, tropical tropopause temperatures, and the mesoscale gravity wave spectrum.

Model problems that apparently remain unsolved with the resolution increase include: position of the polar night jet, lower stratosphere polar cold bias, and the cold bias in the tropical upper troposphere.

2.2.3 Sources of Systematic Errors in SKYHI Winter Climatology

Comparison of early low-resolution seasonal versions of SKYHI with observed middle atmosphere temperatures showed conclusively that the entire winter polar stratosphere is too cold. The discrepancy is most dramatic at the polar stratopause, where the models were too cold by as much as 50°. The origin of this bias is not due to errors in *in situ* radiative cooling, since careful comparisons of the radiative algorithm with laboratory data (see section 1.6.3) show errors of less than 5% in absorption. The problem is therefore almost certainly a dynamical one, and an investigation of its cause continues (669). Figure (2.1) shows the considerable progress that has been made in curing the problem in the polar middle atmosphere, by virtue of simply increasing the model resolution. Indeed, at 62°N latitude, the remaining bias in the N30 model is only 10° or so. At the pole, while there has been a considerable improvement in the mesosphere, the entire stratosphere remains 15-45° too cold. The improvement in the mesosphere is probably due to the better treatment of smaller-scale gravity waves (see 2.2.4), while the upper stratosphere improvement results from the increased planetary wave amplitudes at higher resolutions.

Preliminary estimates for the N90 model are also shown; (these are values for December 8, rather than monthly averages). At 62°N, the difference between model and observed temperatures lies well within the limits of observational error and interannual variability. At the pole, the improvement is equally encouraging; the error of 40-45° at 3 mb in the N30 model has been reduced to 15-20°, and at 0.3 mb, model and observations agree closely.

Although stratospheric cooling rates are very reliable, the same cannot be said of those in the upper troposphere, which depend crucially on the specification and radiative treatment of cirrus clouds. It is possible that failures in the treatment of this aspect of the problem could lead to overly strong westerlies in the lower stratosphere, which in turn adversely affects the propagation of planetary waves into the middle and upper stratosphere, and ultimately, therefore, the entire stratospheric mean thermal structure.

To test this hypothesis, the N30 model was run for 30 days from December 1, with a radiative formulation in which the cirrus were entirely removed in the IR. Even this drastic assumption, however, failed to make a significant difference in the thermal structure; although local IR cooling rates decreased by up to 1°/day, there was little change in temperature (about 3°). The changes in radiative cooling were largely compensated for by changes in convection and large-scale dynamics. It thus appears unlikely that radiative errors in the upper troposphere are responsible for the middle atmospheric cold bias.

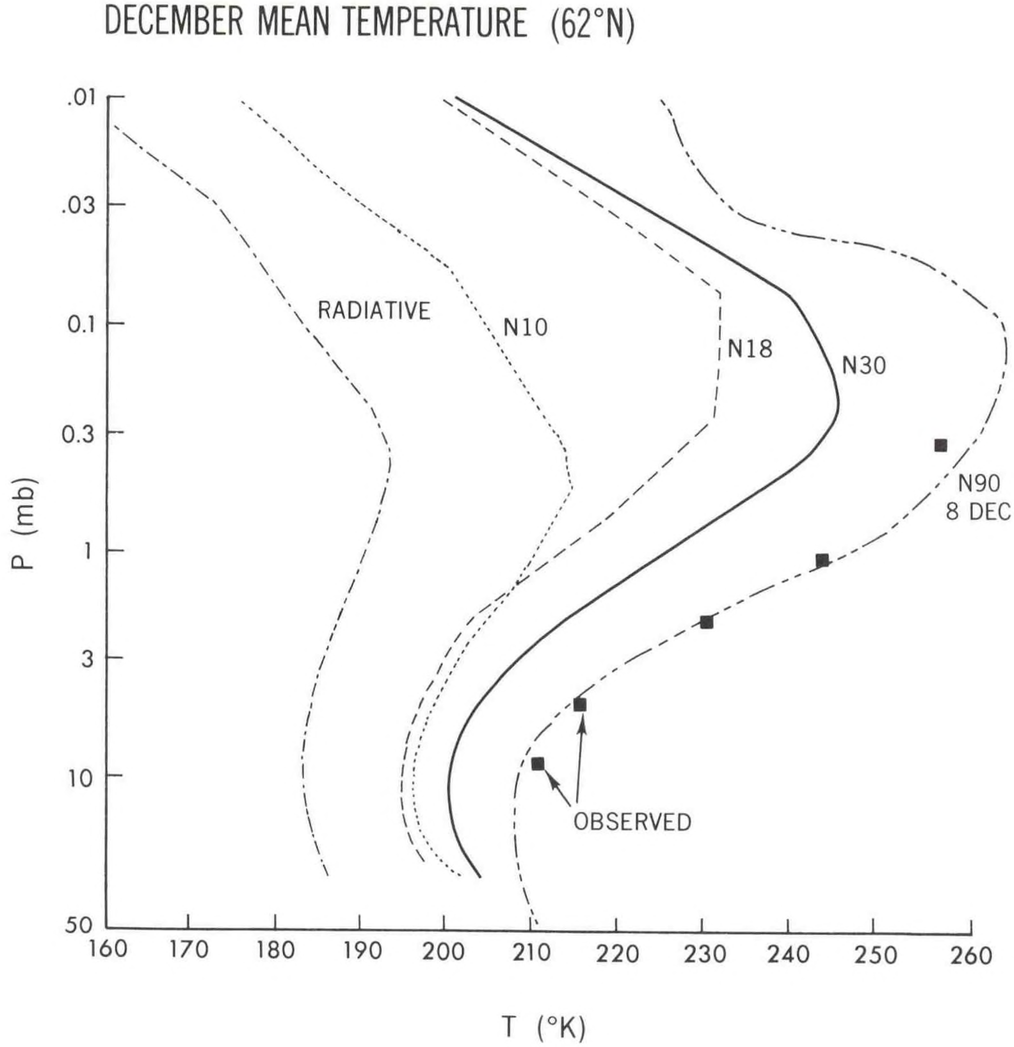

Fig. 2.1 Vertical profiles of zonal mean SKYHI temperatures at 62°N for December. The "radiative" curve at left is obtained from a time marched radiative-photochemical model. From left to right the values are for the N10(9° latitude), N18(5°), N30(3°) and N90(1°) versions of the SKYHI model. The squares are the observed December values. The N90 profiles is a preliminary estimate from 8 December.

2.2.4 Effects of Internal Gravity Waves on Planetary Waves

The first phase of an effort to determine the effect of smaller scale motions (gravity waves) on the larger scale (planetary waves and zonal flows) has been completed (dg). The N30 version of the 40-level "SKYHI" GCM has been used to investigate gravity wave, planetary-scale flow interactions for the months December-February.

Through use of a space-time spectral analysis technique, the gravity waves in the mean westerlies (easterlies) mainly consist of westward (eastward) phase speeds and carry easterly (westerly) momentum upward. This acts to decelerate the mean westerlies (easterlies) in the mesosphere and upper stratosphere.

Thus in each hemisphere, these waves act to decelerate the basic flow. In the summer hemisphere, the gravity wave induced zonal momentum forcing dominates, while it is a little less than that of the planetary waves in the winter hemisphere.

The analysis also shows that the model gravity waves act to dampen the planetary waves in the mesosphere and upper stratosphere. This process yields a drag force roughly analogous to that of Rayleigh friction.

Preliminary calculations using the N90 version of the same model show marked increases in the magnitudes of these gravity wave effects. These results suggest that such processes are even more pronounced in the actual atmosphere. Further information is available in (dg).

2.2.5 Evaluation of Satellite Sampling of the Middle Atmosphere

An investigation is underway to determine the accuracy of derived dynamical fields within the middle atmosphere as inferred from simulated satellite radiance data. This study assumes that the earth's atmospheric state is exactly characterized by calculations from the SKYHI (N30) GCM. The model data are sampled both spatially and temporally to obtain asynoptic satellite temperature fields. The satellite temperatures are used to define channel transmittances and radiances corresponding to the TIROS-N Operational Vertical Sounder (TOVS) instruments (HIRS-2, MSU,SSU). A radiosonde temperature data network is simulated for use in defining linear regression coefficients. These regression coefficients and the simulated satellite radiances are coupled to define vertical temperature profiles. The problem of mapping the asynoptic temperature data onto its synoptic counterpart is also considered. Finally, zonal and time-mean fields of temperature and various derived dynamical quantities are calculated from the simulated satellite temperature fields and compared with the original SKYHI data.

The temperatures inferred from satellite measurements define weighted layer-mean temperatures, not temperatures at specific pressures. However, the method of radiance-to-temperature inversion used by NOAA/NESDIS (National Environmental Satellite Data and Information Service) results in a vertical temperature profile which defines temperatures at specific pressures. Therefore, under conditions intended to parallel the operational analysis of satellite data by NOAA/NESDIS, one-to-one comparisons are made between the SKYHI and satellite-simulated meteorological fields on isobaric surfaces.

Root-mean-square errors in January, mid-stratospheric temperatures vary from 5° at the equator to 2° in middle and high latitudes. These errors increase by a factor of approximately 2 within the mesosphere. There is excellent agreement between the simulated satellite and SKYHI January zonal mean zonal winds. The mesospheric jet core estimated from the satellite radiances is, however, 5 m/sec weaker than that of SKYHI. The conversion of the asynoptic temperature data to its synoptic form decreases the above errors in midlatitudes by 25% while increasing the error in the tropics by approximately 40%. This increased error is due to the presence of highly transient wave activity within the tropics.

PLANS FY86

Efforts will continue to develop the very high resolution (N90) SKYHI model with an emphasis on dissipation physics and efficiency improvements. Analysis of the N90 model will be accelerated with efforts on the systematic climatic biases and on quantifying the role of gravity waves on the larger scale middle atmosphere circulation.

The analysis of satellite sampling errors will be completed.

2.3 PHYSICAL PROCESSES IN THE MIDDLE ATMOSPHERE

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J. D. Mahlman
M. D. Schwarzkopf
L.J. Umscheid
S. C. Liu*
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ACTIVITIES FY85

2.3.1 Seasonal March of Radiative-Photochemical Temperatures

A simplified symmetric radiative-dynamical model has been constructed and used to elucidate the possible effects of "dynamical inertia" on the seasonal evolution of the structure and meridional circulation of the middle atmosphere. These effects have been found to be of little importance, even near the edge of the polar night, where there exist large temperature gradients.

A time-marched version of the GFDL-AL radiative photochemical model has been used to investigate the radiative form of the zonal mean potential vorticity. No structure which might be confused with the dynamically induced "surf zone" (see 2.1.4) was found.

2.3.2 Improvements in Calculation of Infra-Red Cooling Rates

A revision of the Fels-Schwarzkopf CO_2 algorithm has been completed, and the results documented (cj). Changes included use of a more accurate interpolation algorithm, inclusion of all approximately 12,000 lines in the AFGL catalog, a revised quadrature scheme, and construction of an algorithm for accurate interpolation to arbitrary mixing ratio, rather than the customary 330 and 660 ppmv. Extensive studies to determine the accuracy of the method by comparison of theoretical results with laboratory data have been carried out.

An investigation of the accuracy of several more highly parameterized models for calculation of CO_2 transmissivities has been completed. Extensive use is made of the GFDL line-by-line algorithm as a bench-mark. A novel method for parameterization of the Doppler regime can be combined with the exponential broad-band model to give a scheme which is both accurate and reasonably fast.

2.3.3 Ozone Photochemistry

The collaborative effort with NOAA Aeronomy laboratory scientists has been renewed with an accelerated effort to develop an ozone chemistry capable of running self-consistently in the SKYHI GCM (2.2). The chemistry codes have been modified to be compatible with the constraints from the GCM. The theory described in 2.1.1 has been used to prescribe the zonal-mean mixing ratios of the long-lived precursor gases in a manner self consistent with SKYHI's own 3-D simulation of N_2O. The GCM itself is being modified to allow addition of a number of new trace constituent dependent variables.

PLANS FY86

The effort to incorporate a self consistent ozone photochemistry into the SKYHI model will continue and preliminary tests will be underway. The recent improvements in the infra-red radiative transfer algorithm will be incorporated into the SKYHI model.

3. EXPERIMENTAL PREDICTION

GOALS

* To develop more accurate and efficient atmospheric and oceanic GCM's suitable for monthly and seasonal forecasting, and to reduce the systematic biases of the models.

* To identify external forcing mechanisms important in the forecast range of several weeks to several months, and to develop means of accurately specifying the initial states of the atmosphere, oceans, and snow/ice cover.

* To investigate the influence of internal processes such as orographic forcing, cloud-radiation interaction and cumulus convection on atmospheric variability.

* To advance the understanding of a broad range of phenomena of importance in the atmosphere, including blocking, orographic cyclogenesis, equatorial ocean-atmosphere interaction, tropical circulations, teleconnections, transient eddy fluxes and dynamics of regions of concentrated vorticity.

3.1 MODEL IMPROVEMENT

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J. Sirutis	W. F. Stern	R. K. White
B. Wyman	T. Knutson	P. L. Baker

ACTIVITIES FY85

3.1.1 Spectral Model for Seasonal Integrations

An advanced spectral model suitable for integrations over seasonal time scales is being developed. The model permits spatial resolution of up to 63 waves in each horizontal direction (with rhomboidal truncation) and 18 levels in the vertical. In addition to the conventional subgrid scale physics, it includes envelope orography, lateral diffusion, cloud-radiation interaction, an advanced cumulus convection parameterization, and shallow convection (cf. 3.1.4). Experiments with various gravity wave-drag parameterizations are also anticipated. In order to investigate the effect of spatial resolution, various lateral as well as vertical resolutions have been tested in concert with the subgrid scale turbulence parameterization. An important thrust of this project is the improvement of computational efficiency of the model.

3.1.2 Cloud-radiation Interaction

The sensitivity of the GCM-predicted time mean circulation to cloud-radiation diabatic forcing has been examined for two winter and two summer cases (dw). The forcing is specified through monthly mean global fields of low and high effective cloud amount. The latter were generated from NIMBUS 7 satellite radiation flux data (dv). The impact of this forcing on the 5-day mean height forecast is favorable in the 15 to 30 day range, although the model climate drift eventually becomes dominant and increasingly contaminates the forecast. In addition to these experiments, two versions of a humidity-dependent cloud prediction scheme have been implemented in the GCM and tested. This has demonstrated sensitivity of forecasts to the method used for cloud parameterization, but a clear beneficial effect of cloud prediction on forecast skill has not yet been achieved.

3.1.3 Orographic Effects

Two approaches to the improvement of representation of orographic effects in GCM's are being pursued. The first is the use of envelope orography, in which the model mountain heights are augmented by a proportion of the subgrid scale standard deviation of mountain height. Envelope mountains have been incorporated in the spectral GCM, and 30-day forecast experiments have been run comparing effects of 1σ and $\sqrt{2}\,\sigma$ increments. The 1σ increment has been found to have a generally neutral to beneficial effect on skill. The second approach is the parameterization of gravity wave drag. Research is currently underway on a semi-empirical drag law formulation based on observations of wave drag and on nonlinear mesoscale simulations.

3.1.4 Comparison of Various Versions of Subgrid-Scale (SGS) Processes

Investigations of the relative merits of four different physical parameterization packages (A, E, F, and FM in order of increasing sophistication) have continued. 30-day GCM integrations have been carried out for eight cases with each version. The importance of accurate parameterization of SGS processes on this time scale has been clearly demonstrated. Results based on 4 winter cases have been presented at a workshop held at the European Center for Medium Range Weather Forecasting. A further, and very stringent, test of the merit of high quality SGS parameterization has been carried out by NMC, where a large number of forecasts have been made in a quasi-operational context using GFDL physical parameterization packages (cf. 3.6). Efforts have begun on the incorporation of shallow convection along lines proposed by Tiedtke* and on the improvement of surface roughness effects as suggested by Sud and Smith.**

3.1.5 HIBU Model

Work on the HIBU advanced gridpoint model has concentrated on improving its computational efficiency. Further progress on vectorization has been achieved, and a much more efficient convective adjustment scheme has been formulated. In addition, a fast polar filtering algorithm has been identified, and is currently under investigation.

PLANS FY86

The wave-drag parameterization will be tested in the spectral GCM. Effects of cloud radiation interaction on forecasts within El Niño and non-El Niño periods will be investigated. Efforts directed at reducing climate drift and improving computation efficiency of GCM's will be continued.

3.2 THEORETICAL STUDIES OF ATMOSPHERIC DYNAMICS

R. T. Pierrehumbert	L. Brevdo	A. Navarra
J. Bacmeister	F. Parham	D. Dritschel
B. Carissimo	B. Wyman	Y. Bar-Sever
K. Miyakoda		

ACTIVITIES FY85

3.2.1 Planetary Waves, Low Frequency Variability, and Storm Track Structure

Elucidation of the relationship between storm tracks (regions of high synoptic scale variability) and the large scale planetary wave pattern is the key to a number of outstanding problems in dynamic meteorology. For example, a long range forecast model may successfully predict the time-mean positions

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*Tiedke, M., 1984: The sensitivity of the time-mean large-scale flow to cumulus convection in the ECMWF model. Proceedings of ECMWF Workshop on Convection in Large Scale Numerical Models, 297-316.

**Sud, Y. C., and W. E. Smith, 1985: The influence of surface roughness of deserts on the July circulation - A numerical study. Boundary Layer Meteorology. (In press) of the major jet regions; can we then expect the correct prediction of regions of anomalous storm activity to follow? Moreover, the feedback of transient eddies on the large scales arises in theories of blocking and of the climatological planetary wave amplitude. Several theoretical developments along these lines have been pursued. An analytic treatment of the baroclinic instability of zonally varying flow has been completed (621). Based on the solutions reported therein, simple models of the distribution of the fluxes of heat and vorticity along storm tracks have been devised (dk); in many regards, these compare favorably with observations. The results suggest a mechanism whereby eddies may act to maintain blocking. Another analysis (dc) has shown that certain kinds of damping, which may plausibly be taken as models of transient eddy effects, actually tend to increase the amplitude of planetary waves, even though the direct effect of the damping is to draw energy out of the large scale waves.

The mechanism of low frequency atmospheric variability is still a mystery. It is recognized that most atmospheric forcings fluctuate in time, so that a natural attack on the problem is to examine the response of an atmosphere to a pulsating source. Work on this problem has yielded the surprising result that the response consists of a spatially amplifying baroclinic wavetrain, in addition to the more familiar equivalent barotropic Rossby waves. The amplification rate of the baroclinic motion can be significant even at quite low frequencies. For details, see (dz).

3.2.2 Orographic Effects

Mountains influence atmospheric motions of a wide variety of scales, and even small scale effects can exert an influence on large scale dynamics, through their effect on the orographic forcing of planetary waves. In FY85, work on orographic effects has continued to emphasize blocking of flow by mountains, and lee cyclogenesis. Two analytic and numerical studies of flow blocking have been completed (646 and 650). A theory of the effect of flow blocking in cyclogenesis has also been advanced (656). In addition, a review article on lee cyclogenesis has been completed (dl).

A three-dimensional linear model of rotating stratified flow over orography has been completed, and applied to both idealized and realistic Alpine topography. Analysis of the recently arrived ALPEX Level IIb data set has begun. Finally, investigation of upstream influence along the lines discussed in (650) is being extended to the nonhydrostatic case, which will permit more precise comparison with laboratory experiments.

3.2.3 Dynamics of Concentrated Regions of Vorticity

Many phenomena in the atmosphere (as well as in fluids in general) involve the evolution of concentrated regions of vorticity. These include breakup of the stratospheric polar vortex and the multiple vortex phenomenon in tornadoes. Two studies on the merger and breakup of two-dimensional patches of vorticity have been completed and a Ph.D. thesis including results on three-dimensional instabilities has been approved.

Also on the subject of three-dimensional instabilities, a very general instability of vortex filaments in shear fields has been discovered (do). It is believed that this instability is related to the transition to three-dimensional turbulence in free shear layers.

3.2.4 Anomaly Models

A major accomplishment has been the completion of a three-dimensional anomaly model. The equations for this model are obtained by linearizing the primitive equations about a three-dimensional basic state; the steady state anomaly response to specified forcing is then obtained by solving the resulting large linear system by a novel application of the Krylov method (cw). This model was applied to the January 1983 El Niño case. Three kinds of anomaly forcings in the tropics were investigated. The first is heating based on observed sea surface temperatures, the second is heating based on sea surface temperature observations modified to agree with observed outgoing longwave radiation, and the third consists of an idealized profile. A degree of similarity between predicted and observed circulation patterns has been found. The three dimensional anomaly model provides a powerful tool for future investigations of the influence of basic state zonal inhomogeneities on teleconnection patterns.

PLANS FY86

The effects of meridional shear on local baroclinic instability will be investigated. Mechanisms of excitation of spatially growing baroclinic disturbances will be studied. Eddy flux patterns associated with spatial baroclinic instability of a zonally varying current will be determined, and their dependence on excitation frequency will be studied. Analyses of flow blocking and lee cyclogenesis with the final ALPEX data set will be carried out. The mechanism of upstream influence will be probed in detail. Within the context of the anomaly model, sensitivity to the form of tropical heating will be investigated, and comparisons between stationary linear and time-dependent nonlinear solutions will be made.

3.3 AIR-SEA COUPLING FOR UPPER OCEAN FORECASTS

A. Rosati   S. G. H. Philander   K. Miyakoda
J. Sirutis   R. K. White

ACTIVITIES FY85

3.3.1 Development of Upper Ocean GCM

A higher resolution (1° x 1°) global ocean GCM was adapted from the GFDL ocean group and modified to include nonlinear lateral viscosity, a turbulent closure model, penetrative insolation and high vertical resolution in the upper hundred meters. Further, a variable resolution grid has been introduced, allowing 1/3° resolution in the tropics.

3.3.2 Application to 1982/83 El Niño Event

In order to simulate the El Niño oceanic variation, the upper ocean GCM was forced with NMC observed wind, temperature and moisture fields for 1982 and 1983. The simulations were run using both twice-daily and monthly mean forcings, in order to ascertain the effects of high frequency fluctuations.

PLANS FY86

The simulation experiment for the case 1982/83 will be continued. Investigations of data assimilation techniques for ocean GCM's will be carried out.

3.4 FOUR DIMENSIONAL DATA ASSIMILATION

J. J. Ploshay   W. F. Stern
R. K. White   K. Miyakoda

ACTIVITIES FY85

3.4.1 Improvement of Four-Dimensional Analysis Scheme

Two deficiencies in the GFDL data assimilation technique noticed in the FGGE analyses are the noisiness of the analyzed fields and the underestimation of the depth of the central pressure in cyclones. In order to eliminate these shortcomings, a test has been carried out on the application of linear normal mode initialization to the data increments for high frequency modes only, the usage of a geostrophic correction technique to produce winds where only mass data are available, and the increase of the data collection range in the optimum interpolation scheme. The study indicates that the new four dimensional analysis method appreciably ameliorates the drawbacks (dy).

3.4.2 Re-Analysis of FGGE Data

A revised analysis of the FGGE Level IIb data for the special observing periods is in preparation. In addition to the changes noted in 3.4.1, the improvements include use of a high resolution model (R42L18 instead of R30L18), shallow convection, and incorporation of Level II satellite moisture data and revised LIMS data.

PLANS FY86

The re-analysis of the FGGE data will be continued, with special attention to the simultaneous diagnosis of heat sources and sinks.

3.5 LONG RANGE FORECASTING

K. Miyakoda R. T. Pierrehumbert J. Sirutis
W. F. Stern J. J. Ploshay Y. Lu
R. Reynolds* B. Wyman *CAC/NMC

ACTIVITIES FY85

3.5.1 Monthly Forecasts

Based on a series of monthly prediction experiments for 8 January cases, carried out with climatological sea surface temperature, the following conclusions are drawn. A marginal skill is found for monthly forecasts of 10-day mean fields. All the forecasts suffer from an appreciable systematic bias (climate drift). The predictive skill scores are substantially raised by the subtraction of the climate drift from the prognosis. Therefore, monthly forecasts by dynamical means may be feasible, particularly if the systematic error can be removed either by model improvements or statistical correction techniques.

Figure 3.1 is a summary of this series of experiments, showing the forecast skill scores for the 500 mb geopotential height over the northern hemisphere. The left panel shows the correlation coefficients between observed and predicted time mean (10, 20, and 30 days) height anomaly. The right panel shows the root-mean square error of the height, normalized by the error of the persistence forecasts, the abscissa being the forecast time range. For details, see (ea).

3.5.2 Effect of Sea Surface Temperature (SST)

The effect of SST on forecasts of the January 1983 El Niño case has been studied using observed SST analyses. The tentative conclusions are that: (a) the equatorial SST has a substantial effect on the tropical condensation and circulation; (b) the specification of SST in the equatorial Pacific is delicate, and so far the incorporation of observed SST improves the forecast of the tropical circulation but degrades the extratropical forecasts; (c) the Arakawa-Schubert cumulus parameterization scheme provides better tropical forecasts than does moist convective adjustment; (d) envelope orography has an adverse effect in the tropics, causing excessive condensation. A modified SST field based on outgoing longwave radiation produced considerably improved forecasts in the extratropics as well as in the tropics.

PLANS FY86

Studies will continue on the exploration of the impact of observed sea surface temperatures on monthly forecasts.

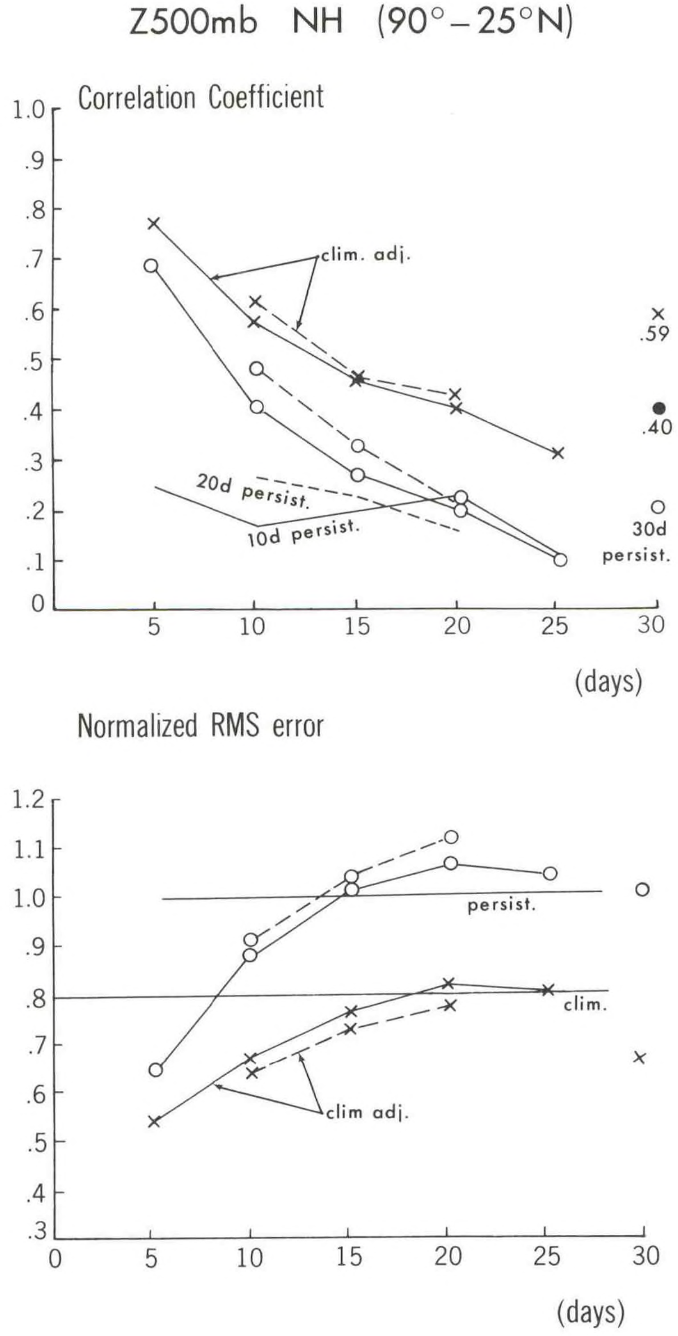

Fig. 3.1 Averaged monthly forecast skill scores for the 8 January cases. The small circles and crosses are for the original forecast and the empirically adjusted forecasts with climate drift removed, respectively. The solid lines and the dashed lines are for the 10 day and the 20 day means, respectively. The 30-day mean scores are plotted at the right hand side of each panel. "Persist" indicates the persistence forecast, and "clim" indicates the climate forecast.

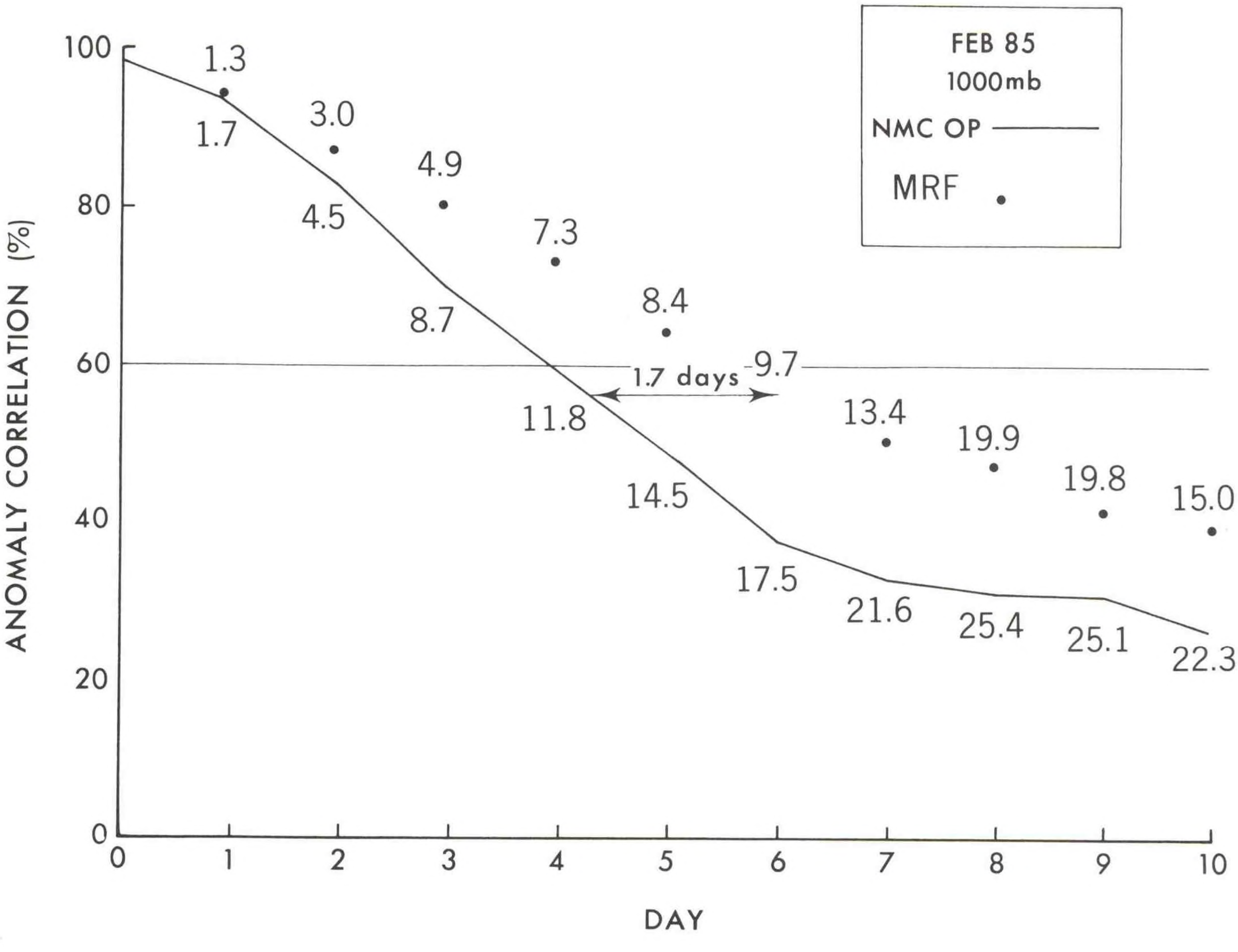

Fig. 3.2 The scores for February 1985 of the new NMC model for medium range forecast (MRF), in terms of the correlation coefficients of 1000 mb geopotential height anomalies between forecasts and observation; the verification domain: northern hemisphere between 20°N and 80°N. The horizontal line at 60% indicates the threshold level of pracitcal usage of the forecasts. Forecasts which fall below the 60% line have no practical usefulness. The numbers plotted are the standard deviations for the respective forecasts.

3.6 COOPERATION WITH THE NATIONAL METEOROLOGICAL CENTER (NMC)

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*NMC

ACTIVITIES FY85

The first phase of the cooperation was the development of an NMC R40L18 resolution spectral model with the GFDL E2 physics package. After much debugging of code and many careful comparison tests with a GFDL counterpart model, a series of quasi-operational 10-day forecast runs was launched in January 1985. The results turned out to be spectacular. The usefulness of the forecasts was extended by about 1.5 days in the February statistics, as compared with the conventional NMC model. However, this dramatic improvement starts to decrease as summer is approached.

Figure 3.2 shows a 500 mb verification score for 1 to 10 day forecasts from the conventional system (NMC OP) and the NMC/GFDL systems. A score of 60% or more is generally accepted as indicating a forecast that has useful skill in predicting day to day weather changes.

PLANS FY86

The second phase of the cooperative effort will be pursued. This phase includes implementation of the turbulent closure scheme (E4 physics), shallow convection and improvements to the computational efficiency of the radiation calculation.

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.

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

4.1 OCEANIC RESPONSE STUDIES

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P. Chang
R. C. Pacanowski
W. Hurlin
S. G. H. Philander

ACTIVITIES FY85

4.1.1 Air-Sea Interactions in the Tropics

During El Niño events in the Pacific Ocean there is a tendency towards spatially homogeneous conditions: sea surface temperatures in the central and eastern Pacific increase so that zonal temperature gradients are minimized, and the major convergence zones - the ITCZ, the South Pacific Convergence Zone, and the convergence zone over the western tropical Pacific - tend to merge into one large convergence zone over the central part of the ocean basin. A spatially homogeneous state may appear stable, but if this were so then El Niño conditions should persist indefinitely. A simple model of air-sea interactions, which has previously been used to study the evolution of El Niño (585), indicates that spatially homogeneous conditions in the tropics are unstable. Consider an easterly wind perturbation over the eastern side of the ocean basin. This induces local equatorial upwelling, lower sea surface temperatures in the east, and a westward contraction of the atmospheric convergence zone. The winds that blow into the convergence zone therefore become more easterly in the eastern side of the ocean basin, thus causing a further westward contraction of the convergence zone. In this manner are large zonal gradients and low sea surface temperatures established after El Niño events (bu). Both the warm (El Niño) phase of the Southern Oscillation, and the complementary cold phase can therefore be attributed to unstable interactions between the ocean and atmosphere.

4.1.2 Simulation of the Seasonal Cycle of the Tropical Atlantic Ocean

The realism of a simulation of the tropical Atlantic has been checked by comparing results with currents inferred from ship drift data, and with density variations measured by means of Inverted Echo Sounders. The agreement between model results and measurements is, on the whole, excellent (dx). The model displaces a region of thermocline shoaling in the northwestern tropical Atlantic too far north, and displaces effects associated with the Gulf of Guinea, too far west. Whether these features are attributable to the wind will be determined by simulating variability during 1982, 1983, and 1984 when simultaneous wind and oceanographic measurements are available.

A comparison between simulations with the general circulation model, and with a linear version of the model, indicates that nonlinearities are important primarily in the equatorial zone and in the African coastal zone to the south of the equator. The westward surface flow at the equator is weaker, by a factor of two approximately, in the nonlinear case. Below the thermocline the linear and nonlinear results differ because disturbances arrive in the deep ocean by propagating through the fixed, specified thermocline in a linear model, but are forced directly by vertical movements of the thermocline in a nonlinear model.

4.1.3 Simulation of Variability in the Tropical Pacific Ocean

After the successful simulation of El Niño of 1982-1983 (cc), the Pacific model has been run, each month, with wind data for the previous month obtained from the National Meteorological Center in Washington. The results are reported in the monthly Climate Diagnostics Bulletin of CAC. The model provides a coherent picture of current conditions in the tropical Pacific. Such a picture is unavailable from the few scattered "real-time" measurements that are made but the measurements are used to verify the model. The model is now in the process of being transferred to the National Meteorological Center, Washington, where it will be run operationally.

PLANS FY86

In support of the effort to run a GCM of the tropical Pacific operationally, studies will be conducted to determine the data that are necessary to initialize the model.

Model heat and mass budgets will be investigated to determine the role of equatorial upwelling in the large spatial/temporal variability of the tropical Atlantic Ocean.

General circulation models of the atmosphere capable of simulating the Southern Oscillation (av,cq), and of the ocean capable of simulating El Niño (cc) now exist at GFDL. The ambitious task of developing a coupled ocean-atmosphere general circulation model will be started during FY86.

4.2 MARINE GEOCHEMISTRY

F. Bryan	R. Rotter
S. Hellerman	J. L. Sarmiento
M. Jackson	R. Slater
M. Kawase	R. D. Slater
R. Key	J. R. Toggweiler
D. Papademetriou	L. S. Yan

ACTIVITIES FY85

In an effort to produce a biological driver for future ocean chemistry studies, idealized formulations of the ocean's biology are being explored. Aside from ocean circulation, the major pathway by which carbon and other reactive chemical species are cycled within the ocean is the rapid sedimentaion of large bio-organic aggregates produced by grazing marine zooplankton. A simple and generalized set of rules governing the production and flux of these aggregates to depth has been defined, leading to the preparation of a set of coupled differential equations describing the major steps in this sedimentaion process. At present various formulations of the model are being tested under both high and low latitude boundary conditions. Preliminary box models show that atmospheric carbon dioxide is very sensitive to the level of preformed nutrients in high latitude deep water formation regions (611,653).

A study of the interaction between the surface salinity balance and deep water formation and its relevance to the global thermohaline circulation was initiated. To date it has been shown that a sector ocean general circulation model forced symmetrically about the equator has multiple equilibria involving inter-hemispheric circulations and model generated asymmetries in high latitude surface salinities. The development of a seasonally driven model of the North Atlantic Circulation was completed. An analysis of the heat balance in the model is finished (dq) and tracer experiments aimed at understanding the role of surface buoyancy forcing in interior ventilation are underway. The Sr-90 input function is described in (620).

A comprehensive analysis of oxygen, nitrate, and silicate distributions in the North and Tropical Atlantic was carried out using Transient Tracers in the Oceans Project (TTO) data. Comparisons between this and other contemporaneous data sets were conducted in order to provide a firm basis for ongoing work with the three dimensional tracer model. It was found that there exist regions of the interior oceans, namely the equatorial Atlantic and Mediterranean water tongue, where cross-isopycnal mixing of tracers cannot be neglected (cf).

Analysis of samples collected during TTO cruises (676) continues in the Radium-228 laboratory. The techniques developed for these measurements have been described in (674). Measurements made in the Amazon River show a surprisingly large flux of Radium-228 out of sediments in the estuary region (675).

PLANS FY86

The next phase of work on the global carbon cycle will involve integrating the biological formulations into a primitive equation ocean model to simulate carbon cycle response to both ice-age and modern day conditions. An effort will be underway to use the biological cycling model to investigate trace metal cycling.

TTO samples will be analyzed in the bottom waters and the potential vorticity field will be investigated. Field programs involving the study of exchange across the Gulf Stream and a study of tracer/chemical dynamics in the deep northeast Pacific are in the planning stages for the summer of 1986.

4.3 WORLD OCEAN STUDIES

K. Bryan	M. Cox
N. Bogue	K. Dixon
R.-X. Huang	R. Wajsowicz

ACTIVITIES FY85

Eddy-resolving ocean circulation calculations using the full primitive equations of motion (ch) permit a study of the role of mesoscale eddies in the thermohaline circulation. Model calculations indicate that the oceans' mesoscale eddies play a very different role in ocean circulation than would be predicted from an analogy with synoptic scale motions in the atmosphere. Mesoscale eddies in the model are largely generated as instabilities on wind-driven currents. Motion associated with the eddies is irreversible, but largely density conserving. As a result very little net buoyancy transport across latitude circles is associated with the eddies. There is a transport signature associated with the time variant flow, but this heat transport component is approximately cancelled by eddy-driven Eulerian mean flows. On the other hand, the eddy-resolving model calculations do confirm that eddies play a very important role in the redistribution of potential vorticity and tracers within the main thermocline. The model illustrates the great complexity of direct measurements of the role of eddies in the World Ocean Circulation Experiment (WOCE).

Band-pass filtering of the eddy resolving model indicates unusual features at low frequencies. Periods of 40-60 days are dominated by the mesoscale eddies. At longer periods of about one year, zonal jets are present in the subtropical gyre which drift slowly in the meridional direction. These jets are largely barotropic and may be the counterpart of the jet stream in the atmosphere, but with a much smaller scale corresponding to that of the mesoscale eddies. Somewhat similar jets have been observed in the Antarctic Circumpolar Current in the vicinity of the Drake Passage. On the time scale of several years, the subtropical gyre expands and contracts in a regular cycle (see Fig. 4.1). The oscillation appears to be associated with periods of intense ventilation of the subtropical gyre.

A separate study with a coupled model of the ocean and atmosphere (an,ck) indicates the response of the thermohaline circulation of the ocean to a sudden climate warming due to a large increase of atmospheric CO_2. A warming of surface waters at high latitudes means that sinking can only take place to intermediate levels. The thermohaline circulation partially collapses and can no longer support the thermocline, which tends to spread downward. The thickening of the thermocline is important because it could provide a possible short-term negative feed-back for greenhouse climate warming, since a downward movement of the thermocline allows the ocean to sequester more heat from the atmosphere than would be possible otherwise. A partial collapse of the thermohaline circulation could also seriously effect the normal uptake of atmospheric CO_2 by the ocean (see Fig. 4.2).

PLANS FY86

Examination of the eddy-resolving model results will continue with an analysis of the energy propagation by the mesoscale waves. Water mass formation on a global scale will be studied in a model with 100 km by 100 km resolution and 44 vertical levels. The observed distribution of geochemical tracers in the deep sea will be used to test the accuracy of the predicted thermohaline circulation in a hierarchy of models of increasing resolution.

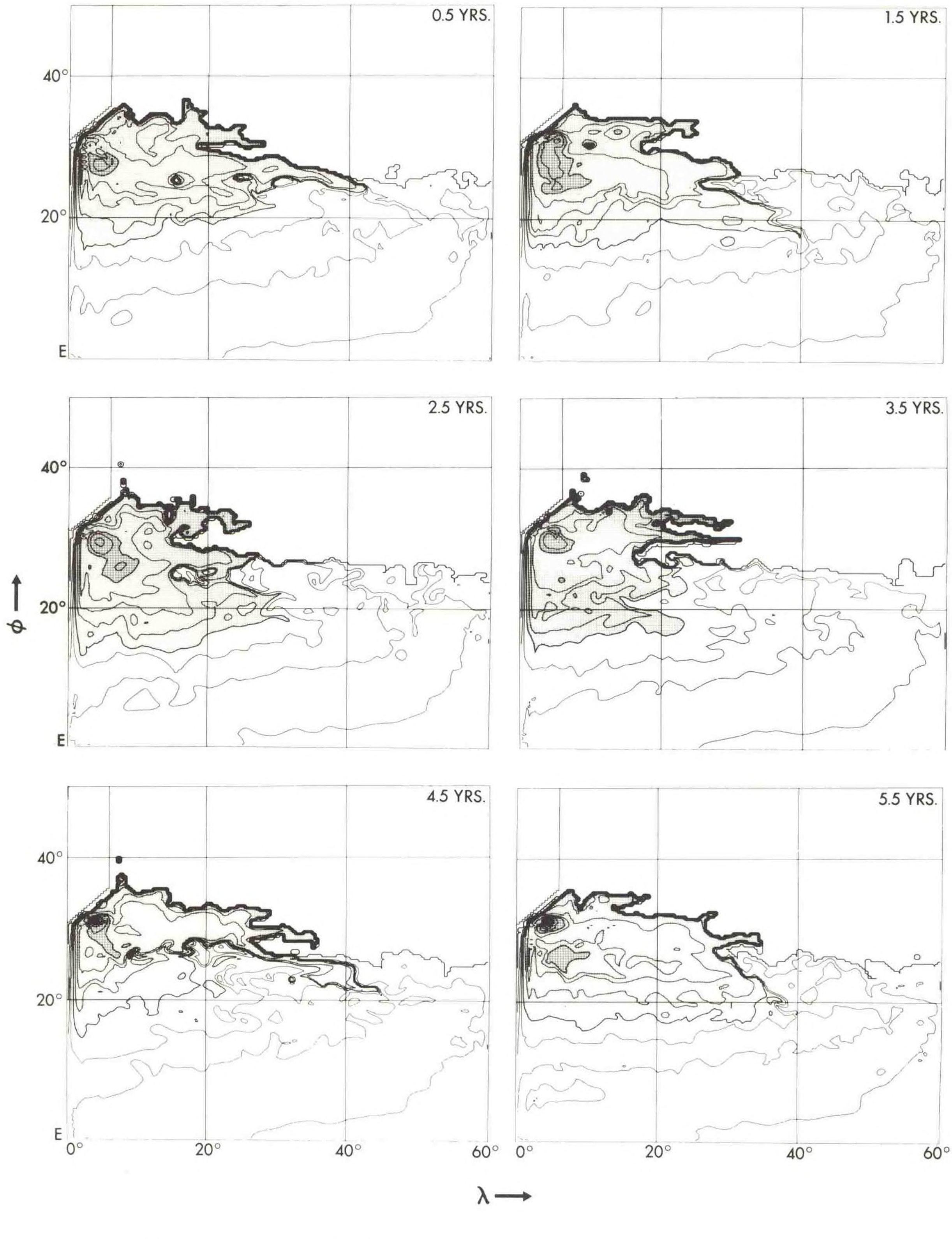

Fig. 4.1 Depth of the 25.5 sigma surface with contour interval of 50 meters and shading greater than 200 meters. Ventilation occurs on a 4 year cycle whereafter the deep section of the surface recedes to the west as a Rossby wave.

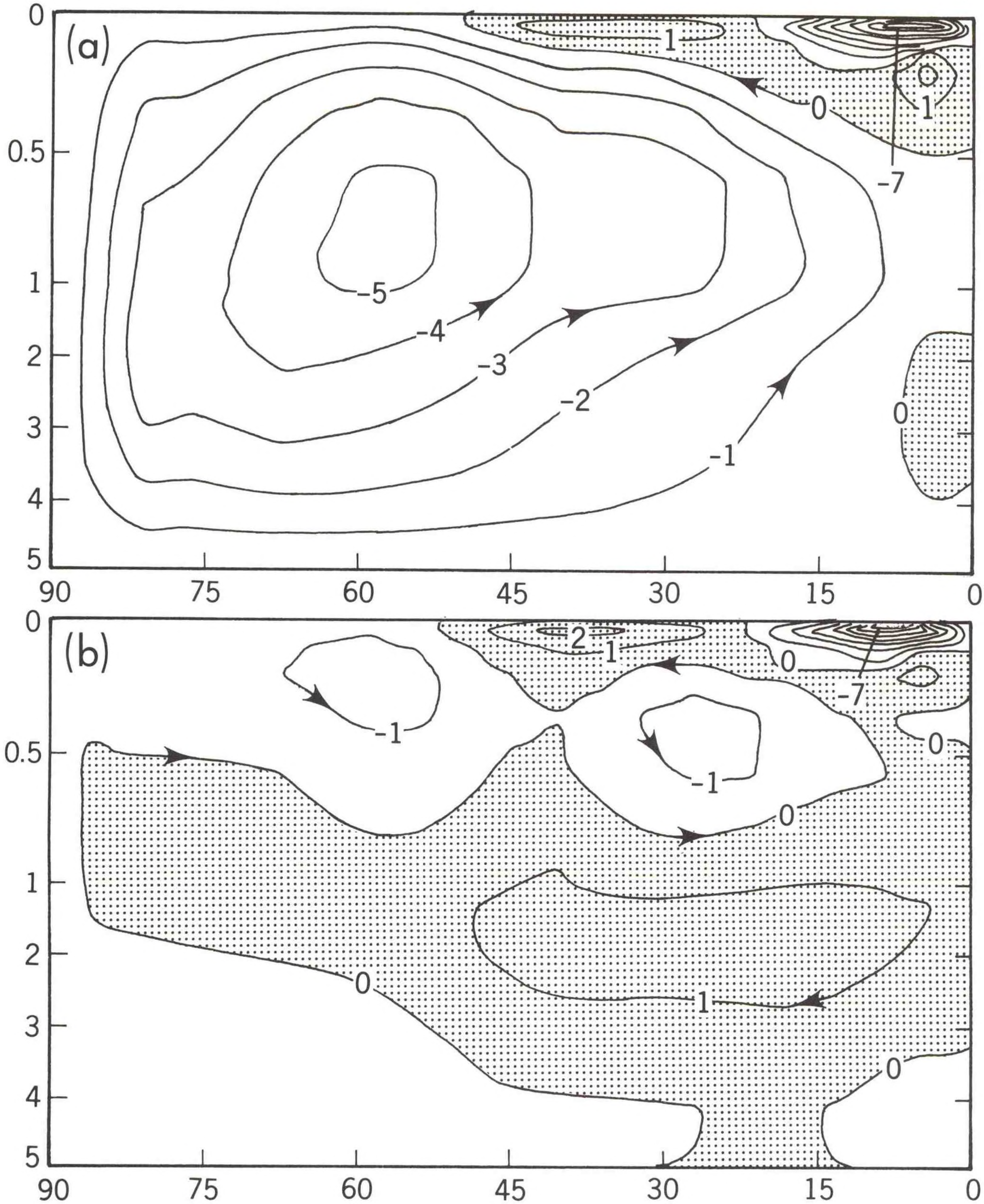

Fig. 4.2 Transport streamlines in the meridional plane in units of 10^9kg s^{-1}. The ocean model has idealized geometry with a symmetry condition at the equator. It is coupled to an atmospheric model. a) The meridional circulation corresponding to an equilibrium climate. b) The "collapsed" meridional circulation averaged over the third decade following a sudden four-fold increase of atmospheric CO_2.

4.4 OCEAN MODEL DEVELOPMENT

K. Bryan M. Cox
R.-X. Huang

ACTIVITIES FY85

An optimized and documented version of the ocean circulation code has been produced and widely distributed within the laboratory and to outside users. Improvements have been made in the parameterization of mixing in the surface mixed layer of the model to represent the effects of forced convection.

Further tests have been made with the ocean circulation model using isopycnal coordinates (cv). This model has been extended to a multilayer configuration. The solutions have been compared to a variety of analytic and numerical results obtained in previous studies. A sea ice model including ice interaction effects has been optimized for the CYBER 205.

PLANS FY86

The model calculation of global water formation will guide further improvements in the representation of vertical mixing in the ocean model. A new diffusion parameterization will be tested on the z-coordinate model in which the mixing tensor is rotated to align with isopycnal surfaces. The development of the isopycnal coordinate model will be extended so that it can be used in tracer studies.

4.5 COASTAL AND ESTUARINE OCEANOGRAPHY

G.L. Mellor
B. Galperin

ACTIVITIES FY85

A cooperative program of numerical modeling, observations and comparisons of simulated and real data is in progress with NOS scientists. The site is the Delaware Estuary and includes the Bay, River and a sizeable portion of the continental shelf. The period for which model simulations and observations coincide is April 1984 to June 1985. A fairly large amount of elevation, current and hydrographic data will be collected. The model is time dependent and three-dimensional and features a free surface, a bottom following, 10 level, "σ-coordinate" grid and a second moment turbulence closure scheme to provide vertical mixing coefficients. The physically larger shelf region (5 km x 4 km) is matched to the Bay (1 km x 1 km) at each time step in the calculation. Preliminary studies indicate that most but not all of the sea level variability due to winds can be calculated even though the alongshore extent of the model shelf is limited.

A numerical simulation study of the New York/Raritan Estuary has been described in (h).

PLANS FY86

The main effort will be a fifteen month simulation of the Delaware Bay, River and adjacent continental shelf followed by analyses of observational and model data and comparisons of the two data sets. Additional studies will attempt to optimize the model forecast skill assuming that winds are known.

4.6 DYNAMICS AND THERMODYNAMICS OF OCEAN-SEA ICE INTERACTION

G.L. Mellor
M. Steele

ACTIVITIES FY85

The Mellor-Yamada turbulence closure model as applied to the ocean surface boundary layer has been extended to include interaction with freezing or melting sea ice. As one example, ice suddenly overlaying relatively warm seawater has been studied. The melting process stabilizes the water column due to the surface production of fresh water. The melting rate is initially rapid, then attenuates within an inertial period as the store of warm water in the mixed layer is cooled.

PLANS FY86

The turbulence closure model, now enhanced to interact with freezing or melting ice, will be incorporated into a two-dimensional (x,z) ocean model. This ocean model will be further extended to include a dynamic and thermodynamic ice model. An attempt will be made to model the marginal ice zone and compare with an available model. This work will be the precursor to a full, three-dimensional model.

4.7 ATMOSPHERIC AND OCEANIC BOUNDARY LAYERS

R. Rajkovic
G.L.Mellor

ACTIVITIES FY85

The goal of this research is to derive an understanding of the dynamic and thermodynamic interaction between the atmosphere and the coastal ocean.

Even though a fully coupled ocean-atmosphere model of the coastal circulations remains an ultimate goal, we have concentrated on the sensitivity of the atmospheric part to the different mean temperature fields and different profiles of the sea surface temperature.

A major result is that when the ocean is forced with wind-stress from a case where the sea surface temperature was variable in the cross-shore direction, we obtained significantly larger upwelling velocities compared to the case that had constant sea surface temperature as the lower boundary condition for the atmospheric run.

5. PLANETARY CIRCULATION

GOALS

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

* To develop numerical models capable of simulating the major features of other planetary atmospheres.

5.1 PLANETARY CIRCULATIONS

G. P. Williams   R. J. Wilson

ACTIVITIES FY85

5.1.1 Planetary Vortices

The dynamics of barotropic planetary scale vortices has been studied in detail and found to be richer and more complex than originally thought. Long-lived vortices were found to occur in midlatitudes and at the equator, but those in the subtropics dispersed unless certain zonal currents were present. Although both sets of long-lived vortices exist under similar forces, the equatorial ones obey a KdV equation, behave like solitons, and exist only for a narrow range of amplitudes and shapes; while the midlatitudinal ones obey the intermediate geostrophic equation, coalesce during collisions, and exist for a wide range of amplitudes. Subtropical vortices behave like midlatitudinal vortices in the presence of certain zonal currents due to the alteration of the eigenfunction character by the latter. A subtropical vortex resembling Jupiter's Great Red Spot was followed for over 100 years to establish the possible longevity of such barotropic vortices.

The genesis of coherent vortices by barotropically unstable currents was found to be complex with a wide variety of end states possible. Factors controlling the number of vortices are the inhomogeneity of the initial perturbation, the width and criticality of the shear zone and the history of the interactions of unequal vortices. Single vortex states - such as the Red Spot - have been duplicated.

An equation that describes all scales of geostrophic motion on a sphere was obtained (654), and found to be most useful for understanding the regional differences in vortex behavior. This equation contains the equations of quasi-geostrophy, intermediate-geostrophy, and planetary-geostrophy as subcases.

5.1.2 Comparative Global Circulations

The diagrams chosen to illustrate the solutions and their analysis for the multiple experiments made to examine the response of different versions of the GFDL spectral GCM to changes in the external parameters (rotation rate, obliquity, diurnal period) were completed. This has allowed the near completion of the work summarizing these calculations.

These comparative circulations hold interesting analogs for the other planets and can be used to construct preliminary or provisional models for them. For example, they suggest that during the upcoming Voyager encounter with Uranus (whose pole now faces the sun directly) the summer hemisphere will not appear banded but just contain broad easterly flow as in the terrestrial summer stratosphere. The winter hemisphere should be banded and a Hadley circulation straddle the equator for about 15°. The status of circulation theory and planetary plus comparative atmospheric modeling was analyzed and described (670).

PLANS FY86

Immediate goals call for the completion of the manuscripts describing the dynamics of barotropic planetary vortices and comparative global circulations.

Model development will continue for the atmospheric circulations of Jupiter and Venus and be used initially to explore the existence of coherent vortices in baroclinic fluids to develop more realistic models of the Great Red Spot.

5.2 VENUS ATMOSPHERIC TIDES

S. B. Fels

ACTIVITIES FY85

The main work using the WKB-like method developed previously for treating the Venus tidal problem has been completed (640). The simplicity of the technique has made it possible to work backward from the structure of the observed tidal radiances to that of the underlying zonal mean wind. A plot of this field is shown in Fig. (5.1a), while Fig. (5.1b) shows the same quantity as deduced by Schubert and his collaborators based on very different considerations. While there are differences, the similarities are striking. Especially interesting is the midlatitude jet, whose existence was first inferred in the tidal study .

The above study was primarily concerned with the effect of the zonal mean flow on the tides, but the converse problem is equally important. Results from the tidal model can be used to calculate the Eliassen-Palm flux divergence, and therefore the tidal forcing on the zonal flow. The results of such calculations suggest strongly that the dramatic decrease in the strength of the zonal wind above 80 km is due largely to absorption of the upward propagating semi-diurnal tide by radiative damping. For details, see (db).

PLANS FY86

In collaboration with workers at Harvard, an attempt will be made to construct a self-consistent tidal-mean flow model of the Venus upper atmosphere.

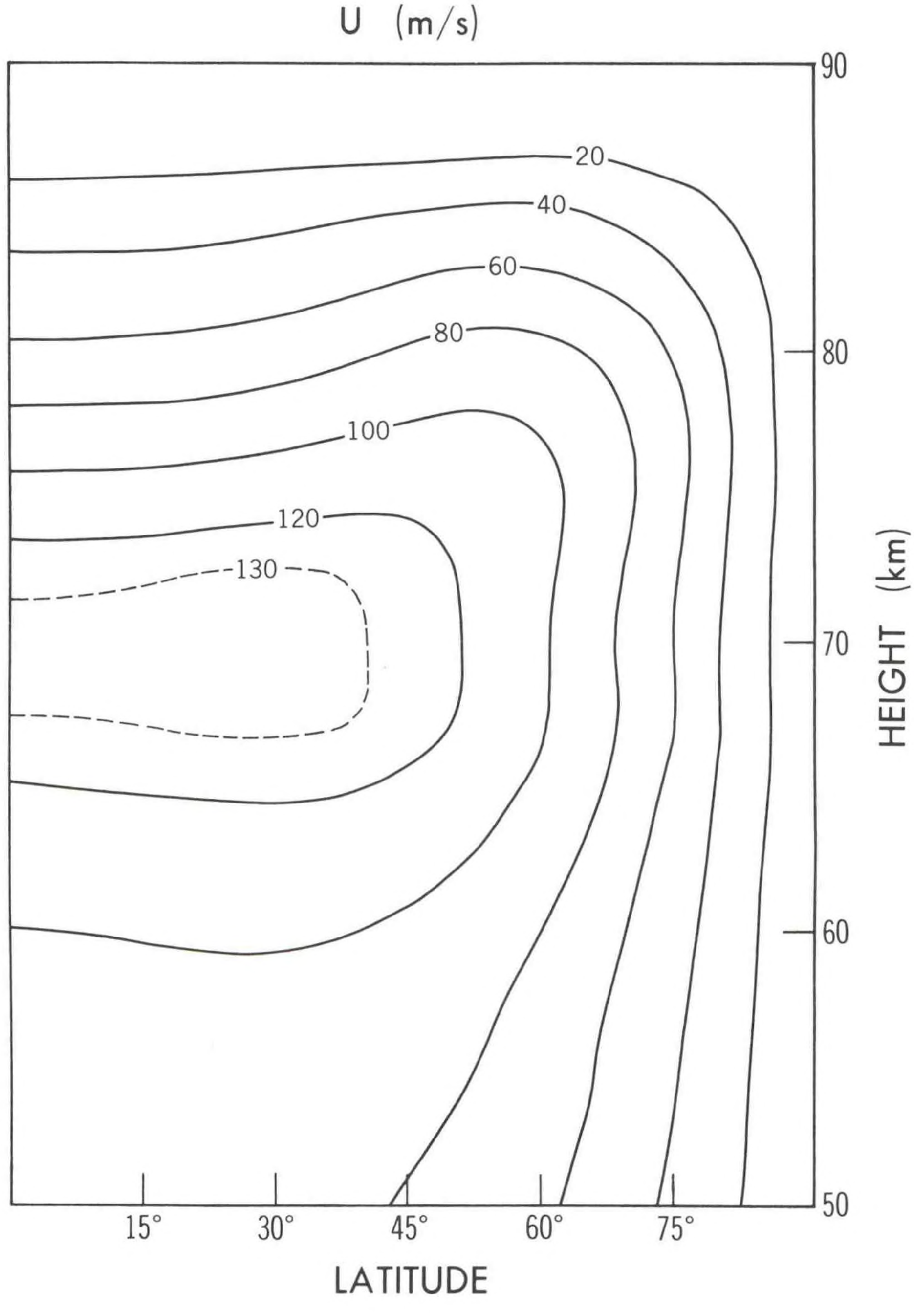

Fig. 5.1(a) Vertical and meridional structure of the zonal mean wind deduced from the theoretical tidal model.

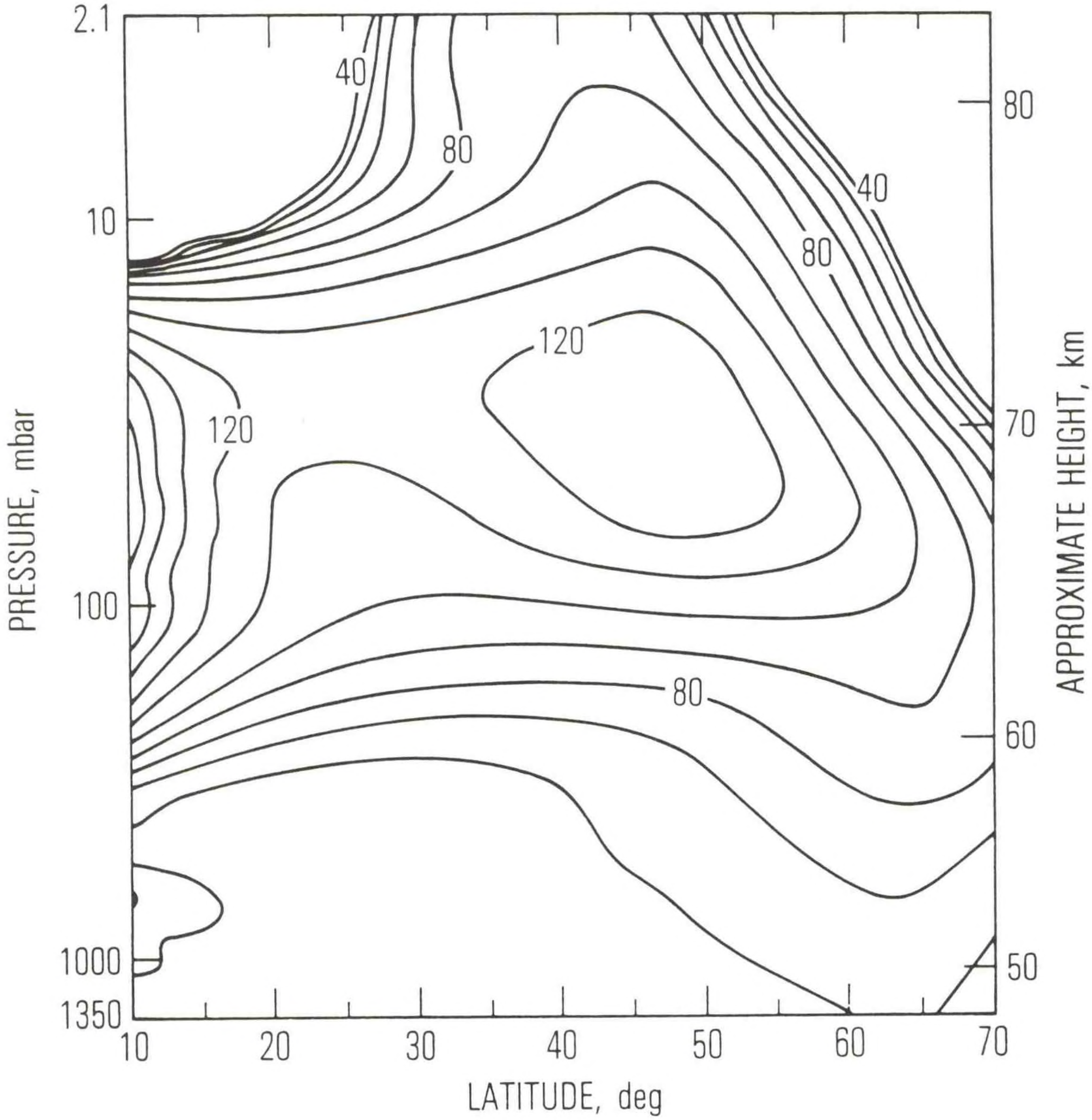

Fig. 5.1(b) As in Fig. 5.1a, but deduced by G. Schubert and collaborators based on different considerations.

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 model atmospheres and model oceans developed at GFDL and thereby develop a feedback to enhance understanding in both areas.

6.1 CLIMATE OF THE ATMOSPHERE

N.-C. Lau
N. Nakamura
M. J. Nath
A. H. Oort
M. Rosenstein
S. Fagen
M. Forman
J. P. Peixóto *

* University of Lisbon, Portugal

ACTIVITIES FY85

6.1.1 Data Processing and Comparisons Between Various Analyses

Improved checking and processing procedures for the daily rawinsonde data from the operational NMC tapes since May 1973 were completed in order to update the GFDL 15-year data set up to the FGGE period (1979). The objective analysis scheme for the monthly statistics has been converted to work on the CYBER 205 computer, and is being revised to allow for an increase in spatial resolution from about 5° to 2° latitude. The data distribution on the NMC tapes appears adequate for global analyses of the monthly anomaly fields.

Monthly, seasonal and annual circulation statistics based on FGGE Level III-B analyses produced by GFDL have been completed (624). A subset of these statistics has been compared with the corresponding products generated by ECMWF (629). The major findings have been summarized (632,cn). Computer software has been developed to make these data sets readily accessible by outside users.

A comparison between monthly statistics based on FGGE level III-B analyses produced by GFDL and ECMWF and those based on the GFDL traditional objective analysis scheme has been completed (643). Interpretation of the differences shows deficiencies in each of the independent approaches, and suggests that both should be pursued in the near future.

6.1.2 Hydrological Cycle

Earlier results (628) on the differences in the water balance over oceans and continents have been analyzed in more detail for the Asian monsoon region (ci). The aerological method showed a very strong source of water vapor over the eastern Arabian Sea during the months of May through September. Year-to-year variations in precipitation and evaporation over the western Equatorial Pacific and over Northern India were found to be well correlated with ENSO events.

6.1.3 Structural and Propagation Properties of Transient Eddies

The three-dimensional structure and propagation characteristics of observed transient waves with different time scales have been investigated using gridded analyses produced by the NMC for the past 18 years. Teleconnection charts reveal baroclinic wave activity along the principal cyclone tracks, Rossby wave dispersion along preferred ray paths, as well as geographically fixed see-saw phenomena. A parallel study employing GCM-simulated time series indicates that similar phenomena are generated in the model atmosphere (597,666).

6.1.4 Diagnosis of GCM Simulation of 30-50 Day Oscillations in the Tropics

A strong signal of tropical oscillations with a period of 30-50 days has been detected in a 15-year GCM integration. These eastward moving oscillations are of global scale. They influence the zonal wind, sea level pressure and 200 mb height fields, as well as the monsoonal precipitation over South Asia. Prominent wave activity related to these oscillations is also evident in the wintertime extratropics. The above characteristics are in close agreement with existing observational results.

PLANS FY86

Processing of the post-April 1973 rawinsonde data will continue and global monthly anomaly fields will be generated. For the Southern Hemisphere extensive comparisons will be made between our analyses and those made operationally in Australia in a joint project with Dr. David Karoly of Monash University, Australia.

Research on the energy transports in the ocean-atmosphere system (644) will continue in collaboration with Drs. Tom Vonder Haar and Garrett Campbell from Colorado State University. Regional energy balance studies are planned for polar caps in the Arctic and Antarctic, and for other regions jointly with Prof. José Peixóto, University of Lisbon, Portugal.

In collaboration with the Royal Observatory of Hong Kong, a 10-year set of observed meteorological fields over East Asia will be analyzed. Particular attention will be paid to the Mei-yu front, the low-level jet associated with the summer monsoon, the severe cold air outbreaks associated with the winter monsoon (631), and synoptic disturbances over the Tibetan Plateau.

The ongoing diagnosis on eddy structures and the interaction between transient waves and the time averaged flow will continue. Long-term data sets of both the observed and model atmospheres will be analyzed.

The origin of the 30-50 day oscillations in GCM integrations will be further investigated by diagnosing model runs with different boundary conditions to show the role of SST variability, orography, land-sea contrast and the seasonal cycle. The fidelity of these model features will be tested using the observed global outgoing long-wave radiation and NMC wind data sets.

6.2 AIR-SEA INTERACTIONS

N.-C. Lau	M. Rosenstein
S. Levitus	M. Forman
M. J. Nath	Y.-H. Pan*
A. H. Oort	

ACTIVITIES FY85

6.2.1 Data Processing

Using an objective analysis scheme developed earlier (528), monthly 1°x1° analyses of the sea surface temperature were generated based on the Comprehensive Ocean-Atmosphere Data Set (COADS). A reliable climatology was created using the recent 1950-79 data north of 20°S and all historical data south of this latitude. The SST anomaly analyses for each month since January 1920 show the general similarity between the different ENSO events during the last 60 years but with more pronounced events during the second half of the period (bw).

6.2.2 Diagnosis of GCM Simulations of Atmospheric ENSO Phenomena

In collaboration with the Climate Dynamics Project at GFDL, two 15-year GCM integrations have been performed with the lower boundary over the tropical Pacific being forced by observed SST fluctuations during the 1962-76 period. Composite analysis indicates that typical ENSO events are realistically simulated (av,cq).

A comparison study has been performed contrasting the atmospheric variability in the above ENSO experiment with that in a control experiment with no interannual SST changes imposed. The perturbed SST experiment exhibits significantly stronger variance along the entire tropical belt, whereas the corresponding enhancement in the middle latitudes is much weaker. Certain spatial modes of variability are generated internally in the GCM, whereas other modes are strongly linked to anomalous SST forcing in the tropical Pacific.

Detailed budget analysis of the balances of water vapor, heat and moist static energy of the model atmosphere during different stages of ENSO has begun.

PLANS FY86

The analysis of the COADS data set will be extended to include other parameters, such as air temperature, pressure, specific humidity and the horizontal wind components. This will involve close cooperation with Drs. E. Rasmusson and R. Reynolds of the Climate Analysis Center in Washington, D.C.

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* On one-year visit beginning June 1985 from Academia Sinica, Beijing, China supported by grant from EPOCS Council.

Budget analysis of the balances of moisture and heat energy during an ENSO episode will continue, with specific emphasis being placed on the role of interactions between the tropical and extratropical circulations.

In collaboration with the Climate Dynamics and Oceanic Circulations Projects at GFDL, a simulation of ENSO phenomena using ocean-atmosphere coupled GCMs will be attempted, and history tapes from these preliminary trial runs will be analyzed.

6.3 CLIMATE OF THE OCEAN

S. Levitus S. Fagen
A. H. Oort

ACTIVITIES FY85

6.3.1 Data Processing

Because of great demand the Climatological Atlas of the World Ocean (528) is being reprinted by the U.S. Government Printing Office. A systematic reordering of the subsurface data has begun to allow for interannual variability studies of the oceanic heat storage.

6.3.2 Heat and Salinity Balances

Research on the general features of the annual cycle of salinity and salt content in the world ocean has been completed (di). Large seasonal variations in the global salt content are found suggesting important seasonal variations in oceanic evaporation and in storage of water in liquid and solid form over land.

Computations of the meridional Ekman heat transport in the world ocean were performed in collaboration with Dr. Eric Kraus of CIRES, Boulder, showing a large seasonal variation in the tropical heat flux.

PLANS FY86

The updated (1985) Fleet Numerical Oceanographic Center (FNOC) MOODS data set will be obtained and unpacked. FNOC has added an additional 500,000 XBT casts to their file. The new data set doubles the number of XBT casts used in the previous analyses.

Fourier analyses of the sea surface temperature and heat content will be completed for the World Ocean. Interannual variations of the oceanic heat content in the North Atlantic will be studied. Research on the role of the oceans in the angular momentum (see Fig. 6.1), hydrological and energy cycles of the earth will continue.

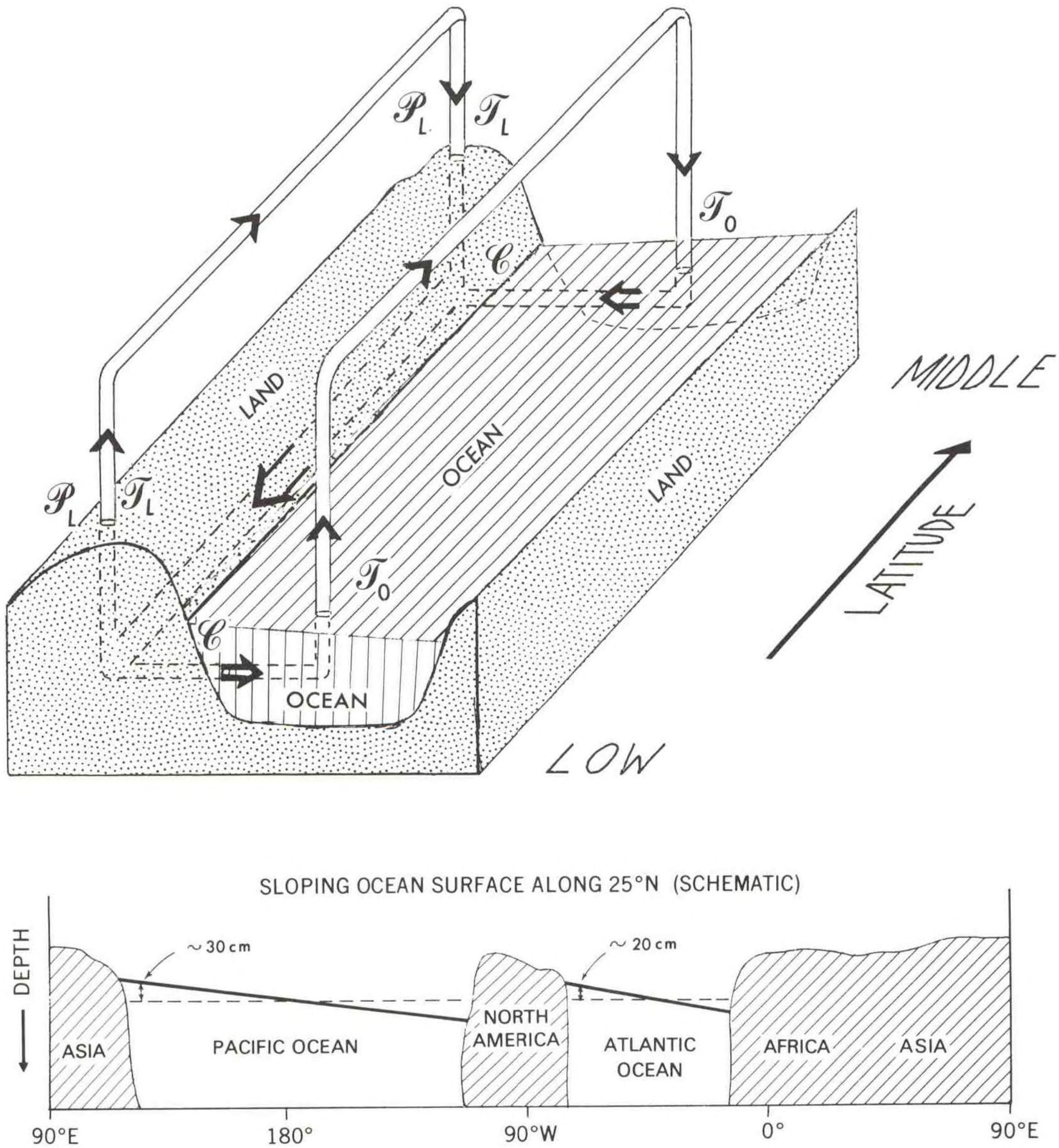

Fig. 6.1: A new picture of the global cycle of angular momentum in the atmosphere-ocean-solid earth system (665):

(top) Schematic diagram of the poleward flow of westerly angular momentum in the atmosphere from the low-latitude source regions to the middle and high-latitude sink regions, and the necessary equatorward return flow in the land. The atmosphere gains and/or looses its angular momentum over land through the mountain ($\mathcal{P}_L$) and friction ($\mathcal{T}_L$) torques and over the oceans through the friction ($\mathcal{T}_0$) torque.

(bottom) Since the ocean currents are too weak to transport the required angular momentum equatorward, the entire return flow has to take place in the land. The role of the oceans is only to transfer the angular momentum in the east-west direction and into the continents through the continental pressure torque ($\mathcal{C}$). This last torque comes about by the observed east-west slope of sea level, as shown here near 25°N and by similar (but of opposite sign) sea level differences in middle latitudes.

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.

* To investigate the capability of numerical models in the prediction of hurricane movement and intensity.

7.1 GENESIS AND DECAY OF TROPICAL CYCLONES

R. E. Tuleya Y. Kurihara
M. A. Bender

ACTIVITIES FY85

7.1.1 Effects of Mountainous Islands

To study the effects of mountainous islands on the behavior of tropical cyclones, model storms, which developed from simple, idealized initial conditions, were time integrated with realistic land and mountain distributions specified. This work is an extension of the previous work (647). Use of a triply nested, movable mesh model with the finest resolution of 1/6 degree enabled the detailed topography to be resolved in the storm area.

Simulation experiments with easterly steering flows of 5 and 10 m s^{-1} were carried out for three regions of high tropical cyclone frequency: (1) Northern Caribbean Sea, with a chain of mountainous islands (Cuba, Hispaniola, Puerto Rico) extending in a west-east direction, (2) Taiwan, with a narrow, steep mountain range, and (3) Luzon Island of the Philippines, with wider mountain ranges than that of Taiwan. It was found that the movement of tropical cyclones, both direction and speed, is significantly affected by realistic mountains, especially in the case of 5 m s^{-1} steering flow. Computed tracks are shown in Fig. 7.1 together with some observed ones. An important factor, which contributed to the intensity change of hurricanes in the Caribbean Sea as well as the weakening of typhoons upstream of Taiwan, was the advection of dry air from mountain areas. Also, some interesting structural changes, such as the formation of low level vortices at the lee side of mountains of Taiwan and the redevelopment of tropical storms over the open sea west of Luzon after crossing the island, were simulated. The obtained results agree rather well with observational statistics or synoptic analyses of certain actual cases. Thus, it can be suggested that the inclusion of detailed topography is necessary for the numerical study of regional characteristics and the prediction of tropical cyclones in particular regions.

7.1.2 Hurricane David

Work has continued to study the evolution of Hurricane David (1979) from a wave disturbance. A model of 1/4 degree grid resolution was intialized with the ECMWF FGGE IIIB data set for 00Z, 25 August 1979. Several experiments, some of which using modified initial conditions, were performed. Accurate prediction of the moisture field including the estimate of latent heat release as well as vertically coherent structure of the initial disturbance are essential for the simulation of the genesis phase of a tropical storm in general. The degree of correspondence between the distribution of computed precipitation rate after 18 h of model integration and the satellite cloud imagery is seen in Fig. 7.2. Movement of the model storm for 72 h agreed fairly well with the observed track. Comparison experiments confirmed a previously obtained result (465), namely the effect of radiation makes a significant, positive contribution to the development tendency.

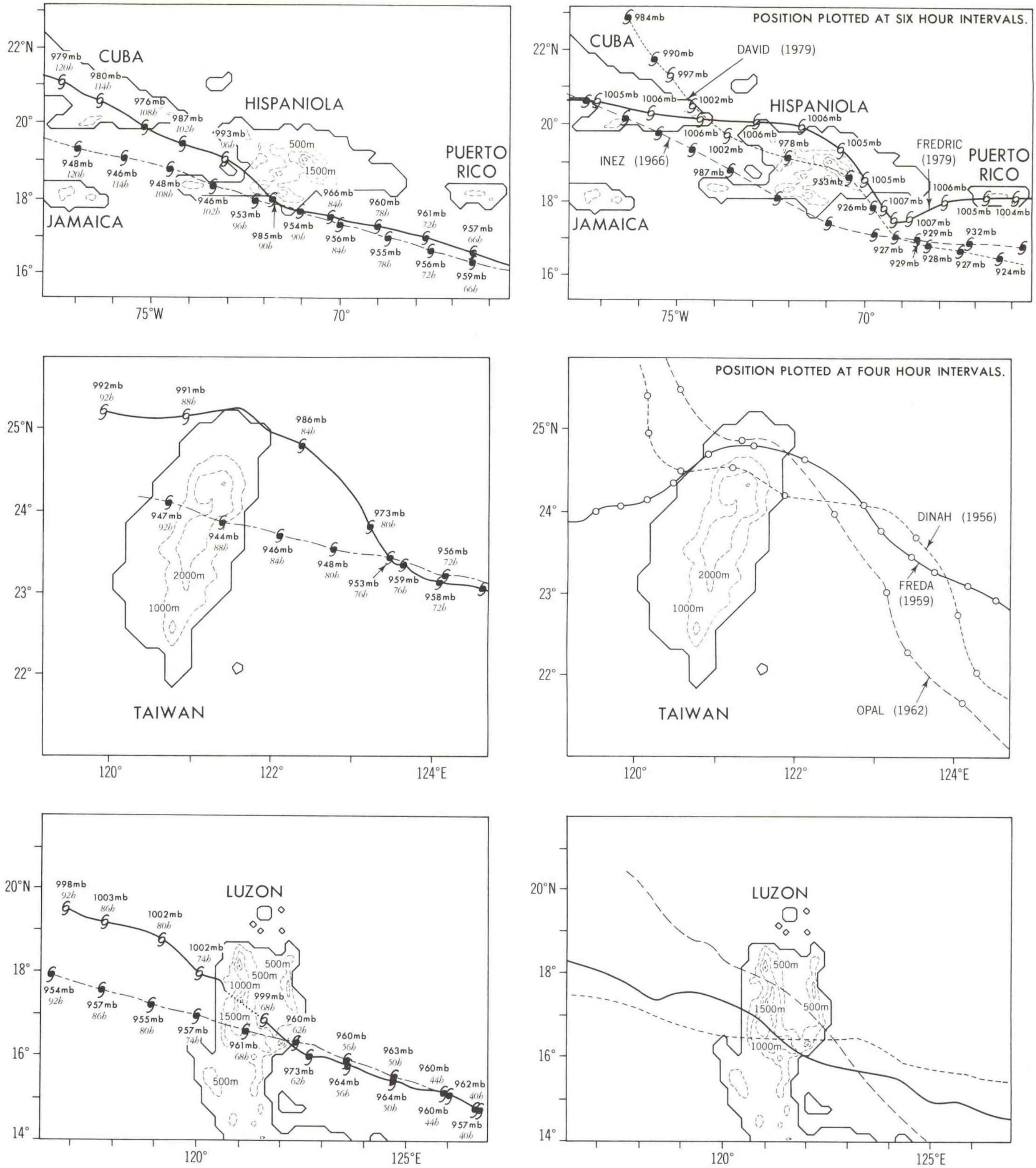

Fig. 7.1 Left: computed track and surface minimum pressure of tropical cyclones superposed on a 5 m s^{-1} zonal wind, with the effects of the indicated land and mountain distributions (solid lines) and with these effects excluded (dash-dotted lines). Right: observed tracks of some tropical cyclones.

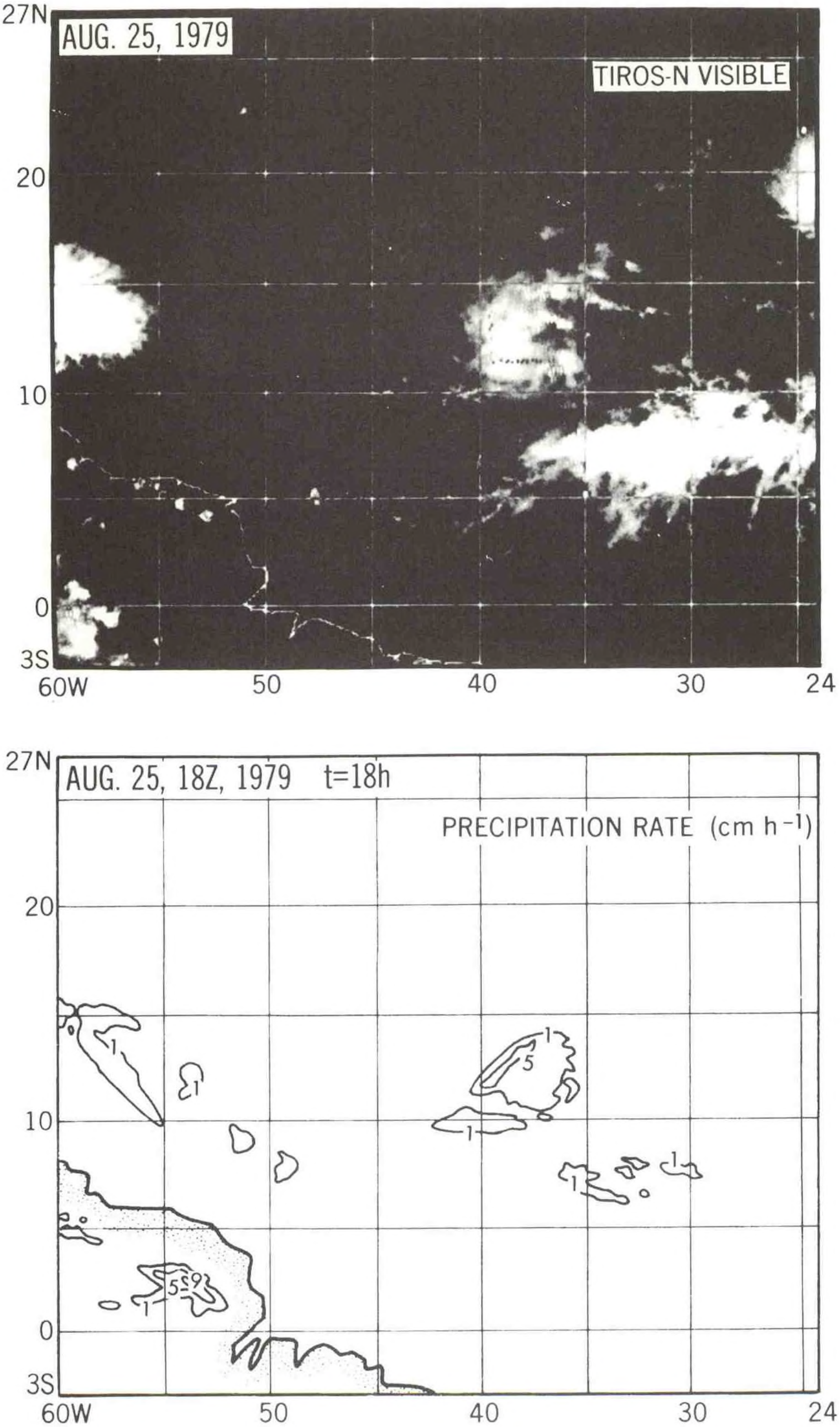

Fig. 7.2 Top: Tiros-N visible imagery on 25 August, 1979. Bottom: computed distribution of precipitation intensity at 18Z, 25 August, 1979, i.e., 18 hours after the initial time.

7.1.3 Supertyphoon TIP

Prediction capability of the present model was examined by the specification of an unusually large real vortex in the initial condition. The selected case is the Supertyphoon Tip (1979), 00GMT, 9 October 1979. Comparison of the two FGGE IIIB data sets, one processed at GFDL and the other at ECMWF, revealed common features as well as differences between the two data sets. Results of preliminary experiments are being analyzed to examine the role of various physical processes and numerical procedures in this enormous circulation system.

PLANS FY86

Results of the simulation experiments of tropical cyclones influenced by realistic land and mountain distributions will be further analyzed and summarized.

Study on the genesis of Hurricane David will continue with attention to boundary layer structure and vertical coupling process.

Investigation on the effects of the large-scale environment on the structural change of tropical cyclones will continue by means of idealized experiments.

7.2 EXPERIMENTAL HURRICANE PREDICTION

M. A. Bender R. E. Tuleya
Y. Kurihara M. DiPaola

ACTIVITIES FY85

7.2.1 Model Improvement

Through the numerical simulation studies of Hurricane David and Supertyphoon Tip (7.1.2 and 7.1.3), it was found that the present parameterization scheme of diffusion effects might need modification. A problem concerning the level 2 formula of turbulence closure scheme is the cut-off of diffusion at the critical Richardson number. Methods to alleviate it were sought and examined. It seems that the addition of background turbulence may be a simple solution. As to the horizontal diffusion, comparison of the so-called fourth order scheme with the present scheme of non-linear diffusion is under way.

Better formulation of lateral boundary conditions for regional models is a continuing problem. A test of various schemes to treat mass flux at the boundary was conducted.

Progress is being made to improve the analysis program, including the graphics package, in order to raise the quality and promptness of the analysis of the numerical results of simulation experiments.

7.2.2 Initialization Scheme

An initialization method of a tropical cyclone model was considered, consisting of non-static diagnosis of mass field, diagnosis of heating rate, diabatic dynamic initialization and diagnosis of moisture field. It was assumed that the available data in worst cases would be only wind data in the free atmosphere. Part of the scheme was tested with a slab symmetric model and promising results were obtained. The level of representation of real atmospheric state by the initial state derived with the proposed scheme will be below that with four-dimensional continuous data assimilation but definitely above that with adiabatic initialization schemes.

PLANS FY86

Model performance with modified formulation of the diffusion effects will be tested in the simulation experiments of Hurricane David and Supertyphoon Tip. Study of open lateral boundary conditions will continue.

Programming and testing of the initialization scheme formulated in the previous year will be performed first with a slab symmetric model. Application to the three dimensional model may be considered later.

With the purpose of improving the operational prediction skill of hurricanes, collaboration with the National Meteorological Center may be established to discuss strategy for developing an advanced operational model.

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 dynamics of mesoscale phenomena and their interaction with larger and smaller scales.

* To determine practical limits of mesoscale predictability by means of sensitivity studies on numerical simulations of mesoscale phenomena.

8.1 THE GENERATION OF MESO-CYCLONES

I. Orlanski N. Nakamura
L. Polinsky

ACTIVITIES FY85

8.1.1 Local Baroclinicity

A study has been made using a two-dimensional numerical model to investigate the evolution of mesoscale disturbances on a mean baroclinic state. Three main problems were considered: the effect of static stability on meso-baroclinic waves in a periodic domain; downstream instability in an open domain, including the effect of surface sensible heat; and the effect of moisture on these unstable waves.

It was found that a flow can be unstable to mesoscale baroclinic waves. The instability condition that wavelengths be less than 1000 km is similar to that for the planetary, quasi-geostrophic baroclinic waves. These unstable waves will only be sensitive to the baroclinicity of the atmosphere in a layer with a depth of the Rossby penetration height. Characteristics of the finite-amplitude unstable waves suggest that the limiting amplitude for the baroclinic waves is achieved by an energy cascade to frontal scales. The most significant finding of this study has been to demonstrate the importance of localized surface heating in producing the more intense development of short baroclinic waves. It was also found that waves in the presence of surface heating grew twice as fast as those without. These waves, which have a depth on the order of the boundary layer and horizontal scales of a few hundred kilometers, can organize convergence of surface moisture on these scales. With the addition of moisture, the waves will explosively develop into an intense meso-cyclone (Section 8.1.2).

Also, basic characteristics of mesoscale, non-geostropic baroclinic instability are being examined by means of a simple analytic model. Results show that non-geostrophy causes the system to be significantly unstable for scales of several hundred kilometers, whereas it is otherwise stable.

8.1.2 Polar Lows

A study has been made (615) of cold air cyclones, known as polar lows, which develop over extratropical oceans in the unstable air mass behind a major frontal cloud band. A 48-hour numerical simulation was made of one such observed polar low (occurring on 11-12 January 1979) which exhibited explosive cyclogenesis. In order to clarify the importance of latent heating versus surface sensible heat flux for the cyclone's development, sensitivity tests were performed with three different cases: one without moisture, one with observed moisture, and one with enhanced moisture. The case without moisture (and hence without latent heat) produced a weak low-pressure system which did not grow in time. However, with the inclusion of moisture, and particularly with enhanced moisture, both the polar low and the frontal system showed an intensifying surface vorticity, with the comma cloud associated with the polar low and the frontal cloud band tending to merge in the case with enhanced moisture. These results indicate that latent heating is crucial to the explosive cyclogenesis of the polar low, whereas surface sensible heat flux provides the triggering mechanism (Section 8.1.1) which causes the initial disturbance to develop.

PLANS FY86

A manuscript describing the polar low research will be prepared.

Further studies will be made of the effect of surface heat flux on cyclogenesis.

An analytical investigation of the local baroclinicity problem will be carried out in connection with numerical experiments to better understand the physical mechanism involved.

8.2 COASTAL CYCLOGENESIS

I. Orlanski J. Katzfey

ACTIVITIES FY85

The nested limited-area (HIBU) model has successfully predicted the explosive development of the Presidents' Day snowstorm of 18-19 February 1979. A detailed representation of the performance of the model with 50-km resolution is shown in Figure 8.1, which contains 18-hr and 24-hr forecasts and corresponding observations (from Bosart, 1981).* The success of the model's forecast of wind speed, pressure, and temperature is remarkable, although some discrepancies are evident. For the 6-hr accumulated precipitation forecast (shading), reasonable agreement is found west of the storm, while the forecast fails to produce sufficient precipitation north of the storm center. The initial development occurred in a manner consistent with the theoretical study described in (8.1.1). Latent heat release caused this initial disturbance to rapidly intensify.

Model sensitivity to the quality of initial data, quality of boundary data, and model resolution were conducted with: (i) the global spectral model; (ii) the nested HIBU model at low resolution (150 km); and (iii) the nested HIBU model at high resolution (50 km). Both the GFDL and ECMWF four-dimensional analyses of the global FGGE data were used as initial conditions. It must be emphasized that FGGE data used for initialization is of relatively coarse horizontal resolution (800 km) for mesoscale simulations. This coarse initial data did not prevent the high-resolution model from accurately predicting the mesoscale structure of the low pressure system. Moreover, these results indicate that high model resolution is required to produce accurate forecasts of the storm's structure, intensity, and position.

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*Bosart, L. F., 1981: The Presidents' Day snowstorm of 18-19 February 1979: A synoptic-scale event. Monthly Weather Review, 109, 1542-1566.

TEMPERATURE, PRESSURE, WINDS, AND 6 HR. PRECIPITATION (Z=sea level)

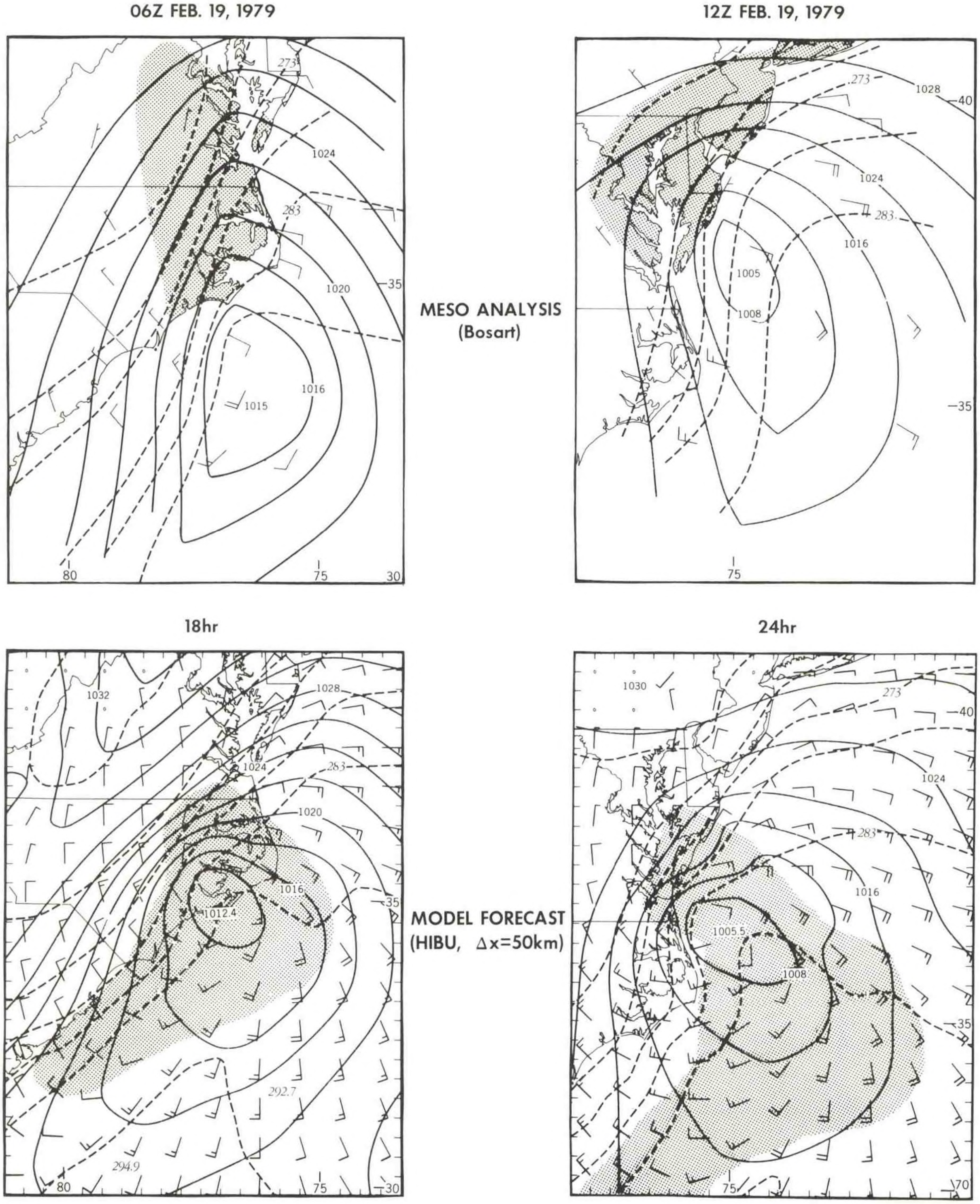

Fig. 8.1 Horizontal distributions of 18 and 24-hr forecasts of the high resolution (50 km) HIBU model (bottom) together with the corresponding observed distributions as analyzed from ship reports and local stations (top) (from Bosart, 1981). Winds (half barb = 5 ms^{-1}; full barb = 10 ms^{-1}), temperature (K, dashed), surface pressure (mb, solid), and precipitation (Shaded areas indicate accumulated 6-hr precipitation greater than 1 cm). No precipitation observations are available over oceanic areas.

PLANS FY86

Testing of the importance of initial and boundary conditions for numerical predictions will be completed. The dynamics of coastal cyclogenesis will continue to be studied through analysis of frontogenesis and the use of trajectories.

8.3 MESO-CONVECTIVE SYSTEMS

I. Orlanski B. Ross

ACTIVITIES FY85

8.3.1 Low-Level Updrafts in Stable Subcloud Layers

An investigation has been completed (dm) of the stability of a convectively unstable atmosphere in the presence of a stable stratified layer beneath, moving with a constant velocity relative to the upper air. This work is an extension of a linear model which was developed earlier (613) to explain the structure of a simulated squall line. A stability analysis shows two unstable modes to be possible: a convective or gravitational mode and a Kelvin-Helmholtz mode. The convective mode, which is of primary physical interest, produces an updraft structure similar to updrafts in the subcloud layer of convective systems. Analysis of the vertical structure of the convergence field in this mode indicates that the slope of the updraft depends primarily on the wind, the stratification, and the depth of the stable lower layer. A simple relationship between these parameters, shown graphically in Fig. 8.2, provides a method for determining whether a dual (upshear sloping) or single (vertical) updraft will occur in the subcloud layer of a convective system.

8.3.2 Mesoscale Forcing of Convective Systems

A detailed analysis has been made of a simulation of the formation of the squall line which developed over Texas during the first observing day of the SESAME Experiment. While this simulation with 20-km resolution used a mesoscale model with simplified physics, it has been shown (ce) to produce a successful simulation of the squall line. Comparison of solutions with and without latent heating indicates that the evolution of a mesoscale convergence zone in the non-latent-heat case is sufficient to explain the development of the squall line. This convergence was created through the interaction of three different air masses. Initially, lifting occurred at the edge of the capping inversion as very warm but drier air from the Mexican Plateau moved up over cooler, moist air from the Gulf of Mexico. This upgliding motion was responsible for earlier cellular convection in the moist model. However a third air mass, indicated by a cold front moving from the northwest, was necessary to generate the squall line. As this front moved into the moist maritime air to the east and realigned the pre-existing convergence zone, the frontal lifting triggered a line of deep squall-line convection in the moist model as was observed. While latent heating was not required for the proper evolution of the convergence zone, diabatic effects acted to intensify and narrow this zone and to produce the resulting deep penetrative convection.

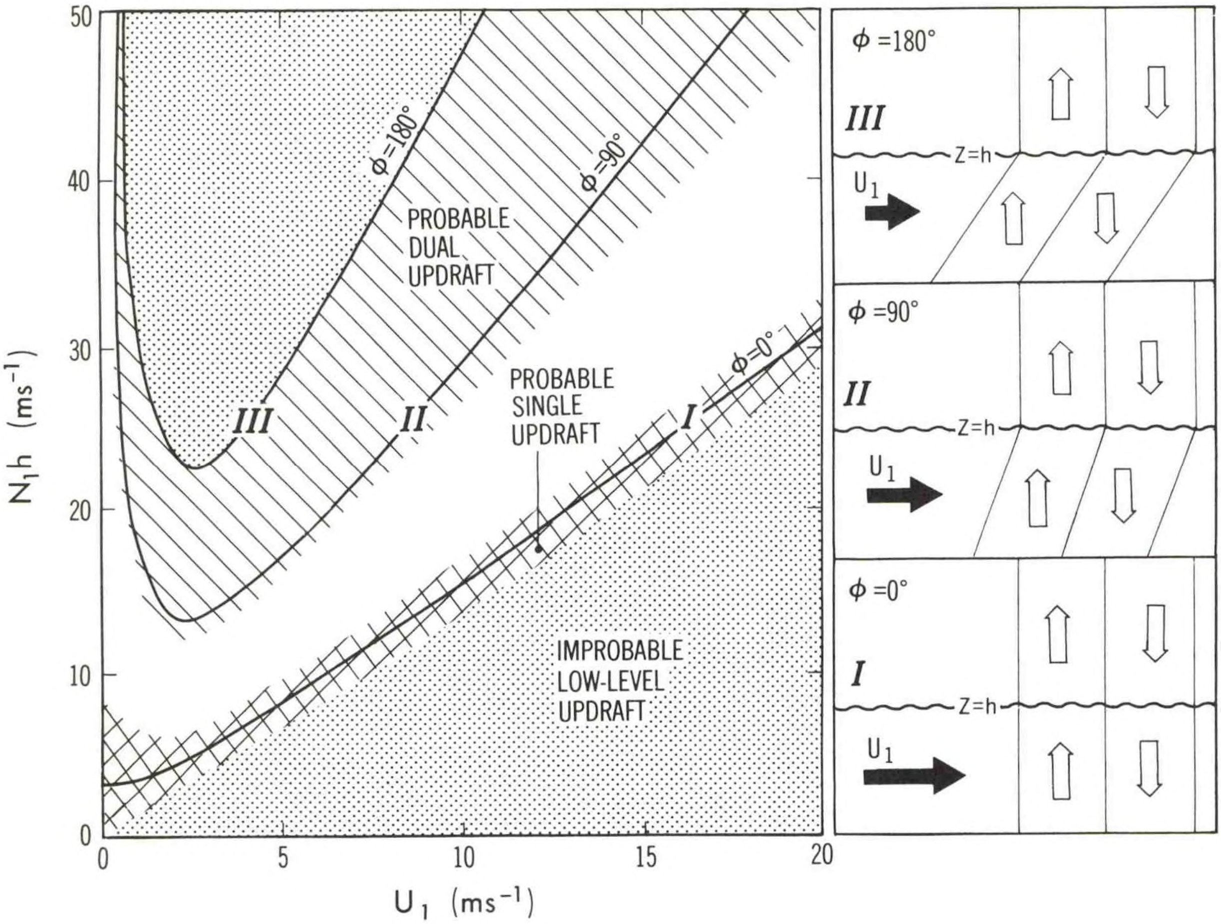

Fig. 8.2 Figure summarizing dependence of phase shift, ϕ, on low-level wind, U_1, and the product of stratification, N_1, and depth, h, of the stable lower layer for a representative convective system. Cross-hatching indicates the range of probable single updraft, hatching indicates probable dual updraft, and stippling designates parameter ranges for which low-level updrafts are unlikely to occur in nature. Schematic diagrams on the right show the structure of the updraft-downdraft system for cases with phase shifts of 0°, 90°, and 180° with the Roman numerals I, II, and III on the curves corresponding to those in the schematic diagrams.

PLANS FY86

Further meso-β simulations will be carried out to investigate the development of other mesoscale convective systems.

Also, collaborative research will be carried out in conjuction with the GFDL Convection Group to use the above simulation to provide boundary conditions for a nonhydrostatic, meso-γ cloud model in an effort to resolve the formation of convective cells at the leading edge of the squall line.

8.4 OROGRAPHIC EFFECTS ON MESOSCALE SYSTEMS

I. Orlanski B. Wang
J. Katzfey

ACTIVITIES FY85

Cyclogenesis in the lee of the Andes Mountains of Chile is under investigation using the nested limited-area (HIBU) model. Development of mesoscale lee cyclones forced by the high, narrow mountain chain has not been studied extensively and is inaccurately predicted in the global models. However, these cyclones have important implications for the weather and climate of the region. The role of the mountains in upstream blocking also needs to be investigated. Simulations of this phenomenon will provide an additional test of the nested HIBU model.

The heavy rainfall vortex (known as the Southwest Vortex) is an important meso-α scale weather system in the Asian summer monsoon region. It usually originates on the eastern periphery of the Tibetan Plateau and develops in the conditionally unstable tropical air mass over the Sichuan basin. Both orographic influence and convective latent heating appear to play crucial roles in the vortex development. Preliminary analysis has been done in preparation for the numerical simulation of the development of this vortex.

PLANS FY86

The dynamics of lee cyclogenesis associated with the Andes Mountains will be studied.

The causes of vortex genesis of the Southwest Vortex in China will be investigated using numerical simulations.

8.5 MODEL DEVELOPMENT

I. Orlanski B. Ross
J. Katzfey L. Polinsky

ACTIVITIES FY85

The limited-area HIBU model has been enhanced in several ways. New terrain coordinate and advection schemes have been tested without physics. The initialization procedure has been streamlined. The HIBU analysis package was greatly enhanced to construct horizontal maps and cross-sections of various parameters. Model vectorization was initiated. A more efficient spectral model was implemented.

Several critical routines in the MAC/BES model have been vectorized, producing a 30% improvement in computational efficiency. An interactive analysis program has been developed for the CYBER 730 computer which permits more effective analysis of three-dimensional model results.

PLANS FY86

The new terrain coordinate and advection schemes in the HIBU model will continue to be tested. Vectorization of the model will continue. The analysis package will be further expanded. An 18-level model will be developed. An R42L18 spectral model will be tested to obtain boundary conditions for the HIBU model.

An extensive review of the MAC/BES model will be made with the specific goal of incorporating a terrain-following coordinate and improving overall model efficiency.

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 understand the dynamics of deep moist convection and its role in the vertical transfer of heat, moisture, momentum and atmospheric tracers.

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

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

9.1 MOIST CONVECTION

R. S. Hemler F. B. Lipps

ACTIVITIES FY85

9.1.1 Simulation of Continental Convection

A primary emphasis has been the simulation of observed deep moist convection in the central United States. The basic structure of the numerical model is described in (516) and (303) with subsequent modifications in the subgrid-scale turbulence and the added option of using either open or periodic lateral boundary conditions. For the present calculations the vertical depth of the model is 17 km and the ground level is at 950 mb. The horizontal grid lengths are 1.0 km and the vertical grid spacing is 0.5 km. In this study three model cases are compared: (1) a two-dimensional calculation with a length of 128 km in the east-west direction and open lateral boundary conditions, (2) a three-dimensional calculation with a length of 96 km in the east-west direction and 32 km in the north-south direction, with periodic lateral conditions on the north and south boundaries and open conditions on the east and west boundaries, and (3) another three-dimensional calculation with open lateral conditions on all boundaries and a horizontal length of 64 km in the east-west direction and 48 km in the north-south direction. In the discussion below these three model configurations will be denoted by Case 1, Case 2, and Case 3 respectively.

Detailed comparisons have been made for a north-south squall line which was observed in west-central Oklahoma on May 22, 1976. A set of four-hour numerical simulations has been carried out using observed profiles of temperature, water vapor and vertical wind shear for the base state. Since the first cell in each calculation was forced by the initial conditions, comparison with observations was not made until secondary cells developed from the gust front outflow associated with the initial cell. The best agreement with the observations was for Case 2 in which a line of precipitation extended in nearly unbroken form across the 32 km north-south domain of the model. This feature was present for the last 1.5 hours of the simulation. The poorest agreement was for Case 3 in which isolated cells of convection were simulated rather than an organized line. The cells in Case 3 moved more slowly eastward than the line and the maximum surface cooling behind the gust front was much less than observed. The two-dimensional calculation, Case 1, was intermediate in its agreement with observations.

For the above model simulations, a preliminary examination of the vertical momentum transfer due to moist convection has been made. In lower levels where the vertical shear of the zonal wind is strong, the momentum flux is downgradient, with the maximum damping of the zonal mean wind due to momentum flux convergence of approximately 1 m s^{-1} per hour. It should be noted, however, that the horizontal mean zonal pressure gradient opposed the zonal momentum flux convergence for all three calculations. For Case 2 the mean zonal pressure gradient is one half the magnitude of the momentum flux convergence and for Cases 1 and 3 the mean zonal pressure gradient dominates the momentum flux convergence. Analysis of the above calculations indicates that the assumption of undilute parcel ascent applied to in-cloud momentum transfer may give qualitatively correct results for the three-dimensional calculations but gives very poor results for the two-dimensional calculation.

9.1.2 Simulation of Shallow GATE Convection

Calculations have been performed to simulate the shallow convection observed on Day 226 of GATE. The large-scale feature of this convection was a line of towering cumulus oriented in a northwest to southeast direction with cloud tops near 3000 m and cloud bases nominally at 400 m. The line was building toward the northeast.

The dynamics of this convection was examined using a three-dimensional model with a vertical depth of 4.5 km. The horizontal domain for this model has a length of 10 km oriented northeast to southwest and a width of 6 km oriented northwest to southeast. The finite-difference grid lengths were 250 m in the horizontal and 62.5 m in the vertical. The short vertical grid length was chosen so that observed boundary layer data could be used in specifying the initial conditions for the calculations. Open lateral boundary conditions were applied in the horizontal.

Model calculations demonstrated a succession of convective turrets forming at the leading edge and progressing through the line toward the southwest. Cloud tops reached near 3000 m before exiting the model domain through the southwest boundary. In addition, the line had a clearly defined leading edge which moved toward the northeast. All of these features are in excellent agreement with the observations. The rainfall rate was somewhat weak compared with the radar observations and computed cloud bases were slightly higher than observed.

9.1.3 Passive Tracer Study

The available numerical models used for simulation of continental convection have also been used to examine the vertical transport of passive trace constituents due to deep convection. During the past year the tracer model has been expanded to include the calculation for an infinitely soluble tracer as well as that for a fully insoluble tracer. The initial distribution for both cases, before the onset of deep convection, is a layer of constant tracer mixing ratio from the surface to 1.75 km with no tracer above that level.

Calculations have been carried out using the two-dimensional model denoted as Case 1 in Section 9.1.1. Data obtained from this model after 3 hours of time integration are shown in Fig. 9.1. The mixing ratio for the fully insoluble tracer is given in Fig. 9.1a and the corresponding distribution for the infinitely soluble tracer is shown in Fig. 9.1b. In Fig. 9.1c is shown a schematic cross section of the flow field and the vertical shaft where significant rain is present. The clouds are indicated by the stippled areas. The value of the initial tracer mixing ratio near the surface has been normalized to 1.0 for both Figs. 9.1a and 9.1b. The outstanding feature seen in comparing Fig. 9.1b with Fig. 9.1a is the efficiency of the rain water in removing the soluble tracer from the cloud and thus preventing its penetration to upper levels.

A quantitative measure of the vertical mixing of trace constituents is the vertical mass flux into the upper atmosphere through the 6 km level. For

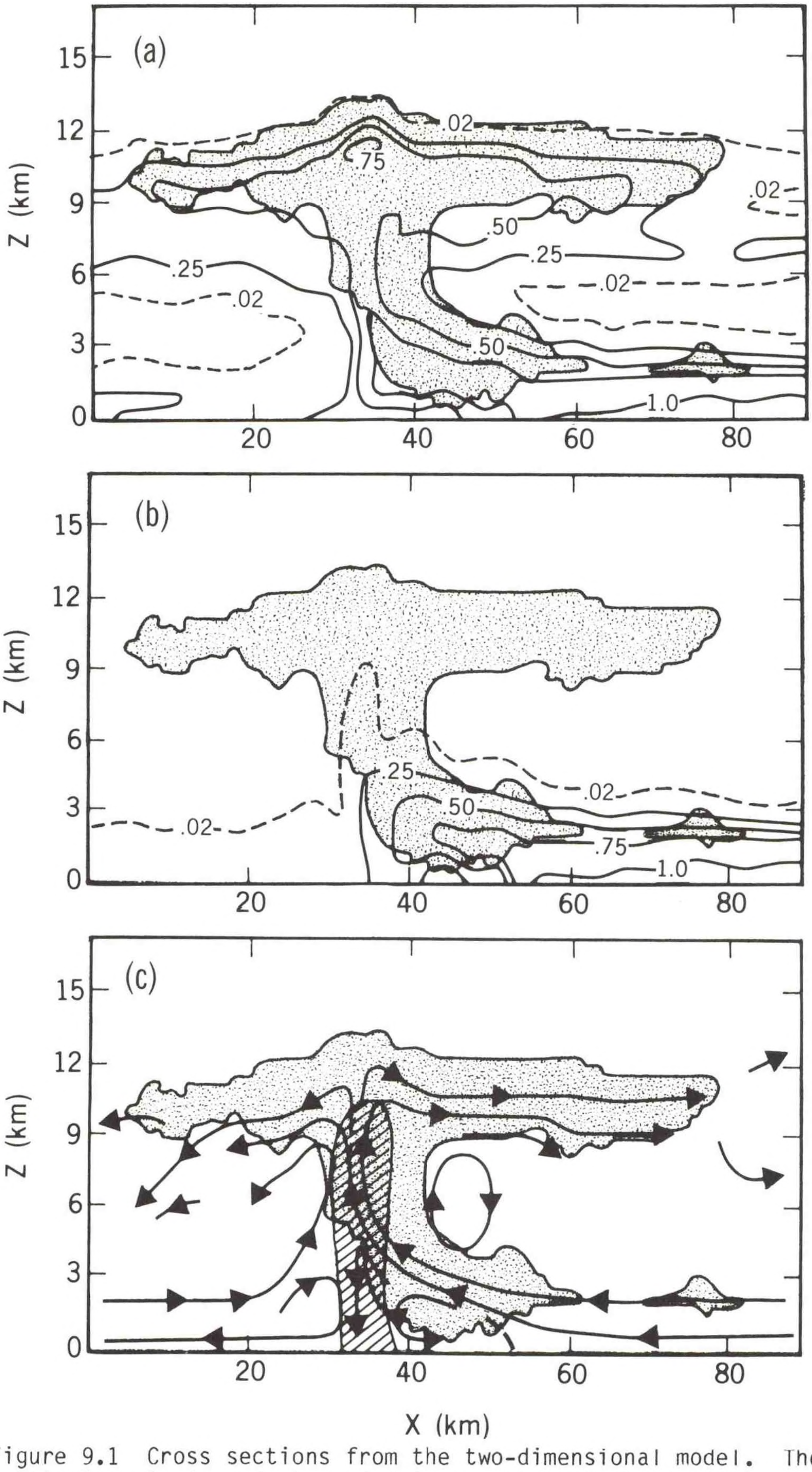

Figure 9.1 Cross sections from the two-dimensional model. The vertical scale is a factor of 3 larger than the horizontal scale. (a) Distribution of mixing ratio at 3 hours for the insoluble tracer. Clouds are indicated by the stippled areas. (b) Corresponding distribution for the soluble tracer. (c) Schematic plot of the flow field at 3 hours. Hatched area indicates the vertical shaft with rain present. Heavy dashed line represents the surface gust front.

the insoluble tracer in Fig. 9.1a, if the initial distribution of tracer is assumed to extend a length of 750 km at the surface, then the mean mass flux through the 6 km level is two per cent of the initial tracer mass per hour. Similar calculations have been carried out for the three-dimensional model, Case 2. For this simulation the mean mass flux is 28 per cent of that in the two-dimensional calculation. The mass flux is less for this simulation since isolated clouds form rather than a solid line of convection. The above values of mass flux represent periods when the convection is active. For a representative time mean, however, periods when the convection is inactive must be included as well. Taking this consideration into account, time mean values may be a factor of one-third to one-sixth of those given above. Finally, as suggested by Fig. 9.1b, the vertical mass flux across the 6 km level is negligible for the infinitely soluble tracer calculation.

It should be noted that the results reported here were obtained with an earlier version of the convection model in which the fallspeed of precipitation was increased at vertical levels where ice particles were thought to exist. Thus the dynamics of the convection in these calculations is somewhat different than that presented in Section 9.1.1. At the present time we are updating the passive tracer calculations to be fully consistent with the simulations presented in Section 9.1.1.

PLANS FY86

The development of the moist convection model will continue with inclusion of variable grid resolution in the vertical. This change will allow for a more accurate resolution of the planetary boundary later. A cooperative effort will be carried out with the Mesoscale Dynamics Group to simulate an observed case of deep moist convection. Their meso-β scale model will supply the large-scale flow and side boundary conditions for the present model. In this way an attempt will be made, using the present model, to simulate the observed meso-γ scale convection.

The examination of vertical momentum transfer will be completed for the continental convection calculations. A detailed comparison will be made between the cases of line type convection and the formation of isolated cells.

The passive tracer model will be generalized so that calculations can be carried out for tracers with characteristics intermediate to the fully insoluble and infinitely soluble cases. In addition, calculations will be carried out for a specific atmospheric tracer.

APPENDIX A

GFDL Staff Members

and

Affiliated Personnel

during

Fiscal Year 1985

Jerry D. Mahlman, Director FTP
Betty M. Williams, Secretary FTP
Douglas G. Hahn, Assistant Director FTP
Joyce C. Jarvis, Actg. Admin. Assistant PTP

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Uveges, Frank	Actg. Support Services Supv.	FTP
Amend, Beatrice	Clerk Typist	WAE
Bennett, Lois	Management Support Clerk	FTP
Byrne, James	Jr. Technician	FTP
Chandler, Annette	Secretary	WAE
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Shaffer, Daryl	Administrative Officer	FTP*
Tunison, Philip	Supv. Scientific Illustrator	FTP
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Raphael, Catherine	Office Draftsman	PTP
Varanyak, Jeffrey	Jr. Office Draftsman	FTP
Zadworney, Michael	Jr. Office Draftsman	FTP

* Affiliation Terminated Prior to September 30, 1985

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Lewis, Lawrence	Computer Sys. Analyst	FTP
Shaginaw, Richard	Computer Sys. Programmer	FTP
Yeager, William	Computer Sys. Programmer	FTP

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Mellor, George	Professor	PU
Galperin, Boris	Program Scientist	PU
Rajkovic, Borivoje	Student	PU
Steele, Michael	Student	PU

* Affiliation Terminated Prior to September 30, 1985

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Broccoli, Carol	Technical Specialist	PU
Bryan, Frank	Student	PU
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Hellerman, Solomon	Computer Programmer PT	PU
Kawase, Mitsuhiro	Student	PU
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Levy, Adam	Laboratory Aid	PU
Lin, Shian-Jiann	Student	PU
Ma, Chung-Chun	Student	PU
Najjar, Raymond	Student	PU
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Park, Jeffrey	Program Scientist	PU
Slater, Richard	Computer Programmer	PU
Toggweiler, John	Research Staff	PU
Tsao, David	Laboratory Aid	PU

CONTROL DATA CORPORATION

B. Kazawic, Sales Representative

Glassbrook, Richard A.	Project Leader	CDC*
Feder, Michael	Analyst	CDC*
Siebers, Bernard	Senior Analyst	CDC
Stringer, John	Analyst in Charge	CDC
Decker, Gregory	Consultant	CDC*
Hess, Julie	Analyst	CDC
Markowitz, Alan	Systems Analyst	CDC*
Reiss, Israel	Systems Analyst	CDC
Helster, Paul	Senior Eng. in Chg.	CDC
Armbrister, Richard	Senior Customer Eng.	CDC
Csapo, Michael	Customer Engineer	CDC
Dorado, Manual	Senior Customer Eng.	CDC
Egland, Randall	Senior Customer Eng.	CDC*
Greshko, Edward	Senior Customer Eng.	CDC*
Johnson, Eric	Senior Customer Eng.	CDC
Thompson, Robert	Senior Customer Eng.	CDC
Valin, Chris	Customer Engineer	CDC
Weiss, Edward	Senior Customer Eng.	CDC

* Affiliation Terminated Prior to September 30, 1985

PERSONNEL SUMMARY

September 30, 1985

FTP - Full Time Permanent (GFDL)	83
PTP - Part Time Permanent (GFDL)	3
WAE - When Actually Employed (GFDL)	3
Junior Fellows (GFDL)	12
Program Scientists (Princeton University)	8
US-TOGA Visiting Scientist	1
Students (Princeton University)	17
Professors (Princeton University)	2
Research Staff (Princeton University)	2
Support Staff (Princeton University)	8
Control Data Corporation Computer System Program Support Staff	13
	150

APPENDIX B

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Bibliography

1980-1985

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(393) Manabe, Syukuro, and Richard T. Wetherald, On the Horizontal Distribution of Climate Change Resulting from an Increase in CO_2 Content of the Atmosphere, Journal of the Atmospheric Sciences,37(1), 99-118, 1980.

(394) Lipps, Frank B., and Richard S. Hemler, Another Look at the Thermodynamic Equation for Deep Convection, Monthly Weather Review, 108(1), 78-84, 1980.

* (395) Rossow, William B., Stephen B. Fels, and Peter H. Stone, Comments on A Three-Dimensional Model of Dynamical Processes in the Venus Atmosphere, Journal of the Atmospheric Sciences, 37(1), 250-252, 1980.

(396) Philander, S.G.H., and R.C. Pacanowski, The Generation of Equatorial Currents, Journal of Geophysical Research, 85(C2), 1123-1136, 1980.

(397) Hayashi, Yoshikazu, Estimation of Nonlinear Energy Transfer Spectra by the Cross-Spectral Method, Journal of the Atmospheric Sciences, 37(2), 299-307, 1980.

* (398) Sarmiento, J.L., and C.G.H. Rooth, A Comparison of Vertical and Isopycnal Mixing Models in the Deep Sea Based on Radon 222 Measurements, Journal of Geophysical Research, 85(C3), 1515-1518, 1980.

(399) Mahlman, J.D., H. Levy II, and W.J. Moxim, Three-Dimensional Tracer Structure and Behavior as Simulated in Two Ozone Precursor Experiments, Journal of the Atmospheric Sciences, 37(3), 655-685, 1980.

*In collaboration with other organizations

* (400) Blackmon, Maurice L., and Ngar-Cheung Lau, Regional Characteristics of the Northern Hemisphere Wintertime Circulation: A Comparison of the Simulation of a GFDL General Circulation Model with Observations, Journal of the Atmospheric Sciences, 37(3), 497-514, 1980.

* (401) Held, Isaac M., and Arthur Y. Hou, Nonlinear Axially Symmetric Circulation in a Nearly Inviscid Atmosphere, Journal of the Atmospheric Sciences, 37(3),515-533, 1980.

(402) Philander, S.G.H,, The Equatorial Undercurrent Revisited, Annual Review of Earth and Planetary Sciences, 8, 191-204, 1980.

* (403) Blumberg, Alan F., and George L. Mellor, A Coastal Ocean Numerical Model, Mathematical Modeling of Estuarine Physics, Proceedings of the International Symposium, Hamburg, West Germany, J. Sundermann, and K-P. Holz (eds.), Springer-Verlag, Berlin, 203-219, 1980.

* (404) Mellor, George, and Paul T. Strub, Similarity Solutions for the Stratified Turbulent Rayleigh Problem, Journal of Physical Oceanography 10(3), 455-460, 1980.

* (405) Willebrand, J., S.G.H. Philander, R.C. Pacanowski, The Oceanic Response to Large-Scale Atmospheric Disturbances, Journal of Physical Oceanography, 10(3), 411-429, 1980.

(406) Smagorinsky, J., GARP - An Interim Retrospective, WMO Bulletin, 29(2), 92-100, 1980.

(407) Orlanski, I., and B. B. Ross, Reply (in reference to The Circulation Associated with a Cold Front, Part I: Dry Case), Journal of the Atmospheric Sciences, 37(4), 909-911, 1980.

* (408) Hamilton, Kevin, The Geographical Distribution of the Solar Semidiurnal Surface Pressure Oscillation, Journal of Geophysical Research, 85(C4), 1945-1949, 1980.

* (409) Orlanski, I., and C. P. Cerasoli, Resonant Wave-Wave Interactions for Internal Gravity Waves, Marine Turbulence, Jacques C. J. Nihoul (ed.), Proceedings of the 11th International Colloquium on Ocean Hydrodynamics, Elsevier Oceanogr. Series, 28, 65-100, 1980.

(410) Hayashi, Y., and D.G. Golder, The Seasonal Variation of Tropical Transient Planetary Waves Appearing in a GFDL General Circulation Model, Journal of the Atmospheric Sciences, 37(4), 705-716, 1980.

*In collaboration with other organizations

* (411) Lau, Ngar-Cheung, A Diagnostic Study of the Local Sources and Sinks of Momentum, Kinetic Energy, Vorticity and Heat in the Observed Northern Hemisphere Wintertime Circulation, Workshop on the Diagnostics of Diabatic Processes, European Centre for Medium Range Weather Forecasts, Reading, UK, 33-60, 1980.

* (412) Sun, W.Y., A Foreward-Backward Time Integration Scheme to Treat Internal Gravity Waves, Monthly Weather Review, 108(4), 402-407, 1980.

(413) Levy, Hiram II, and J.D. Mahlman, Modeling Tropospheric N_2O, Proceedings of the NATO Advanced Study Institute on Atmospheric Ozone: Its Variation and Human Influences, Algarve, Portugal, FAA Report, FAA-EE-80-20, 893-907, 1980.

(414) Levy, H. II, J.D. Mahlman, and W.J. Moxim, A Stratospheric Source of Reactive Nitrogen in the Unpolluted Troposphere, Geophysical Research Letters, 7(6), 441-444, 1980.

* (415) Hamilton, Kevin, Observations of the Solar Diurnal and Semidiurnal Surface Pressure Oscillations in Canada. Atmosphere-Ocean, 18(2), 89-97, 1980.

* (416) Stefanik, M., The Impact of Atmospheric Noise on the Detection of Interannual Climate Variations - an Observational Study of the Atmosphere-Ocean System During 1963-1973, unpublished thesis, Geophysical Fluid Dynamics Program, Princeton University, 1980.

* (417) Roether, W., K.O. Munnich, B. Ribbat, and J.L. Sarmiento, A Transatlantic ^{14}C Section near $40^{O}N$, Meteor Forschungsergeb, Reihe A, 21, 57-69, 1980.

* (418) Hibler, W.D. III, Modeling Pack Ice as Viscous-Plastic Continuum, Some Preliminary Results, Sea Ice Processes in Models, R. Pritchard (ed.), Proceedings of ICSI/AIDJEX Symposium, University of Washington Press, Seattle, 163-176, 1980.

(419) Hayashi, Yoshikazu, A Method of Estimating Space-Time Spectra from Polar Orbiting Satellite Data, Journal of the Atmospheric Sciences, 37(6), 1385-1392, 1980.

(420) Wetherald, Richard T., and Syukuro Manabe, Cloud Cover and Climate Sensitivity, Journal of the Atmospheric Sciences, 37(7), 1485-1510, 1980.

(421) Moxim, W.J., and J.D. Mahlman, Evaluation of Various Total Ozone Sampling Networks using the GFDL 3-D Tracer Model, Journal of Geophysical Research, 85(C8), 4527-4539, 1980.

*In collaboration with other organizations

(422) Cox, Michael D., Generation and Propagation of 30-Day Waves in a Numerical Model of the Pacific, Journal of Physical Oceanography, 10(8), 1168-1186, 1980.

* (423) Dickey, T.D., and G.L. Mellor, Decaying Turbulence in Neutral and Stratified Fluids, Journal of Fluid Mechanics, 99(I), 13-31, 1980.

(424) Hellerman, S. Charts of the Variability of the Wind Stress Over the Tropical Atlantic, GATE-2: Equatorial and A-Scale Oceanography, Deep Sea Research, 26(II), 63-75, 1980.

* (425) Philander, George, and Walter Duing, The Oceanic Circulation of the Tropical Atlantic, and its Variability, as Observed During GATE, GATE-2: Equatorial and A-Scale Oceanography, Deep Sea Research, 26(II), 1-27, 1980.

* (426) Sarmiento, J.L., and W.S. Broecker, Ocean Floor ^{222}Rn Standing Crops in the Atlantic and Pacific Oceans, Earth and Planetary Science Letters, 49(2), 341-350, 1980.

* (427) Stegen, G.R., and R.L. Thorpe, Vertical Coherence in the Atmospheric Boundary Layer, Wind Engineering, C.E. Cermak (ed.), Pergamon Press, NY, 195-202, 1980.

(428) Manabe, Syukuro, and Ronald Stouffer, Sensitivity of a Global Climate Model to an Increase of CO_2 Concentration in the Atmosphere, Journal of Geophysical Research, 85(C10), 5529-5554, 1980.

(429) Manabe, Syukuro, and Ronald J. Stouffer, Study of Climatic Impacts of CO_2 Increase with a Mathematical Model of the Global Climate, Report from AAAS-DOE Workshop on Environmental and Societal Consequences of a Possible CO_2-Induced Climate Change, Annapolis, MD, Department of Energy, 127-140, 1980.

* (430) Holopainen, Eero O., Ngar-Cheung Lau, and Abraham H. Oort, A Diagnostic Study of the Time-Averaged Budget of Atmospheric Zonal Momentum over North America, Journal of the Atmospheric Sciences, 37(10), 2234-2242, 1980.

(431) Fels, S.B., J.D. Mahlman, M.D. Schwarzkopf, and R.W. Sinclair, Stratospheric Sensitivity to Perturbations in Ozone and Carbon Dioxide: Radiative and Dynamical Response, Journal of the Atmospheric Sciences, 37(10), 2265-2297, 1980.

* (432) Mechoso, Carlos R., The Atmospheric Circulation Around the Antarctica: Linear Stability and Finite-Amplitude Interactions with Migrating Cyclones, Journal of the Atmospheric Sciences, 37(10), 2209-2233, 1980.

*In collaboration with other organizations

* (433) Liu, S.C., D. Kley, M. McFarland, J.D. Mahlman, and H. Levy II, On the Origin of Tropospheric Ozone, Journal of Geophysical Research, 85(C12), 7546-7552, 1980.

(434) Kurihara, Yoshio, and Morris A. Bender, Use of a Movable Nested-Mesh Model for Tracking a Small Vortex, Monthly Weather Review, 108(11), 1792-1809, 1980.

(435) Hayashi, Yoshikazu, The Recent Development of Space-Time Spectral Analysis Methods and Their Applications to Large-Scale Atmospheric Waves, Tenki, 27(11), 782-801, 1980.

(436) Mahlman, J.D., and R.W. Sinclair, Recent Results from the GFDL Troposphere-Stratosphere-Mesosphere General Circulation Model, Collection of Extended Abstracts Presented at ICMUA Sessions and IUGG Symposium 18, XVII IUGG General Assembly, Canberra,

(437) Mahlman, J.D., Coupling of Atmospheric Observations with Comprehensive Numerical Models, Collection of Extended Abstracts Presented at ICMUA Sessions and IUGG Symposium 18, XVII IUGG General Assembly, Canberra, Australia, NCAR, 253-259, 1980.

* (438) Haidvogel, Dale B., and Isaac M. Held, Homogeneous Quasi-Geostrophic Turbulence Driven by a Uniform Temperature Gradient, Journal of Atmospheric Sciences, 37(12), 2644-2660, 1980.

* (439) Hamilton, Kevin, Numerical Studies of Wave-Mean Flow Interaction in the Stratosphere, Mesosphere, and Lower Thermosphere, unpublished thesis, Geophysical Fluid Dynamics Program, Princeton University, 1981.

(440) Wetherald, Richard T., and Syukuro Manabe, Influence of a Seasonal Variation upon the Sensitivity of a Model Climate, Journal of Geophysical Research, 86(C2), 1194-1204, 1981.

(441) Fels, Stephen B., and M.D. Schwarzkopf, An Efficient, Accurate Algorithm for Calculating CO_2 15 m Band Cooling Rates, Journal of Geophysical Research, 86(C2), 1205-1232, 1981.

(442) Cox, M.D., A Numerical Study of Surface Cooling Processes During Summer in the Arabian Sea, Proceedings of Joint IUTAM/IUGG International Symposium on Monsoon Dynamics, New Delhi, India, Lighthill & Pearce (eds.), Monsoon Dynamics, Cambridge Univ. Press, 529-540, 1981.

* (443) Hamilton, Kevin, Latent Heat Release as a Possible Forcing Mechanism for Atmospheric Tides, Monthly Weather Review, 109(1), 3-17, 1981.

(444) Philander, S.G.H., The Response of Equatorial Oceans to a Relaxation of the Trade Winds, Journal of Physical Oceanography., II(2), 176-189, 1981.

*In collaboration with other organizations

* (445) Holopainen, E.O., and A.H. Oort, On the Role of Large-Scale Transient Eddies in the Maintenance of the Vorticity and Enstrophy of the Time-Mean Atmospheric Flow, Journal of the Atmospheric Sciences, 38(2), 270-280, 1981.

* (446) Holopainen, E.O., and A.H. Oort, Mean Surface Stress Curl Over the Oceans as Determined from the Vorticity Budget of the Atmosphere, Journal of the Atmospheric Sciences, 38(2), 262-269, 1981.

(447) Philander, S.G.H., and R.C. Pacanowski, Response of Equatorial Oceans to Periodic Forcing, Journal of Geophysical Research, 86(C3), 1903-1916, 1981.

(448) Lipps, Frank B., and Richard S. Hemler, Reply (in reference to Another Look at the Thermodynamic Equation for Deep Convection, Monthly Weather Review, 109(3), p. 675, 1981.

* (449) Mesinger, Fedor, Horizontal Advection Schemes of a Staggered Grid - An Enstrophy and Energy-Conserving Model, Monthly Weather Review, 109(3), 467-478, 1981.

(450) Orlanski, Isidoro, The Quasi-Hydrostatic Approximation, Journal of the Atmospheric Sciences, 38(3), 572-582, 1981.

* (451) Lau, Ngar-Cheung, Glenn H. White, and Roy L. Jenne, Circulation Statistics for the Extratropical Northern Hemisphere Based on NMC Analyses, NCAR Technical Note, NCAR/TN-171+STR, 1-138, 1981.

(452) Miyakoda, K., and R.F. Strickler, Cumulative Results of Extended Forecast Experiment, III: Precipitation, Monthly Weather Review, 109(4), 830-842, 1981.

(453) Levy, H. II, J.D. Mahlman, and W.J. Moxim, A Three-Dimensional Numerical Model of Atmospheric N_2O, Proceedings of Quadrennial International Ozone Symposium, II, Boulder, CO, International Ozone Commission IOC), 943-947, 1981.

* (454) Orlanski, I., and C.P. Cerasoli, Energy Transfer Among Internal Gravity Modes: Weak and Strong Interactions, Journal of Geophysical Research, 26(C5), 4103-4124, 1981.

(455) Smagorinsky, J., CO_2 and Climate - A Continuing Story, Climatic Variations and Variability: Facts and Theories, A. Berger (ed.), D. Reidel Publ. Co., 661-687, 1981.

(456) Philander, S.G.H., and R.C. Pacanowski, The Oceanic Response to Cross-Equatorial Winds (with application to coastal upwelling in low latitudes), Tellus, 33, 201-210, 1981.

*In collaboration with other organizations

* (457) Gonella, Joseph, Michele Fiuex, and George Philander, Evidence for Equatorial Rossby Waves in the Indian Ocean from Drifter Buoys, Proc. C.R. Academy of Sci., Paris, 292(II), 1397-1399, 1981.

* (458) Stefanik, Michael, Space and Time Scales of Atmospheric Variability, Journal of the Atmospheric Sciences, 38, 988-1002, 1981.

* (459) Andrews, David G., A Note on Potential Energy Density in a Stratified Compressible Fluid, Journal of Fluid Mechanics, 107, 227-236, 1981.

(460) Hayashi, Yoshikazu, Vertical-Zonal Propagation of a Stationary Planetary Wave Packet, Journal of the Atmospheric Sciences, 38(6), 1197-1205, 1981.

* (461) Lau, Ngar-Cheung, and Abraham H. Oort, A Comparative Study of Observed Northern Hemisphere Circulation Statistics Based on GFDL and NMC Analyses, Part I: The Time Mean Fields, Monthly Weather Review, 109(7), 1380-1403, 1981.

* (462) Hamilton, Kevin, Effects of Atmospheric Tides on the General Circulation of the Stratosphere, Mesosphere and Lower Thermosphere, Proceedings of IAMAP Symposium on Middle Atmospheric Dynamics and Transport, Urbana, IL, S.K. Avery (ed.), Handbook for MAP, 2, 246-255, 1981.

(463) Andrews, D.G., J.D. Mahlman, and R.W. Sinclair, The Use of the Eliassen-Palm Flux as a Diagnostic of Wave, Mean-Flow Interaction in a General Circulation Model, Extended Abstracts from International Symposium on Middle Atmosphere Dynamics and Transport,July 28-August 1,1980, Urbana, Ill.

* (464) Hsu, C-P F., Air Parcel Motions During a Simulated Sudden Stratospheric Warming, Proceedings of IAMAP Symposium on Middle Atmospheric Dynamics and Transport, Urbana, IL, S.K. Avery (ed.), Handbook for MAP, 2, 201211, 1981.

(465) Kurihara, Yoshio, and Robert E. Tuleya, A Numerical Simulation Study on the Genesis of a Tropical Storm, Monthly Weather Review, 109(8), 1629-1653, 1981.

* (466) Sun, Wen-Yih, and Isidoro Orlanski, Large Mesoscale Convection and Sea Breeze Circulation, Part I: Linear Stability Analysis, Journal of the Atmospheric Sciences, 38(8), 1675-1693, 1981.

* (467) Sun, Wen-Yih, and Isidoro Orlanski, Large Mesoscale Convection and Sea Breeze Circulation, Part II: Nonlinear Numerical Model, Journal of the Atmospheric Sciences, 38(8), 1694-1706, 1981.

*In collaboration with other organizations

* (468) Held, Isaac M., David I. Linder, and Max J. Suarez, Albedo Feedback, The Meridional Structure of the Effective Heat Diffusivity, and Climate Sensitivity: Results from Dynamic and Diffusive Models, Journal of the Atmospheric Sciences, 38(9), 1911-1927, 1981.

(469) Hayashi, Y., Space Time Cross Spectral Analysis Using the Maximum Entropy Method, Journal of the Meteorological Society, Japan, Ser. II, 59(5), 620-624, 1981.

(470) Smagorinsky, J., Climate Modelling, Proceedings of Technical Conference on Climate - Asia and Western Pacific, Guangzhou, China, WMO 578, 139-151, 1981.

* (471) Virasaro, M.A., Variational Principle for Two-Dimensional Incompressible Hydrodynamics and Quasigeostrophic Flows, Physical Review Letters, 47(17), 1181-1183, 1981.

(472) Smagorinsky, J., Epilogue: A Perspective of Dynamical Meteorology, Dynamical Meteorology - An Introductory Selection, B.W. Atkinson (ed.), Methuen & Co., Ltd., NY, 205-219, 1981.

(473) Manabe, S., R.T. Wetherald, and R.J. Stouffer, Summer Dryness Due to an Increase of Atmospheric CO_2 Concentration, Climate Change, 3(4), 336-376, 1981.

(474) Manabe, Syukuro, and Douglas G. Hahn, Simulation of Atmospheric Variability, Monthly Weather Review, 109(11), 2260-2286, 1981.

* (475) Lau, Ngar-Cheung, A Diagnostic Study of Recurrent Meteorological Anomalies Appearing in a 15-Year Simulation with a GFDL General Circulation Model, Monthly Weather Review, 109(11), 2287-2311, 1981.

(476) Hayashi, Y., and D.G. Golder, The Effects of Condensational Heating on Midlatitude Transient Waves in Their Mature Stage: Control Experiment with a GFDL General Circulation Model, Journal of the Atmospheric Sciences, 38(11), 2532-2539, 1981.

(477) Pacanowski, R.C., and S.G.H. Philander, Parameterization of Vertical Mixing in Numerical Models of Tropical Oceans, Journal of Physical Oceanography, 11(11), 1443-1451, 1981.

* (478) Meleshko, V.P., and R.T. Wetherald, The Effect of a Geographical Cloud Distribution on Climate: A Numerical Experiment with an Atmospheric General Circulation Model, Journal of Geophysical Research, 86(C12), 11, 995-12,014, 1981.

* (479) Liu, S.C., D. Kley, M. McFarland, J.D. Mahlman, and H. Levy II, Reply in reference to On the Origin of Tropospheric Ozone, Journal of Geophysical Research, 86(C12), 12,165-12,166, 1981.

*In collaboration with other organizations

* (480) Ripa, P., On the Theory of Nonlinear Wave-Wave Interactions Among Geophysical Waves, Journal of Fluid Mechanics, 103, 87-115, 1981.

* (481) Yoon, Jong-Hwan, Effects of Islands on Equatorial Waves, Journal of Geophysical Research, 86(C11), 10,913-10,920, 1981.

* (482) Mahlman, J.D., D.G. Andrews, H.U. Dutsch, D.L. Hartmann, T. Matsuno, and R.J. Murgatroyd, Transport of Trace Constituents in the Stratosphere, Report of MAP Study Group - 2, Handbook for MAP, C.F. Sechrist, Jr. (ed.), 3, 14-43, 1981.

(483) Tuleya, Robert E., and Yoshio Kurihara, A Numerical Study of the Effects of Environmental Flow on Tropical Storm Genesis, Monthly Weather Review, 109(12), 2487-2506, 1981.

(484) Bryan, K., F.G. Komro, S. Manabe, and M.J. Spelman, Transient Climate Response to Increasing Atmospheric Carbon Dioxide, Science, 215 (4528), 56-58, 1982.

* (485) Sarmiento, J.L., and K. Bryan, An Ocean Transport Model for the North Atlantic, Journal of Geophysical Research, 87(C1), 394-408, 1982.

* (486) Holopainen, Eero, Long-term Budget of Zonal Momentum in the Free Atmosphere over Europe in Winter, Quarterly Journal of the Royal Meteorological Society, 108, 95-102, 1982.

(487) Held, Isaac M., On the Height of the Tropopause and the Static Stability of the Troposphere, Journal of the Atmospheric Sciences, 39(2), 412-417, 1982.

(488) Ross, Bruce B., and Isidoro Orlanski, The Evolution of an Observed Cold Front, Part I: Numerical Simulation, Journal of the Atmospheric Sciences, 39(2), 297-327, 1982.

(489) Hayashi, Y., Space-Time Spectral Analysis and its Application to Atmospheric Waves, Journal of the Meteorological Society, Japan, 60(1), 156-171, 1982.

(490) Kurihara, Y., and Morris A. Bender, Structure and Analysis of the Eye of a Numerically Simulated Tropical Cyclone, Journal of the Meteorological Society, Japan, 60(1), 381-395, 1982.

(491) Bryan, K., Poleward Heat Transport by the Ocean: Observations and Models, Annual Review of Earth and Planetary Sciences, 10, 15-38, 1982.

(492) Hayashi, Yoshikazu, Interpretations of Space-Time Spectral Energy Equations, Journal of the Atmospheric Sciences, 39(3), 685-688, 1982.

*In collaboration with other organizations

(493) Miyakoda, K., J. Sheldon, and J. Sirutis, Four-Dimensional Analysis Experiment During the GATE Period - Part II, Journal of the Atmospheric Sciences, 38(3), 486-506, 1982.

(494) Smagorinsky, Joseph, Scientific Basis for the Monsoon Experiment, Proc. International Conference on the Scientific Results of the Monsoon Experiment, Denpasar Bali, ICSU/WMO-GARP, XXXV-XLII, 1982.

(495) Levy II, H., J.D. Mahlman, and W.J. Moxim, Tropospheric N_2O Variability, Journal of Geophysical Research, 87(C4), 3061-3080, 1982.

(496) Fels, Stephen B., A Parameterization of Scale-Dependent Radiative Damping Rates in the Middle Atmosphere, Journal of the Atmospheric Sciences, 39(5), 1141-1152, 1982.

(497) Williams, Gareth P., and J. Leith Holloway, The Range and Unity of Planetary Circulations, Nature, 297(5864), 295-299, 1982.

* (498) Keshavamurty, R.N., Response of the Atmosphere to Sea Surface Temperature Anomalies Over the Equatorial Pacific and the Teleconnections of the Southern Oscillation, Journal of the American Meteorological Society, 39(6), 1241-1259, 1982.

(499) Smagorinsky, Joseph, Carbon Dioxide and Climate: A Second Assessment, Report of the CO_2/Climate Review Panel (Chairman), National Research Council, 1-72, 1982.

(500) Miyakoda, K., and A. Rosati, The Variation of Sea Surface Temperature in 1976 and 1977 - 1: The Data Analysis, Journal of Geophysical Research, 87(C7), 5667-5680, 1982.

* (501) Oey, Li-Yauw, Implicit Schemes for Differential Equations, Journal of Computational Physics, 45(3), 443-468, 1982.

(502) Smagorinsky, Joseph, Some Thoughts on Contemporary Global Climatic Variability, Drought and Man - the 1972 Case History, 1, Nature Pleads Not Guilty, R.V. Garcia (ed.), Pergamon Press, 265-296, 1982.

(503) Gordon, Charles T., and William F. Stern, A Description of the GFDL Global Spectral Model, Monthly Weather Review, 110(7), 625-644, 1982.

* (504) Philander, S.G.H., and J.-H. Yoon, Eastern Boundary Currents and Coastal Upwelling, Journal of Physical Oceanography, 12(8), 862-879, 1982.

*In collaboration with other organizations

* (505) Wahr, John M., The Effects of the Atmosphere and Oceans on the Earth's Wobble - I. Theory, Geophysical Journal of the Royal Astronomy Society, 349-372, 1982.

(506) Kurihara, Y., and R.E. Tuleya, Influence of Environmental Conditions on the Genesis of a Tropical Storm, Topics in Atmospheric and Oceanographic Sciences - Intense Atmospheric Vortices, Bengtsson-Lighthill (eds.), Springer-Verlag, 71-79, 1982.

(507) Held, Isaac M., Climate Models and the Astronomical Theory of the Ice Ages, Icarus, 50(2/3), 449-461, 1982.

* (508) Matsuura, Tomonori, and Toshio Yamagata, On the Evolution of Non-Linear Planetary Eddies Larger than the Radius of Deformation, Journal of Physical Oceanography, 12(5), 440-456, 1982.

* (509) Lau, Ngar-Cheung, and Abraham H. Oort, A Comparative Study of Observed Northern Hemisphere Circulation Statistics Based on GFDL and NMC Analyses, Part II: Transient Eddy Statistics and the Energy Cycle, Monthly Weather Review, 110(8), 889-906, 1982.

* (510) Sarmiento, J.L., C.G.H. Rooth, W. Roether, The North Atlantic Tritium Distribution in 1972, Journal of Geophysical Research, 87(C10), 8047-8056, 1982.

(511) Hayashi, Yoshikazu, Confidence Intervals of a Climatic Signal, Journal of the Atmospheric Sciences, 39(9), 1895-1905, 1982.

* (512) Lau, Ngar-Cheung, Some Observational Results Useful for Diagnosing Long-Term Integrations of Climate Models, Proceedings of WMO/ICSU Study Conference on Physical Basis for Climate Prediction on Seasonal, Annual, and Decadal Time Scales, Leningrad, 13-17 September 1982, World Climate Research Programme, WCP-47, 273-291, 1983.

* (513) Miyakoda, K., and Chao Ji-Ping, Essay on Dynamical Long-Range Forecasts of Atmospheric Circulation, Journal of the Meteorological Society, Japan, 60(1), 292-308, 1982.

* (514) Holopainen, Eero O., L. Rontu, and Ngar-Cheung Lau, The Effect of Large-Scale Transient Eddies on the Time-Mean Flow in the Atmosphere, Journal of the Atmospheric Sciences, 39(9), 1972-1984, 1982.

* (515) De Elvira, A. Ruiz, and Peter Lemke, A Langevin Equation for Stochastic Climate Models with Periodic Feedback and Forcing Variance, Tellus, 34, 313-320, 1982.

*In collaboration with other organizations

(516) Lipps, Frank B., and Richard S. Hemler, A Scale Analysis of Deep Moist Convection and Some Related Numerical Calculations, *Journal of the Atmospheric Sciences*, 39(10), 2192-2210, 1982.

* (517) Mellor, George L., and Tetsuji Yamada, Development of a Turbulence Closure Model for Geophysical Fluid Problems, *Reviews for Geophysical and Space Physics*, 20(4), 851-875, 1982.

(518) Welsh, James G., Geophysical Fluid Simulation on a Parallel Computer, *Parallel Computations*, Garry Rodrigue (ed.), Academic Press, 269-277, 1982.

(519) Kurihara, Yoshio, and Robert E. Tuleya, On a Mechanism of the Genesis of Tropical Storms, *Proceedings of Regional Scientific Conference on Tropical Meteorology, Tsukuba, Japan, WMO*, 17-18, 1982.

(520) Bryan, Kirk, Seasonal Variation in Meridional Overturning and Poleward Heat Transport in the Atlantic and Pacific Oceans: A Model Study, *Journal of Marine Research*, 40 (Suppl.), 39-53, 1982.

* (521) Yoon, J.-H., and S.G.H. Philander, The Generation of Coastal Undercurrents, *Journal of the Oceanographical Society, Japan*, 38(4), 215-224, 1982.

* (522) Bowman, Kenneth P., Sensitivity of an Annual Mean Diffusive Energy Balance Model with an Ice Sheet, *Journal of Geophysical Research*, 87(C11), 9667-9674, 1982.

* (523) Sarmiento, J.L., C.G.H. Rooth, and W.S. Broecker, Radium 228 on a Tracer of Basin Wide Processes in the Abyssal Ocean, *Journal of Geophysical Research*, 87(C12), 9694-9698, 1982.

(524) Smagorinsky, J., Large-Scale Climate Modeling and Small-Scale Physical Processes, *Land Surface Processes in Atmospheric General Circulation Models*, P.S. Eagleson (ed.), Cambridge University Press, 3-17, 1982.

(525) Manabe, Syukuro, Simulation of Climate by General Circulation Models with Hydrologic Cycles, *Land Surface Processes in Atmospheric General Circulation Models*, P.S. Eagleson (ed.), Cambridge University Press, 19-66, 1982.

(526) Tuleya, Robert E., and Yoshio Kurihara, A Note on the Sea Surface Temperature Sensitivity of a Numerical Model of Tropical Storm Genesis, *Monthly Weather Review*, 110(12), 2063-2069, 1982.

* (527) Zeng, Qing-cun, The Evolution of Rossby-Wave Packet in Three-Dimensional Baroclinic Atmosphere, *Journal of the Atmospheric Sciences*, 40(1), 73-84, 1983.

*In collaboration with other organizations

(528) Levitus, Sydney, Climatological Atlas of the World Ocean, NOAA Professional Paper 13, 188 p., 1982.

* (529) Mellor, George L., Carlos R. Mechoso, and Eric Keto, A Diagnostic Calculation of the General Circulation of the Atlantic Ocean, Deep Sea Research, 29(10A), 1171-1192, 1982.

(530) Cox M.D., A Numerical Model of the Ventilated Thermocline, Ocean Modeling, 49, 5-7, 1983.

(531) Smagorinsky, Joseph, The Beginnings of Numerical Weather Prediction and General Circulation Modeling: Early Recollections, Advances in Geophysics, 25, Theory of Climate, Barry Saltzman (ed.), Academic Press, New York, 3-38, 1983.

(532) Manabe, Syukuro, Carbon Dioxide and Climatic Change, Advances in Geophysics, 25, Theory of Climate, Barry Saltzman (ed.), Academic Press, New York, 39-84, 1983.

* (533) Oort, Abraham H., and Jose P. Peixoto, Global Angular Momentum and Energy Balance Requirements from Observations, Advances in Geophysics, 25, Theory of Climate, Barry Saltzman (ed.), Academic Press, New York, 355-490, 1983.

* (534) Carton, James A., The Long-Period Tides and Coastal Upwelling, unpublished thesis, Geophysical Fluid Dynamics Program, Princeton University, 1983.

* (535) Sardeshmukh, Prashant D., Mechanisms of Monsoonal Cyclogenesis, unpublished thesis, Geophysical Fluid Dynamics Program, Princeton University, 1983.

* (536) MacAyeal, Douglas R., Rectified Tidal Currents and Tidal-Mixing Fronts: Controls on the Ross Ice Shelf Flow and Mass Balance, unpublished thesis, Geophysical Fluid Dynamics Program, Princeton University, 1983.

(537) Smagorinsky, Joseph, Climate Changes Due to CO_2. AMBIO, A Journal of the Human Environment, R. Swedish Acad. Sci., XII(2), 83-85, 1983.

(538) Hayashi, Y., and D.G. Golder, Transient Planetary Waves Simulated by GFDL Spectral General Circulation Models. Part I: Effects of Mountains, Journal of the Atmospheric Sciences, 40(4), 941-950, 1983.

(539) Hayashi, Y., and D.G. Golder, Transient Planetary Waves Simulated by GFDL Spectral General Circulation Models. Part II: Effects of Nonlinear Energy Transfer, Journal of the Atmospheric Sciences, 40(4), 951-957, 1983.

*In collaboration with other organizations

(540) Kurihara, Yoshio, and Morris A. Bender, A Numerical Scheme to Treat the Open Lateral Boundary of a Limited Area Model, Monthly Weather Review, 111(3), 445-454, 1983.

(541) Philander, S.G.H., El Nino Southern Oscillation Phenomena, Nature, 302(5906), 295-301, 1983.

* (542) Palmer, T.N., and C.-P. F. Hsu, Stratospheric Sudden Coolings and the Role of Nonlinear Wave Interactions in Preconditioning the Circumpolar Flow, Journal of the Atmospheric Sciences, 40(4), 909-928, 1983.

(543) Pierrehumbert, R.T., Bounds on the Growth of Perturbations to Non-Parallel Steady Flow on the Barotropic Beta Plane, Journal of the Atmospheric Sciences, 40(5), 1207-1217, 1983.

* (544) Peixoto, Jose P., and Abraham H. Oort, The Atmospheric Branch of the Hydrological Cycle and Climate, Variations in the Global Water Budget, A. Street-Perrot, M. Beran, R. Ratcliffe (eds.), D. Reidel, Holland, 5-65, 1983.

(545) Manabe, Syukuro, and Ronald J. Stouffer, Seasonal and Latitudinal Variation of the CO_2 Induced Change in a Climate of an Atmosphere-Mixed Layer Ocean Model. Proceedings of DOE Workshop on First Detection of Carbon Dioxide Effects, June 8-10, 1981, Harpers Ferry, West Virginia, 79-94, 1982.

(546) Manabe, S., Comments on Paper Simulating CO_2-Induced Climate Change with Mathematical Climate Models: Capabilities, Limitations and Prospects by Michael E. Schlesinger. Proceedings of CO_2 Research Conference and Workshop, Sept. 19-23, 1982, Coolfont, West Virginia, III 145-159, 1983.

(547) Miyakoda, K., T. Gordon, R. Caverly, W. Stern, R. Sirutis, and W. Bourke, Simulation of a Blocking Event in January 1977, Monthly Weather Review, 111(4), 846-869, 1983.

(548) Miyakoda, K., Surface Boundary Forcings, WMO/ICSU Study Conf. on Physical Basis for Climate Prediction on Seasonal, Annual, and Decadal Time Scales, Leningrad, 13-17 Sept. 1982, World Climate Research Programme, WCP-47, 51-78, 1983.

(549) Bender, Morris A., and Yoshio Kurihara, The Energy Budgets for the Eye and Eye Wall of a Numerically Simulated Tropical Cyclone, Journal of the Meteorological Society, Japan, 61(2), 239-243, 1983.

* (550) Yeh, T.-C., R.T. Wetherald, and S. Manabe, A Model Study of the Short-Term Climatic and Hydrologic Effects of Sudden Snow-Cover Removal, Monthly Weather Review, 111(5), 1013-1024, 1983.

*In collaboration with other organizations

(551) Oort, Abraham H., Climate Variability - Some Observational Evidence, WMO/ICSU Study Conf. on Physical Basis for Climate Prediction on Seasonal, Annual and Decadal Time Scales, Leningrad, 13-17 Sept. 1982, World Climate Research Programme, WCP 47, 1-24, 1983.

(552) Ploshay, Jeffrey, J., Robert K. White, and Kikuro Miyakoda, FGGE Level III-B Daily Global Analyses. Part I (Dec 1978 - Feb 1979), NOAA Data Report, ERL GFDL-1, 278 pp., 1983.

* (553) Mesinger, F., and R.F. Strickler, Effect of Mountains on Genoa Cyclogeneses, Journal of the Meteorological Society of Japan, 60(1), 326-338, 1983.

(554) Bryan, Kirk, Poleward Heat Transport by the Ocean, Reviews of Geophysics and Space Physics, 21(5), 1131-1137, 1983.

* (555) Redi, Martha H., Oceanic Isopycnal Mixing by Coordinate Rotation, Journal of Physical Oceanography, 12(10), 1154-1158, 1982.

* (556) Pan, Yi Hong, and Abraham H. Oort, Global Climate Variations Connected with Sea Surface Temperature Anomalies in the Eastern Equatorial Pacific Ocean for the 1958-1973 Period, Monthly Weather Review, 111(6), 1243-1258, 1983.

* (557) Carton, J. A., and J. M. Wahr, The Pole Tide in the Deep Ocean, Proc. Ninth International Symposium on Earth Tides, New York, 16-21 Aug. 1981, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 509-518, 1983.

* (558) Philander, S.G.H., and P. Delecluse, Coastal Currents in Low Latitudes with Application to the Somali and El Nino Currents, Deep Sea Research, 30(8A), 887-902, 1983.

(559) Hellerman, Sol, and Mel Rosenstein, Normal Monthly Wind Stress Over the World Ocean with Error Estimates, Journal of Physical Oceanography, 13(7),1093-1104, 1983.

(560) Hayashi, Y., Modified Methods of Estimating Space-Time Spectra from Polar Orbiting Satellite Data. Part I: The Frequency Transform Method. Journal of the Meteorological Society, Japan, 61(2), 254-262, 1983.

* (561) Sarmiento, J.L., A Tritium Box Model of the North Atlantic Thermocline. Journal of Physical Oceanography, 13(7) 1269-1274, 1983.

* (562) Carton, J.A., The Variation with Frequency of the Long-Period Tides. Journal of Geophysical Research, 88(C12), 7563-7571, 1983.

(563) Orlanski, O., and L.J. Polinsky, Ocean Response to Mesoscale Atmospheric Forcing. Tellus, 35A, 296-323, 1983.

*In collaboration with other organizations

(564) Philander, S.G.H., Anomalous El Nino of 1982-83, Nature, (305) p.16, 1983.

* (565) Held, I.M., and David G. Andrews, On the Direction of the Eddy Momentum Flux in Baroclinic Instability. Journal of the Atmospheric Sciences, 40(9), 2220-2231, 1983.

* (566) Sarmiento, J.L., A Simulation of Bomb Tritium Entry in the Atlantic Ocean. Journal of Physical Oceanography, 13(10), 1924-1939, 1983.

(567) Spelman, M.J., and S. Manabe, Influence of Oceanic Heat Transport upon the Sensitivity of a Model Climate. Journal of Geophysical Research, 89(C1), 571-586, 1984.

(568) Miyakoda, K., J. Ploshay, and W. Stern, Guide and Caution on the GFDL/FGGE III-b Data Set. Global Weather Experiment. Newsletter, No.1, pp.8-14, 1983.

* (569) Andrews, D.G., J.D. Mahlman and R.W. Sinclair, Eliassen-Palm Diagnostics of Wave-Mean Flow Interaction in the GFDL "SKYHI" Circulation Model. Journal of the Atmospheric Sciences, 40(12) 2768-2784, 1983.

(570) Hayashi, Y., Studies of the Mechanism of Planetary-Scale Atmospheric Disturbances using New Analysis Methods. Journal of the Meteorological Society, Japan, Vol.30, No.1, pp.3-12, 1983.

(571) Orlanski, I. and B. Ross, The Mesoscale Structure of a Moist Cold Cold Front Simulation with Explicit Convection. Proceedings of CIMMS Symposium on Mesoscale Modeling, Norman, Okla. June, 1982.

(572) Lau, Ngar-Cheung, Mid-Latitude Wintertime Circulation Anomalies Appearing in a 15-year GCM Experiment. Large-Scale Dynamical Processes in the Atmosphere, Academic Press, January 1981.

(573) Held, Isaac, Stationary and Quasi-Stationary Eddies in the Extra-Tropical Troposphere: Theory, Academic Press, March, 1982.

* (574) Pierrehumbert, R.T. and P. Malguzzi, Forced Coherent Structures and Local Multiple Equilibria in a Barotropic Atmosphere. Journal of the Atmospheric Sciences, 41(2), 246-257, 1984.

* (575) MacAyeal, Douglas R., Numerical Simulations of the Ross Sea Tides. Journal of Geophysical Research, 89(C1), 607-615, 1984.

* (576) MacAyeal, Douglas R., Thermohaline Circulation below the Ross Ice Shelf: A Consequence of Tidally Induced Vertical Mixing and Basal Melting. Journal of Geophysical Research, 89(C1), 597-606, 1984.

*In collaboration with other organizations

* (577) Salby, Murry L., Evidence for Equatorial Kelvin Modes in Nimbus-7 LIMS. Journal of the Atmospheric Sciences, 41(2), 220-235, 1984.

* (578) Wahr, John M., and Abraham H. Oort, Friction- and Mountain-Torque Estimates from Global Atmospheric Data. Journal of the Atmospheric Sciences, 41(2), 190-204, 1984.

* (579) MacAyeal, Douglas R., and R.H. Thomas, Numerical Modeling of Ice-Shelf Motion. Annals of Glaciology 3, 1982.

(580) Tuleya, Robert E., Morris A. Bender and Yoshio Kurihara, A Simulation Study of the Landfall of Tropical Cyclones using a Movable Nested-Mesh Model. Monthly Weather Review, 112(1), 124-136, 1984.

* (581) Carton, J.A., Coastal Circulation Caused by an Isolated Storm, Journal of Physical Oceanography, 14(1) 114-124, 1984.

(582) Orlanski, Isidoro, Orographically Induced Vortex Centers. (Proc. Joint U.S. - China Mountain Meteorology Symposium, Beijing, China, Mountain Meteorology, Sino - U.S. Academies of Sci.) 1982, 311-340.

* (583) Lau, Ngar-Cheung and Eero Holopainen, Transient Eddy Forcing of the Time-Mean Flow as Identified by Geopotential Tendencies, Journal of the Atmospheric Sciences, 41(3), 313-328, 1984.

(584) Gordon, Charles T. and William F. Stern, Medium Range Prediction by a GFDL Global Spectral Model: Results for Three Winter Cases and Sensitivity to Dissipation, Monthly Weather Review, 112(2), 217-245, 1984.

* (585) Philander, S.G.H., T.Yamagata and R.C. Pacanowski, Unstable Air-Sea Interactions in the Tropics, Journal of the Atmospheric Sciences, 41(4), 604-613, 1984.

* (586) Williams, Gareth P., and Toshio Yamagata, Geostrophic Regimes, Intermediate Solitary Vortices and Jovian Eddies, Journal of the Atmospheric Sciences, 41(4) 453-478, 1984.

(587) Miyakoda, K. and A. Rosati, Parameterization of the ABL and OBL in a GFDL Model, "Report of the WMO/CAS Expert Meeting on Atmospheric Boundary Layer Paramerization over the Oceans for Long Range Forecasting and Climate Models" Reading, UK., 5-9 December, 1983, World Climate Programme, 1-10.

(588) Lipps, F., Some Recent Simulations using the GFDL Cloud Model. Proceedings of the International Cloud Modelling Workshop, Aspen, Colorado. April, 1984, 1-21.

*In collaboration with other organizations

* (589) Mahlman, J.D., D. Andrews, D. Hartmann, T. Matsuno, R. Murgatroyd, Transport of Trace Constituents in the Stratosphere. Proceedings of U.S. - Japan Seminar on Middle Atmosphere Dynamics, Tokyo, Japan Advances in Earth and Planetary Sciences, TERRA Scientific Publ. Co. (TERRAPUB), 501-525, 1984.

* (591) Yeh, T.-C., R.T. Wetherald, and S. Manabe, The Effect of Soil Moisture on the Short-Term Climate and Hydrology Change - A Numerical Experiment, Monthly Weather Review, 112(3), 474-490, 1984.

* (592) Sardeshmukh, P.D., and I. Held, The Vorticity Balance in the Tropical Upper Troposphere of a General Circulation Model, Journal of the Atmospheric Sciences, 41(5), 768-778, 1984.

(593) Tuleya, R.E., and Y. Kurihara, The Formation of Comma Vortices in a Tropical Numerical Simulation Model, Monthly Weather Review, 112(3), 491-502, 1984.

* (594) Bryan, K., F.G. Komro, and C. Rooth, The Ocean's Transient Response to Global Surface Temperature Anomalies, Geophysical Monograph, 29(5), 29-38, 1984.

(595) Cox, M.D., and K. Bryan, A Numerical Model of the Ventilated Thermocline, Journal of Physical Oceanography, 14(4), 674-687, 1984.

* (596) Zeng, Qing-Cun, The Development Characteristics of Quasi-Geostrophic Baroclinic Disturbances, Tellus, 40(1), 73-84, 1983.

(597) Lau, Ngar-Cheung, The Frequency Dependence of the Structure and Evolution of Geopotential Height Fluctuations appearing in a GFDL General Circulation Model, NCAR/TN-227, 151-207, 1984.

(598) Oort, Abraham, The Scope of Recent Climate Research in the Observational Studies Group of GFDL, NCAR/TN-227, 151-207, 1984.

(599) Oort, Abraham, Global Atmospheric Circulation Statistics, 1958-1973. NOAA Professional Paper No.14, U.S. Printing Office, Washington, DC, 180 pp., 1983.

* (600) Peixoto, Jose, P., and Abraham Oort, Physics of Climate, Review of Modern Physics, 56(3), 365-429, 1984.

(601) Levitus, S., Annual Cycle of Temperature and Heat Storage in the World Ocean, Journal of Physical Oceanography, 14(4), 727-746, 1984.

* (602) Hibler, W.D. III, and K. Bryan, Ocean Circulations: Its Effect on Seasonal Sea-Ice Simulations, Science, Vol. 224, 489-491, 1984.

*In collaboration with other organizations

(603) Gordon, C.T., R.D. Hovanec, and W.F. Stern, Analyses of Monthly Mean Cloudiness and their Influence upon Model-Diagnosed Radiative Fluxes, Journal of Geophysical Research, 89(D3), 4713-4738, 1984.

* (604) Oort, Abraham H., and Yi-Hong Pan, Sea Surface Temperature Anomalies in the Equatorial Pacific Ocean and Global Climate Variations, Proceedings of the Eighth Annual Climate Diagnostics Workshop Canadian Climate Centre, Atmospheric Environment Service, Downsview, Ontario, 17-21 October, 1983.

(605) Miyakoda, K. and A. Rosati, The Variation of Sea Surface Temperature in 1976 and 1977. 2. The Simulation with Mixed Layer Models, Journal of Geophysical Research, 89(C4), 6533-6542, 1984.

* (606) Nigam, Sumant and Isaac M. Held, The Influence of a Critical Latitude on Topographically Forced Stationary Waves in a Barotropic Model, Journal of the Atmospheric Sciences, 40(11), 2610-2622, 1983.

(607) Bryan, Kirk, Accelerating the Convergence to Equilibrium of Ocean-Climate Models, Journal of Physical Oceanography, 14(4), 667-673, 1984.

* (608) Oey, Li-Yauw, On Steady Salinity Distribution and Circulation in Partially Mixed and Well Mixed Estuaries, Journal of Physical Oceanography, 14(3), 629-645, 1984.

(609) Pierrehumbert, R.T., Linear Results on the Barrier Effects of Mesoscale Mountains, Journal of the Atmospheric Sciences, 41(8), 1984.

* (610) Lemke, P., and T.O. Manley, The Seasonal Variation of the Mixed Layer, and the Pycnocline under Polar Sea Ice, Journal of the Atmospheric Sciences, 89(C4), 6494-6504, 1984.

* (611) Sarmiento, J.L., and J.R. Toggweiler, A New Model for the Role of Determining Atmospheric PCO_2, Nature, 308(5960), 621-624, 1984.

(612) Manabe, S., and A.J. Broccoli, Ice-Age Climate and Continental Ice Sheets: Some Experiments, Annals of Glaciology, 5, 100-105, 1984.

(613) Orlanski, Isidoro and Bruce B. Ross, The Evolution of an Observed Cold Front. Part II: Mesoscale Dynamics, Journal of the Atmospheric Sciences, 41(10), 1669-1703, 1984.

(614) Philander, S.G.H. and R.C. Pacanowski, Simulation of the Seasonal Cycle in the Tropical Atlantic Ocean, Geophysical Research Letters, 11(8), 802-804, 1984.

*In collaboration with other organizations

(615) Orlanski, Isidoro and Larry Polinsky, Predictability of Mesoscale Phenomena, Nowcasting II, Mesoscale Observations and Very Short Range Weather Forecasting, Proceedings of the Second International Symposium on Nowcasting, Norrkoping, Sweden, 3-7 September 1984, 171-280, ESA SP-208.

(616) Manabe, S., and A.J. Broccoli, Influence of the CLIMAP Ice Sheet on the Climate of a General Circulation Model: Implications for the Milankovitch Theory, A.L. Berger et al. (eds) Milankovitch and Climate, Part 2, 789-799, D. Reidel Publishing Co., 1984.

(617) Hayashi, Y., D.G. Golder, and J.D. Mahlman, Stratospheric and Mesospheric Kelvin Waves Simulated by the GFDL "SKYHI" General Circulation Model, Journal of the Atmospheric Sciences, 41(12), 1971-1984, 1984.

(618) Fels, Stephen B., The Radiative Damping of Short Vertical Scale Waves in the Mesosphere, Journal of the Atmospheric Sciences, 41(10), 1755-1764, 1984.

* (619) Salby, Murry L., Survey of Planetary-Scale Traveling Waves: The State of Theory and Observations, Reviews of Geophysics and Space Physics, 22(2), 209-236, 1984.

* (620) Gwinn, Elizabeth and Jorge L. Sarmiento, A Model for Predicting Strontium-90 Fallout in the Northern Hemisphere (1954-1974). Ocean Tracers Laboratory Technical Report #3, 1-57, August 1984.

(621) Pierrehumbert, R.T., Local and Global Baroclinic Instability of Zonally Varying Flow, Journal of the Atmospheric Sciences, 41(14), 2141-2162, 1984.

* (622) Domaradzki, J.A., and G.L. Mellor, A Simple Turbulence Closure Hypothesis for the Triple-Velocity Correlation Functions in Homogeneous Isotropic Turbulence, Journal of Fluid Mechanics, Vol.140, 45-61, 1983.

* (623) Domaradzki, J.A., and G.L. Mellor, The Importance of Large Scales of Turbulence for the Predictability of the Turbulent Energy Decay, Proceedings of a Workshop on Predictability of Fluid Motions, La Jolla, CA. February 1983, American Institute of Physics. 571-575.

(624) Lau, Ngar-Cheung, Circulation Statistics based on FGGE Level III-B Analyses Produced GFDL, NOAA Data Report ERl/GFDL-5, 1-427, U.S. Government Printing Office, 1984.

* (625) Richez, C., G. Philander, and M. Crepon, Oceanic Response to Coastal Winds with Shear, Oceanologica Acta, 1984, 7(4), 409-416, 1984.

*In collaboration with other organizations

* (626) Carton, J.A., and S.G.H. Philander, Coastal Upwelling Viewed as a Stochastic Phenomenon, Journal of Physical Oceanography, 14(9), 1499-1509, 1984.

(627) Miyakoda, K., and J. Sirutis, Impact of Subgrid-Scale Parameterizations on Monthly Forecasts, Proceedings of ECMWF Workshop on Convection in Large-Scale Numerical Models," December 1983, Reading, England. ECMWF Workshop Book, 231-277, 1984.

* (628) Bryan, Frank and Abraham H. Oort, Seasonal Variation of the Global Water Balance based on Aerological Data, Journal of Geophysical Research, 89(D7), 11,717-11,730, 1984.

(629) Lau, Ngar-Cheung, A Comparison of Circulation Statistics based on FGGE Level III-B Analyses Produced by GFDL and ECMWF for the Special Observing Periods, NOAA Data Report, NOAA-ERL-GFDL-6, 237 pp. 1984.

(630) Manabe, S., and A.J. Broccoli, The Influence of Continental Ice Sheets on the Climate of an Ice Age, Journal of Geophysical Research, 90(D1), 2167-2190, 1985.

* (631) Lau, Ngar-Cheung and Ka-Ming Lau, The Structure and Energetics of Midlatitude Disturbances Accompanying Cold-Air Outbreaks over East Asia, Monthly Weather Review, 112(7), 1309-1327, 1985.

(632) Lau, Ngar-Cheung, Comparison of Level III-B FGGE Analyses Produced by GFDL and ECMWF during the Special Observing Periods, Proceedings of the Scientific Seminar on Global Diagnostic Studies Based on Data Collected during the Global Weather Experiment, Helsinki, Finland, 28-31 August 1984, 1-17.

(633) Lau, Ngar-Cheung, Transient Eddy Forcing of the Stationary Waves as Identified by Geopotential Tendencies, Proceedings of workshop on "Dynamics and Long Waves in the Atmosphere" sponsored by the University of Stockholm and Royal Netherlands Meteorological Institute, October 1984, 167-176.

* (634) Mesinger, Fedor, Vertical Finite-Difference Representation in Weather Prediction Models, Report of the Seminar on Progress in Numerical Modelling and Understanding of Predictability as a Result of the Global Weather Experiment held at Sigtuna, Sweden, October 1984, 1-49, GARP Special Report No. 43, 1985.

* (635) Philander, George, David Halpern, Donald Hansen, Richard Legeckis, Laury Miller, Carl Paul, Randolph Watts, EOS, Transactions, American Geophysical Union, 66(14), 154-156, 1985.

*In collaboration with other organizations

* (636) Schemm, Charles E. and Frank B. Lipps, A Three-Dimensional Numerical Study ofTurbulence in Homogeneous Fluids, Computers and Fluids, 13(2), 185-205, 1985.

* (637) Kurihara, Yoshio and Mitsuhiro Kawase, On the Transformation of a Tropical Easterly Wave into a Tropical Depression: A Simple Numerical Study, Journal of the Atmospheric Sciences, 42(1), 68-77, 1985.

* (638) Miyahara, Saburo, Suppression of Stationary Planetary Waves by Internal Gravity Waves in the Mesosphere, Journal of the Atmospheric Sciences, 42(1), 100-107, 1985.

* (639) Levy, H., J. D. Mahlman, W. J. Moxim, and S. C. Liu, Tropospheric Ozone: The Role of Transport, Journal of Geophysical Research, 90(C4),3753-3772, 1985.

* (640) Fels, S. B., J. T. Schofield, and D. Crisp, Observations and Theory of the Solar Semidiurnal Tide in the Mesosphere of Venus, Nature, 312(5993), 431-434, 1984.

* (641) Salby, Murry L., Transient Disturbances in the Stratosphere: Implications for Theory and Observing Systems, Journal of Atmospheric and Terrestrial Physics, 46(11), 1009-1047, 1984.

(642) Miyakoda, K., Impact of the Centre's Research, The History and Achievement of CMRC/ANMRC, Australia, Reprint from CMRC/ANMRC Valedictory Report 1969-1984, Australian Numerical Meterology Research Centre, 32-39, 1984.

* (643) Rosen, Richard D., David A. Salstein, Jose P. Peixoto, Abraham H. Oort, and Ngar-Cheung Lau, Circulation Statistics Derived from Level III-b and Station-Based Analyses during FGGE, Monthly Weather Review, 113(1), 65-88, 1985.

* (644) Carissimo, B.C., A.H. Oort, and T. Vonder Haar, On Estimating the Meridional Energy Transports in the Atmosphere and Ocean. Journal of Physical Oceanography, 15(1), 82-91, 1985.

* (645) Yamagata, Toshio and Y. Hayashi, A Simple Diagnostic Model for the 30-50 Day Oscillation in the Tropics, Journal of the Meteorological Society of Japan, 62(5), 709-717, 1985.

(646) Pierrehumbert, R. T., Stratified Semigeostrophic Flow over Two-Dimensional Topography in an Unbounded Atmosphere, Journal of the Atmospheric Sciences, 42(5), 523-526, 1985.

(647) Bender, M.A., R. Tuleya, and Y. Kurihara, A Numerical Study of the Effect of a Mountain Range on a Landfalling Tropical Cyclone, Monthly Weather Review, 113(4), 567-582, 1985.

*In collaboration with other organizations

* (648) Puri, Kamal, Sensitivity of Low-Latitude Velocity Potential Field in a Numerical Weather Prediction Model to Initial Conditions, Initialization and Physical Processes, Monthly Weather Review, 113(4), 449-466, 1985.

(649) Stern, W.F., J.J. Ploshay, and K. Miyakoda, Continuous Data Assimilation at GFDL during FGGE, Proceedings at European Center for Medium-Range Weather Forecasting on Data Assimilation Systems and Observation Systems Experiment with Particular Emphasis on FGGE. September 3-11, 1984, Vol.2, 125-156.

(650) Pierrehumbert, R. T., and B. Wyman, Upstream Effects of Mesoscale Mountains. Journal of the Atmospheric Sciences, 42(10), 977-1003, 1985.

* (651) Held, I., R.L. Panetta, and R. Pierrehumbert, Stationary External Rossby Waves in Vertical Shear. Journal of the Atmospheric Sciences, 42(9), 865-883, 1984.

* (652) Puri, K., and W. Stern, Investigations to Reduce Noise and Improve Data Acceptance in the GFDL 4-Dimensional Analysis System, ECMWF 1984 Seminar Proceedings - Data Assimilation Systems Observing Systems with Particular Emphasis on FGGE, U.K., August 1984, 157-190.

* (653) Toggweiler, J.R., and J.L. Sarmiento, Glacial to Interglacial Changes in Atmospheric Carbon Dioxide: The Critical Role of Ocean Surface Water in High Latitudes, The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present, E.T. Sundquist and W.S. Broecker, eds., Geophysical Monograph 32, American Geophysical Union, Washington, DC, 163-184, 1985.

(654) Williams, Gareth P., Geostropic Regimes on Sphere and Beta Plane, Journal of the Atmospheric Sciences, 42(12), 1237-1243, 1985.

* (655) Dritschel, David, The Stability and Energetics of Corotating Uniform Vortices. Journal of Fluid Mechanics, 157, 95-134, 1984.

(656) Pierrehumbert, R.T., A Theoretical Model of Orographically Modified Cyclogenesis. Journal of the Atmospheric Sciences, 42(12), 1244-1258, 1985.

(657) Hayashi, Y., and D.G. Golder, Nonlinear Energy Transfer between Stationary and Transient Waves Simulated by a GFDL Spectral General Circulation Model. Journal of the Atmospheric Sciences, 42(12), 1340-1344, 1984.

* (658) Daley, R., A. Hollingsworth, J. Ploshay, K. Miyakoda, W. Baker, E. Kalnay, C. Dey, T. Krishnamurti, and E. Baker, Objective Analysis and Assimilation Techniques used for the Production of FGGE IIIb Analyses. Bulletin of the American Meteorological Society, 66(5), 532-538, 1985.

*In collaboration with other organizations

(659) Orlanski, I., B.B. Ross, L. Polinsky, and R. Shaginaw, Advances in the Theory of Atmospheric Fronts, In Advances in Geophysics, (28), B. Weather Dynamics, B. Saltzman (ed.), Academic Press, New York, 223-252, 1985.

(660) Kurihara, Y., Numerical Modeling of Tropical Cyclones, In Advances in Geophysics, (28), B. Weather Dynamics, B. Saltzman (ed.), Academic Press, New York, 255-281, 1985.

(661) Miyakoda, K., and J. Sirutis, Extended Range Forecasting, Advances in Geophysics, (28), B. Weather Dynamics, B. Saltzman (ed.), Academic Press, New York, 55-85, 1985.

(662) Manabe, S. and R. T. Wetherald, CO_2 and Hydrology, Advances in Geophysics, (28), A. Climate Dynamics, B. Saltzman (ed.), Academic Press, New York, 131-156, 1985.

(663) Philander, S.G., Tropical Oceanography, Advances in Geophysics, (28), A. Climate Dynamics, B. Saltzman (ed.), Academic Press, New York, 461-475, 1985.

* (664) Bryan, K., and J.L. Sarmiento, Modeling Ocean Circulation, Advances in Geophysics, (28), A. Climate Dynamics, B. Saltzman (ed.), Academic Press, New York, 433-459, 1985.

(665) Oort, A.H., Balance Conditions in the Earth's Climate System, Advances in Geophysics, (28), A. Climate Dynamics, B. Saltzman (ed.), Academic Press, New York, 75-97, 1985.

* (666) Wallace, J.M., and N.-C. Lau, On the Role of Barotropic Energy Conversions in the General Circulation, Advances in Geophysics, (28), A. Climate Dynamics, B. Saltzman (ed.), Academic Press, New York, 33-72, 1985.

* (667) Philander, S.G.H. and E.M. Rasmusson, The Southern Oscillation and El Nino, Advances in Geophysics, (28), A. Climate Dynamics, B. Saltzman (ed.), Academic Press, New York, 197-213, 1985.

(668) Mahlman, J.D., Mechanistic Interpretation of Stratospheric Tracer Transport, Advances in Geophysics, (28), A. Climate Dynamics, B. Saltzman (ed.), Academic Press, New York, 301-320, 1985.

(669) Fels, S.B., Radiative-Dynamical Interaction in the Middle Atmosphere, Advances in Geophysics, (28), A. Climate Dynamics, B. Saltzman (ed.), Academic Press, New York, 277-298, 1985.

(670) Williams, Gareth P., Jovian and Comparative Atmospheric Modeling, Advances in Geophysics, (28), A. Climate Dynamics, B. Saltzman (ed.), Academic Press, New York, 381-423, 1985.

*In collaboration with other organizations

(671) Held, Isaac M. and Brian J. Hoskins, Large-Scale Eddies and the General Circulation of the Troposphere, Advances in Geophysics, (28), A. Climate Dynamics, B. Saltzman (ed.), Academic Press, New York, 3-29, 1985.

* (672) Snieder, R., The Origin of the 100,000 Year Cycle in a Simple Ice Age Model, Journal of Geophysical Research, 90(D3), 5661-5664, 1985.

* (673) Sarmiento, J.L., and J.R. Toggweiler, A Preliminary Model of the Role of Upper Ocean Chemical Dynamics in Determining Oceanic CO_2 and Atmospheric CO_2 Levels, Nature, 308(5960), 621-624, 1985.

* (674) Moore, W.S., R.M. Key, and J.L. Sarmiento, High Precision ^{226}Ra and ^{228}Ra Measurements in the North Atlantic Ocean, Journal of Geophysical Research, 90(C4), 6983-6994, 1985.

* (675) Key, R.M., R.F. Stallard, W.S. Moore, and J.L. Sarmiento, Distribution and Flux of Ra^{-226} and Ra^{-228} in the Amazon River Estuary, Journal of Geophysical Research, 90(C4), 6995-7004, 1985.

* (676) Brewer, Peter G., Jorge L. Sarmiento, and William M. Smethie, Jr., The Transient Tracers in the Ocean (TTO) Program, The North Atlantic Study: 1981, The Tropical Atlantic Study: 1983, Journal of Geophysical Research, 90(C4), 6903-6906, 1985.

(677) Mellor, George L., Ensemble Average Turbulence Closure, Advances in Geophysics, (28), B. Weather Dynamics, B. Saltzman (ed.), Academic Press, New York, 345-358, 1985.

*In collaboration with other organizations

MANUSCRIPTS SUBMITTED FOR PUBLICATION

(e) Pierrehumbert, R.T., Formation of Shear Layers Upstream of the Alps. (Submitted to Revista Meteorologica i Aeronautica, Special Issue on Proc. Fifth Course on Meteorology of the Mediterranean, July 1983).

* (h) Oey, L.-Y., G.L. Mellor, and R.I. Hires, Tidal Modeling of the Hudson-Raritan Estuary. (Submitted to Estuarine-Coastal-&-Shelf Science, August 1983).

* (n) Miyahara, Saburo, On the Mean Wind Induced by Internal Gravity Wave Packets in the Atmosphere, (Submitted to Journal of Meteorological Society, Japan, November, 1983).

* (u) Bowman, K., Sensitivity of an Energy Balance Climate Model with Predicted Snowfall Rates. (Submitted to Tellus, April, 1984).

* (x) Toggweiler, J.R., and Susan Trumbore, Bomb-Test ^{90}Sr in Pacific and Indian Ocean as Surface Water Recorded by Banded Corals. (Submitted to Earth and Planetary Science Letters, November 1984).

(ak) Lau, Ngar-Cheung, The Influences of Orography on Large-Scale Atmospheric Flow Simulated by a General Circulation Model. Proceedings of International Symposium on the Tibet Plateau and Mountain Meteorology, Beijing. People's Republic of China, March 20-24, 1984.

(an) Bryan, K., and S. Manabe, A Coupled Ocean-Atmosphere and the Response to Increasing Atmospheric CO_2. Proceedings of the Liege Colloquium (1984), World Climate Research Programme, Symposium on Coupled Ocean-Atmosphere Models, Liege, Belgium.

(av) Lau, Ngar-Cheung and A.H. Oort, Response of a GFDL General Circulation Model to SST Fluctuations Observed in the Tropical Pacific Ocean during the Period 1962-1976. Proceedings of JSC/CCCO 16th International Liege Colloquium "Coupled Atmosphere-Ocean Models" 7-11 May 1984, (Elsevier Oceanography Series).

(ax) Hayashi, Y., Theoretical Interpretations of the Eliassen-Palm Diagnostics of Wave-Mean Flow Interaction. Part I: Effects of the Lower Boundary, (Submitted to Journal of the Atmospheric Sciences, August 1984).

(ay) Hayashi, Y., Theoretical Interpretations of the Eliassen-Palm Diagnostics of Wave-Mean Flow Interaction. Part II: Effects of Mean Damping, (Submitted to Journal of the Atmospheric Sciences, August 1984).

*In collaboration with other organizations

(bf) Hayashi, Y., Dynamical Predictability of Ensemble-Time Means Part I: The Predictability Limit, (Submitted to Journal of the Atmospheric Sciences, August 1984).

(bg) Hayashi, Y., Dynamical Predictability of Ensemble-Time Means Part II: The Statistical Significance (Submitted to Journal of the Atmospheric Sciences, August 1984).

* (bl) Sarmiento, J.L., Three-Dimensional Ocean Models for Predicting the Distribution of CO_2 between the Ocean and Atmosphere, (Proceedings of the Sixth ORNL Life Science Symposium, Springer-Verlag, ed. D.E. Reichle).

(bp) Lipps, F.B., and R.S. Hemler, Another Look at the Scale Analysis for Deep Moist Convection, (Submitted to Journal of the Atmospheric Sciences, September 1984).

(bu) Philander, S.G.H., El Niño Y La Niña, (Submitted to Journal of the Atmospheric Sciences, October 1984).

* (bv) Wajsowicz, Roxana C., Free Planetary Waves in Finite-Difference Numerical Models, (Submitted to Journal of Physical Oceanography, November 1984).

* (bw) Oort, Abraham H., and M.A.C. Maher, Observed Long-Term Variability in the Global Surface Temperatures of the Atmosphere and Oceans, to be published in the Proceedings of the JSC/CCCO 16th International Liege Colloquium "Coupled Atmosphere-Ocean Models," 7-11 May 1984, Elsevier Oceanography Series.

* (bx) Wajsowicz, Roxana, Adjustment of the Ocean under Buoyancy Forces, I: The Role of Kelvin Waves, (Submitted to the Journal of Physical Oceanography, December 1984).

* (by) Wajsowicz, Roxana, Adjustment of the Ocean under Buoyance Forces, II: The Role of Planetary Waves, (Submitted to the Journal of Physical Oceanography, December 1984).

* (bz) Galperin, B., S. Hassid, A Modified Turbulent Energy Model for Geophysical Flows: Influence of the Ground Proximity, (Submitted to Boundary Layer Meteorology, December 1984).

* (ca) Galperin, B., and S. Hassid, A Two-Layer Model for the Barotropic Stationary Turbulent Planetary Boundary Layer, (Submitted to Boundary Layer Meteorology, December 1984).

* (cb) Huang, Rui-Xin, Exact Solution of the Ideal Fluid Thermocline with Continuous Stratification, (Submitted to Journal of Physical Oceanography, December 1984).

*In collaboration with other organizations

(cc) Philander, S.G.H., and A.D. Seigel, Simulation of El Niño of 1982-1983, (Proceedings of the 16th International Liege Colloquium - Coupled Atmosphere-Ocean Models, December 1984).

(ce) Ross, Bruce, Six to Forty-Eight Hour Forecasting: Numerical Weather Prediction, (Mesoscale Meteorology and Forecasting, Peter Ray (ed). American Meteorological Society, December 1984).

* (cf) Kawase, M., and J. Sarmiento, Nutrients in the Atlantic Thermocline, (Submitted to Journal of Geophysical Research, December 1984).

(ch) Cox, Michael D., An Eddy Resolving Numerical Model of the Ventilated Thermocline, (Submitted to Journal of Physical Oceanography, January 1985).

(ci) Oort, A.H., Variability of the Hydrological Cycle in the Asian Monsoon Region, (Submitted to Oceanic Press, Beijing, January 1985).

(cj) Schwarzkopf, M. Daniel, and Stephen B. Fels, Improvements to the Algorithm for Computing CO_2 Transmissivities and Cooling Rates, (Submitted to Journal of Geophysical Research, January 1985).

(ck) Bryan, Kirk, and Michael J. Spelman, The Ocean's Response to a CO_2-Induced Warming, (Submitted to Journal of Geophysical Research, January 1985).

(cl) Held, Isaac M., Pseudomomentum and the Orthogonality of Modes on Shear Flows, (Submitted to Journal of Atmospheric Science, February 1985).

* (cm) Sarmiento, Jorge L., and Pierre E. Biscaye, Radon-222 in the Benthic Boundary Layer, (Submitted to Journal of Geophysical Research, February 1985).

(cn) Lau, Ngar-Cheung, Publication of Circulation Statistics based on FGGE Level III-B Analyses produced by GFDL and ECMWF, (Submitted to Bulletin of the American Meteorological Society, February 1985).

(co) Hemler, Richard S., and Frank B. Lipps, An Investigation of Open Boundary Conditions for a Three-Dimensional Moist Convection Model, (Submitted to Monthly Weather Review, February 1985).

(cp) Wetherald, R.T., and S. Manabe, An Investigation of Cloud Cover Change in Response to Thermal Forcing, (Submitted to Climatic Change, February 1985).

(cq) Lau, Ngar-Cheung, Modeling the Seasonal Dependence of the Atmospheric Response to Observed El Ninos in 1962-1976, (Submitted to Monthly Weather Review, March 1985).

* (cs) Crook, Norman A., The Effect of Ambient Stratification and Moisture on the Motion of Atmospheric Undular Bores, (Submitted to Journal of Atmospheric Sciences, March 1985).

*In collaboration with other organizations

(cu) Manabe, S., and A.J. Broccoli, A Comparison of Climate Model Sensitivity with Data from the Last Glacial Maximum, (Submitted to Journal of Atmospheric Sciences, April 1985).

* (cv) Bogue, Neil M., and Kirk Bryan, Verification Experiments with an Isopycnal Coordinate Ocean Model, (Submitted to Journal of Physical Oceanography, April 1985).

* (cw) Navarra, A., An Application of the Krylor Method to a Geophysical Fluid Dynamics Problem, (Submitted to Journal of Computational Physics, April 1985).

(cy) Lipps, Frank B., and Richard S. Hemler, Numerical Simulation of Deep Tropical Convection Associated with Large-Scale Convergence, (Submitted to Journal of the Atmospheric Sciences, April 1985).

(cz) Mahlman, J. D., H. Levy II, and W. J. Moxim, Three-Dimensional Simulations of Stratospheric N_2O: Predictions for other Trace Constituents, (Submitted to Journal of Geophysical Research, Atmospheres, April 1985).

(da) Manabe, Syukuro and Kirk Bryan, Jr., CO_2 Induced Change in a Coupled Ocean-Atmosphere Model and its Paleoclimatic Implications, (Submitted to Journal of Geophysical Research, May 1985).

(db) Fels, Stephen B., An Approximate Analytical Method for Calculating Tides in the Atmosphere of Venus, (Submitted to Journal of the Atmospheric Sciences, May 1985).

* (dc) Held, Isaac M., Raymond T. Pierrehumbert, and R. Lee Panetta, Dissipative Destabilization of External Rossby Waves, (Submitted to Journal of the Atmospheric Sciences, May 1985).

* (de) Huang, Rui-Xin, Partial Solutions for Inertial Western Boundary Current with Continuous Stratification, (Proceedings of Gulf Stream Workshop, University of Rhode Island, April 1985).

(df) Fels, Stephen B., Analytic Representations of Standard Atmosphere Temperature Profiles, (Submitted to Journal of the Atmospheric Sciences, June 1985).

* (dg) Miyahara, S., Y. Hayashi, and J. D. Mahlman, Interactions Between Gravity Waves and Planetary Scale Flow Simulated by the GFDL "SKYHI" General Circulation Model, (Submitted to Journal of the Atmospheric Sciences, June 1985).

* (dh) Moore, G. W. Kent, On the Organization of Convection in the Narrow-Cold Frontal Rainband, (Submitted to Journal of the Atmospheric Sciences, June 1985).

(di) Levitus, Sydney, Annual Cycle of Salinity in the World Ocean, (Submitted to Journal of Physical Oceanography, June 1985).

*In collaboration with other organizations

(dk) Pierrehumbert, R. T., The Effect of Local Baroclinic Instability on Zonal Inhomogeneities of Vorticity and Temperature, (Submitted to Advances In Geophysics, June 1985).

(dl) Pierrehumbert, R. T., Lee Cyclogenesis, (Submitted to Mesoscale Meteorology, Chapter II, for publication in AMS).

(dm) Orlanski, Isidoro and Bruce B. Ross, Low-Level Updrafts in Stable Layers Forced by Convection, (Submitted to Journal of the Atmospheric Sciences, June 1985).

(dn) Bryan, Kirk, Poleward Buoyancy Transport in the Ocean and Mesoscale Eddies, (Submitted to Journal of Physical Oceanography, June 1985).

(do) Pierrehumbert, R. T., Remarks on a paper by Aref and Flinchem, (Submitted to Journal of Fluid Mechanics, July 1985).

* (dp) Wang, Bin, and Albert Barcilon, On the Moist Stability of a Baroclinic Zonal Flow with Conditionally Unstable Stratification, (Submitted to Journal of the Atmospheric Sciences, July 1985).

* (dq) Sarmiento, Jorge L., On the North and Tropical Atlantic Heat Budget, (Submitted to Journal of Geophysical Research, July 1985).

* (dr) Greatbatch, Richard J., On the Role Played by Upwelling of Water in Lowering Sea-Surface Temperatures during the Passage of a Storm, (Submitted to Journal of Geophysical Research (Oceans), May 1985).

* (ds) Greatbatch, Richard J. and Toshio Yamagata, Fofonoff-Type Inertial Mode Steady States in a Model of the Equatorial Oceans, (Submitted to the Journal of Physical Oceanography, July 1985).

* (dt) Greatbatch, Richard J., Kelvin Wave Fronts. Rossby Solitary Waves and the Non-Linear Spin-Up of the Equatorial Oceans, (Submitted to the Journal of Geophysical Research (Oceans), July 1985).

(dv) Gordon, Charles T., William F. Stern and Russell D. Hovanec. A Simple Scheme for Generating Two Layers of Radiatively Constrained Effective Clouds in GCM's, (Submitted to Journal of Geophysical Research, August 1985).

(dw) Gordon, Charles Tony, The Specification of Radiatively Constrained, Effective Clouds in GCM's: Methodology and Some Preliminary Results, (Proceedings of the ECMWF Workshop on Cloud Cover and Radiative Fluxes in Large-Scale Numerical Models, Reading, England, November 26-30, 1984).

(dx) Garzoli, Sylvia L., and S. G. H. Philander, Validation of an Equatorial Atlantic Simulation Model using Inverted Echo Sounders Data, (Submitted to Journal of Geophysical Research, August 1985).

*In collaboration with other organizations

(dy) Miyakoda, K. Assessment of Results from Different Analysis Schemes, (Proceedings on the Conference of Global Weather Experiments and their Implications for the World Weather Watch, Geneva, Switzerland, May 1985).

(dz) Pierrehumbert, R. T. Spatially Amplifying Modes of the Charney Baroclinic Instability Problem, (Submitted to Journal of Fluid Mechanics, August 1985).

(ea) Miyakoda, K., J. Sirutis, and J. Ploshay, Monthly Forecast Experiments Part I: Without Anomaly Boundary Forcings, (Submitted to Monthly Weather Review, August 1985).

(eb) Gordon, C. T., The Sensitivity of One Month GCM Forecasts at GFDL to Zonally Symmetric Clouds, Quasi-Realistic Specified Clouds, and Model-Predicted Clouds, (Proceedings of Report of WCRP Workshop on Cloud Capped Boundary Layers - at Fort Collins, CO. April 22-26, 1985).

*In collaboration with other organizations

BIBLIOGRAPHY

1980-1985

CROSS-REFERENCE BY AUTHOR

ANDREWS, David G.	(459),(463),(482),(569),(589),
BAKER, W.	(658),
BARCILON, Albert	(dp),
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BOGUE, Neil M.	(cv),
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CRISP, David	(640),

APPENDIX C

Computational Support

APPENDIX C

Computational Support

The computational support at GFDL comprises three Control Data CYBER computers:

CY1, a 170/720 with 256K words of memory;
CY2, a 205 supercomputer, with 2 Million words of memory; and
CY4, another 205, with 4 Million words of memory.

No augmentation or alteration to the system hardware was accomplished during FY85, but standard operating software, VSOS Version 2.1.5, was finally installed on the 205's early in FY85, and Control Data met their increase in guaranteed availability (from 42 to 44 hours per day on the combined 205's) in December 1984. The reliability of magnetic tapes and operating software on the 205's has been dramatically improved during FY85, when compared with previous years.

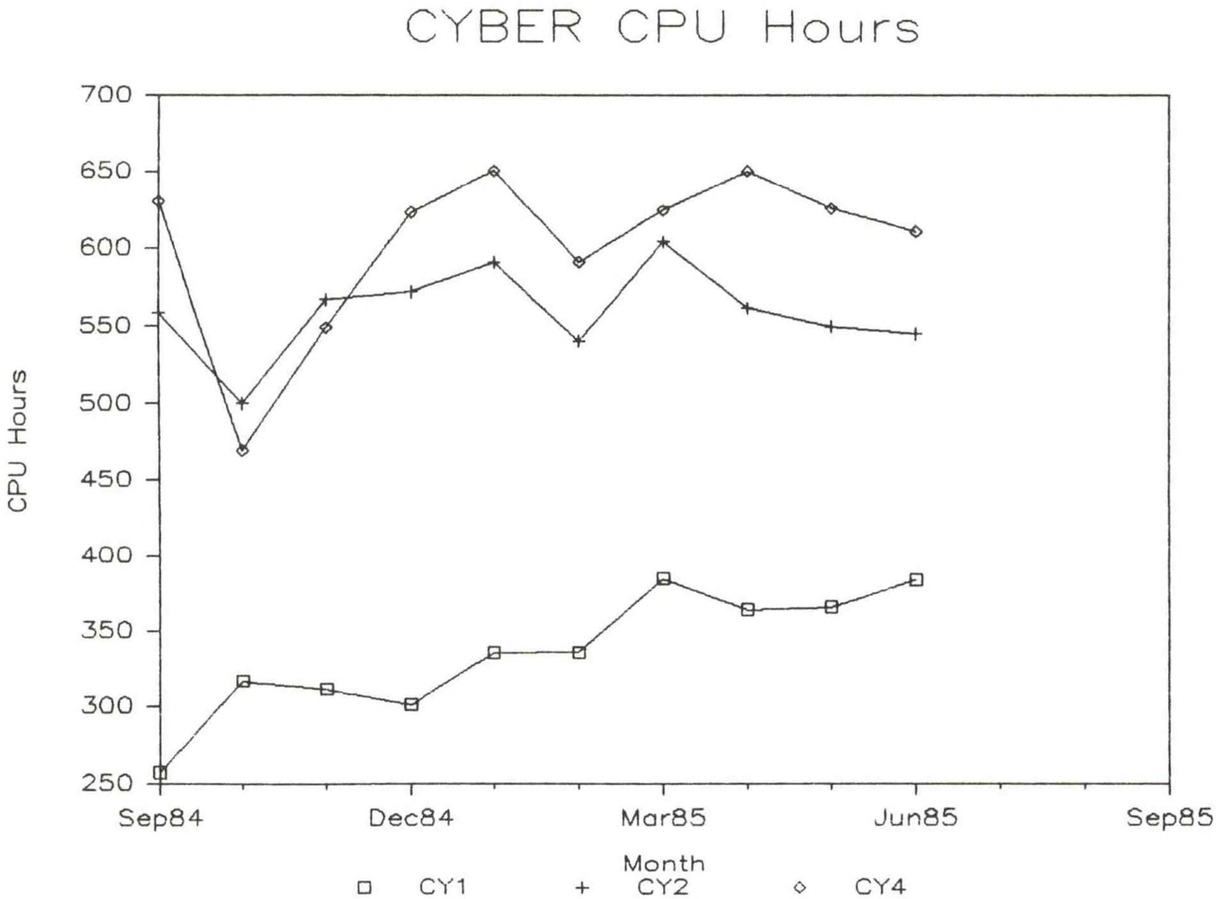
The following table and figure show how many CPU hours were achieved on each machine during the period of this report. The reduction in CPU time during October 1984 was the result of testing of the new operating software, particularly on CY4. That software was fully operational on both 205's in November 1984 and has contributed to the greater general reliability of the system.

FY86 may witness further increase in the number of terminals attached to the CYBER system, but no other significant events are anticipated.

Table C-1. Achieved CPU Hours for GFDL Machines

Month	CY1	CY2	CY4	CY2+CY4
Sep 84	257*	559*	631*	1190*
Oct 84	316	500	469	969
Nov 84	311	568	550	1117
Dec 84	301	572	623	1195
Jan 85	336	591	651	1241
Feb 85	336	540	591	1132
Mar 85	385	604	625	1229
Apr 85	365	562	650	1212
May 85	366	550	626	1176
Jun 85	384	545	611	1156
Jul 85	415	632	643	1275
Aug 85	426	576	620	1196
Sep 85	**	**	**	**

* Not reported in the FY84 Annual Report
** Not available at press time



CYBER CPU Hours
700
650
600
550
500
450
400
350
300
250
CPU Hours
Sep84
Dec84
Mar85
Jun85
Sep85
Month
CY1
CY2
CY4

APPENDIX D

Seminars Given at GFDL

During Fiscal Year 1985

2 October 1984	"New Results on the Stability of a Columnar Vortex: A Possible Explanation for the Multi-Vortex Phenomenon in Tornadoes" by David Dritschel, Geophysical Fluid Dynamics Program, Princeton University
4 October 1984	"Interannual Variability of the Southern Hemisphere Circulation" by Dr. Kevin Trenberth, NCAR, Boulder, CO
9 October 1984	"The Properties of Free Planetary Waves in Finite-Difference Numerical Models" by Roxana Wajsowicz, Geophysical Fluid Dynamics Program, Princeton University
15 October 1984	"Ocean Atmosphere Interactions over Monsoon Regions" by Dr. S. Gadgil, Indian Institute of Science, India
18 October 1984	"Observational Characteristics of Atmospheric Planetary Waves with Bimodal Amplitude Distributions" by Dr. Tony Hansen, Meteorology Research Center, Control Data, Minneapolis, MN
23 October 1984	"Formation of Severe Squall Lines in Oklahoma" by Prof. Howard Bluestein, University of Oklahoma, Dept. of Meteorology, Norman, Oklahoma
25 October 1984	"A Deterministic Computation of Turbulence Generation" by Prof. S.I. Cheng, School of Engineering & Applied Science, Princeton University
26 October 1984	"Diagnostic Analysis of Transient Eddy-Mean Flow Interaction" by Dr. Alan Plumb, CSIRO, Australia
30 October 1984	"Gravity Wave-Large Scale Motion Interaction: A Simple Model and Analyses of SKYHI Model" by S. Miyahara, Geophysical Fluid Dynamics Program, Princeton University
1 November 1984	"A Non-Linear Theory of Stationary Long Waves" by Dr. K.K. Tung, Department of Mathematics, M.I.T. Cambridge, MA
7 November 1984	"Air-Sea-Ice Interaction in the Greenland Sea: Measurements and Models" by Dr. Miles G. McPhee, Yakima, Washington
8 November 1984	"The Influence of the Time Mean Flow on the Midlatitude Response to Sea Surface Temperature Anomalies" by Dr. Grant Branstator, NCAR, Boulder, Colorado
13 November 1984	"Effects of Mean Damping on Wave-Mean Flow Interaction" by Dr. Y. Hayashi, Geophysical Fluid Dynamics Laboratory, Princeton, NJ

15 November 1984	"Circulation of the Venus Atmosphere" by Dr. Arthur Hou, Harvard University, Division of Applied Sciences, Cambridge, MA
20 November 1984	"Effect of a Mountain on a Landfalling Tropical Cyclone" by M. Bender, Geophysical Fluid Dynamics Laboratory, Princeton, NJ
26 November 1984	"Air-Sea Interaction in the Tropics" by Dr. Adrian Gill, Dept. of Atmospheric Physics, University of Oxford, Clarendon Laboratories, Oxford, England
27 November 1984	"Thermocline and Current Structure in Subtropical/ Subpolar Basins" by Dr. Rui-Xin Huang, Geophysical Fluid Dynamics Program, Princeton University, NJ
29 November 1984	"A Numerical Model of River Plume Dynamics" by Dr. James O'Donnell, College of Marine Studies, University of Delaware, Newark, DE
4 December 1984	"Linear Anomaly GCM and the Krylov Method" by A. Navarro, Geophysical Fluid Dynamics Program, Princeton University
6 December 1984	"The Dynamics of Warm and Cold Climates" by Dr. David Rind, Goddard Inst. for Space Studies, New York, NY
10 December 1984	"The Comprehensive Ocean Atmosphere Data Set" by Mr. Scott Woodruff, CIRES, Boulder, CO
12 December 1984	"Comparison of Quasi-Geostrophic and Primitive Equation Models of the Ocean Circulation" by Dr. Mary Batteen, Naval Postgraduate School, Monterey, California
18 December 1984	"Real-Time" Oceanography" by Dr.G. Philander, Geophysical Fluid Dynamics Laboratory, Princeton, NJ
20 December 1984	"Nonlinear Characteristics of Stratified Flow over Topography" by Dr. Peter Baines, C.S.I.R.O. Div. of Atmospheric Physics, Aspendale, Australia
15 January 1985	"Linear Dynamics of the Transient Planetary Waves, by B. Wang, Geophysical Fluid Dynamics Program, Princeton University
25 January 1985	"Ice Ocean Interaction" by Dr. Peter Lemke, Max Planck Institute, Federal Republic of Germany
31 January 1985	"Measurements of Oceanic Variability in the Equatorial Pacific during El Nino of 1982-1983" by Dr. D. Halpern, University of Washington, Seattle, WA

5 February 1985	"Statistical Theories of Turbulent Convection" by Bill Dannevik (MAE).
8 February 1985	"Turbulence Flow Over Hills - Observations and Theory" by Prof. Paul Mason, Meteorological Research Unit, Royal Air Force, Cardington, Bedford, England
12 February 1985	"Mechanisms of Interaction in a Coupled Model Simulation of El Nino/Southern Oscillation" by Dr. Stephen E. Zebiak, M. I. T., Cambridge, MA
12 February 1985	"Interactions Between Gravity Waves and Planetary Scale Flow in "SKYHI" by S. Miyahara and Y. Hayashi, Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey
13 February 1985	"Global Scale Intraseasonal Oscillations of Outgoing Long Wave Radiation and 250 mb Zonal Winds during the Northern Hemisphere Summer" by Mr. Thomas Knutson, Department of Meteorology, University of Wisconsin, Madison, WI
14 February 1985	"Review of Dynamical Topics Tackled at United Kingdom Meteorological Office" by Dr. A. Gilchrist, U.K Meteorological Office, Bracknell, England
15 February 1985	"Rossby Wave Saturation" by Dr. Mark R. Schoeberl, Laboratory for Atmospheres, NASA/Goddard Space Flight Center, Greenbelt, MD
19 February 1985	"Depth of Response of Coastal Winds with Shear" by R. S. Gardiner-Gardner, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
20 February 1985	"Lake Levels and Climate Model Verifications" by Dr. F. Street-Perrott, University of Wisconsin, Madison, WI
21 February 1985	"Transport in the Stratosphere: Advection vs. Diffusion" Prof. James R. Holton, Dept. of Atmospheric Sciences, University of Washington, Seattle, WA 98195
22 February 1985	"General Circulation Studies on CO_2 Increase Analysis and Initialization", by Dr. Warren Washington, NCAR, Boulder, CO
26 February 1985	"Pseudomomentum and External Rossby Waves" by Dr. Isaac Held, Geophysical Fluid Dynamics Laboratory, Princeton, NJ
28 February 1985	"A Numerical Experiment on Mountain Effects in a General Circulation Model" by Prof. Qinglin Zheng, Department of Meteorology, University of Utah, Salt lake City, Utah

5 March 1985	"Local Baroclinicity and Meso-convection System" by Dr. Isidoro Orlanski, Geophysical Fluid Dynamics Laboratory, Princeton, NJ
6 March 1985	"Are We Approaching the Limit of Atmospheric Predictability? by Prof. Edward N. Lorenz, Center for Meteorology & Physical Oceanography, M. I. T., Cambridge, MA
12 March 1985	"Puzzling Problems of Inertial Western Boundary Current and a Solution" by Dr. Rui-Xin Huang, Geophysical Fluid Dynamics Program, Princeton University, NJ
14 March 1985	"Strong Interactions between High Frequency Internal Waves and Near-Inertial Motions" by Dr. W. R. Young, Scripps Institute of Oceanography, La Jolla, CA
19 March 1985	"A Numerical and Analytic Study of Atmospheric Undular Bores" by Dr. Norman Crook, Geophysical Fluid Dynamics Program, Princeton University, NJ
22 March 1985	"Atmospheric Motions in Response to Tropical Heating" by Prof. C.-P. Chang, Department of Meteorology, Naval Postgraduate School, Monterey, CA
26 March 1985	"Comparison of Climte Model Sensitivity with Data From The Last Glacial Maximum" by Dr. S. Manabe and A. J. Broccoli, Geophysical Fluid Dynamics Laboratory, Princeton, N.J.
27 March 1985	"Wave, Mean-Flow Interaction in a Model of the Troposphere and Stratosphere" by Dr. Byron Boville, NCAR, Boulder, CO.
28 March 1985	"A Sea Surface Temperature Analysis which Utilizes both In Situ and Satellite Data" by Dr. Richard W. Reynolds, National Weather Service, Washington, DC
29 March 1985	"A Random-Flight Model of Relative Turbulent Dispersion in Two or Three Dimensional Turbulence" by Prof. Alan J. Faller, Inst. of Fluid Dynamics & Applied Mathematics, University of Maryland.
2 April 1985	"Cloud Cover Change in Response to a Thermal Forcing" by Dick Wetherald and Dr. S. Manabe, Geophysical Fluid Dynamics Laboratory, Princeton, NJ
3 April 1985	"Chlorofluoromethanes as Ocean Tracers" by Dr. John Bullister, Scripps Institute of Oceanography, La Jolla, California

4 April 1985	"Links Between ENSO, Interannual Climate Variability, and Intraseasonal Fluctuations" by Prof. E. M. Rasmusson, Diagnostics Branch, Washington, DC
9 April 1985	"Moist Instability of Midlatitude Zonal Flow with Applications to Explosive Cyclonegenesis" by Dr. Bin Wang, Geophysical Fluid Dynamics Program, Princeton University
11 April 1985	"Do Rossby-Wave Critical Layers Absorb, Reflect or Over-Reflect?" by Prof. Michael McIntyre, Dept. of Applied Mathematics, University of Cambridge, Cambridge, England
12 April 1985	"Satellite Altimetry for Sea-Surface Topography Determination and Geoid Improvement - The Use of Ocean Models" by Dr. J. C. Marshall, Imperial College of Science and Technology, London, England
16 April 1985	"Analyses of the Southern Hemisphere Circulation and the Impact of FGGE Observations" by Dr. David Karoly, Monash University and NCAR, Boulder, CO.
17 April 1985	"Interannual Variability of the Southern Hemisphere Troposphere" by Dr. David Karoly, NCAR, Boulder, CO
18 April 1985	"Renormalization Group-Based Closures for Stratified Turbulence" by Prof. Steven Orszag, Engineering Quad, Princeton University
19 April 1985	"Perturbation in the Net Radiation due to El Nino from Nimbus 7 Observations" by Dr. Garrett Campbell, Colorado State University, Fort Collins, CO
19 April 1985	"Sea Surface Temperature and Heat Flux in Equatorial Models" by Dr. Neil C. Wells, The University of Southampton, England
22 April 1985	"An Equatorial GCM Study of Wind Forcing in the Pacific Ocean" by Dr. Max Rowe, The University of Southampton, England.
25 April 1985	"The Effect of Orbital Variations on Pliocene Climates" by Dr. James D. Hays, Lamont-Doherty Geological Observatory, Palisades, NY
30 April 1985	"Rossby-Wave Nonlinear Critical Layers" by Dr. Peter Haynes, Joint Institute for Study of Atmosphere and Ocean, University of Washington, Seattle, WA
2 May 1985	"Regional Acid Rain Modeling: Current Status and Future Prospects" by Dr. Julius S. Chang, NCAR Acid Deposition Modeling Project, Boulder, CO

3 May 1985	"The Use of Special Purpose Super Computers in Fluid Mechanics" by Dr. Dan Nosenchuck, Dept. of Engineering, Princeton University
6 May 1985	"Wave-Mean Flow Interaction - An Alternative to the E-P Flux Vector" by Dr. Richard Pfeffer, Geophysical Fluid Dynamics Institute, Florida State University
7 May 1985	"Monthly Forecast Experiment: Part I. Without Anomaly Boundary Forcing" by Dr. K. Miyakoda, J. Sirutis, and J. Ploshay, Geophysical Fluid Dynamics Laboratory, Princeton, NJ
9 May 1985	"Mesoscale Sensitivity to the NMC Regional Prediction Model to Variations in Analysis and Initialization" by Dr. Ronald D. McPherson, National Meteorological Center, Washington, DC
14 May 1985	"Circulation and Nutrients in the Mid-Depth Atlantic" by M. Kawase, Geophysical Fluid Dynamics Program, Princeton University, NJ.
21 May 1985	"Boundary Layer Separation of a Two-Layer Rotating Flow" by L. Brevdo, Geophysical Fluid Dynamics Program, Princeton University, NJ.
23 May 1985	"Nonlinear Equatorial Waves" by Prof. John Boyd, University of Michigan, Ann Arbor, MI
24 May 1985	"Inertial Circulation in 1 and 2 Layer, Quasi-Geostrophic Numerical Models" by Dr. Glen Ierley, Michigan Technical University, Houghton, MI
28 May 1985	"Meso-Beta Simulation of a Severe Storm Outbreak" by Dr. Bruce Ross, Geophysical Fluid Dynamics Laboratory, Princeton, NJ.
30 May 1985	"The Mechanisms of Atmospheric Response to External Forcing" by Dr. George Boer, Numerical Modeling Division, Downsview, Ontario, Canada
31 May 1985	"Evolution of North Atlantic Surface Ocean Response over the Last Million Years" by Dr. William F. Ruddiman, Lamont-Doherty Geological Observatory, Palisades, NY
14 June 1985	"El Niño of 1982-1983: Comparison Between Measurements and GFDL Models" by Dr. A. Leetmaa, NMC, Washington, DC
26 June 1985	"Steady Almost Free Circulation in a Stratified Quasi-Geostrophic Ocean" by Dr. R. Greatbatch, Imperial College, London, England

2 July 1985	"Meridional Heat Transport by the Global Atmosphere: An Analysis of FGGE III - B Data Produced by ECMWF" by Mr. Kooiti Masuda, University of Tokyo, Tokyo, Japan
2 July 1985	"EPA Requirements for Atmospheric Research Information" by Mr. John Hoffman, Environmental Protection Agency, Washington, DC
23 July 1985	"PROFS: Progress and Possibilities" by Dr. Alexander E. "Sandy" MacDonald, Director, PROFS Program Office ERL/NOAA, Boulder, CO
27 August 1985	"Numerical Experiments Concerning the Origin of Cloud Clusters" by Prof. Taroh Matsuno, University of Tokyo, Tokyo, Japan
29 August 1985	"Design and Test of a GCM Suitable for Climate Modeling" by Prof. Qing-cun Zeng, Institute of Atmospheric Physics, Academia Sinica, Beijing, Peoples Republic of China
30 August 1985	"Variational 4-D Assimilation using Quasi-Geostrophic Constraints" by Dr. John Derber, Dept. of Meteorology, University of Wisconsin, Madison, WI
3 September 1985	"Multiple Equilibria in Tropical Circulation and the Monsoon" by Prof. Bao Zhen Zhu, Institute of Atmospheric Physics, Beijing, Peoples Republic of China

APPENDIX E

Talks, Seminars, and Papers Presented Outside GFDL

During Fiscal Year 1985

Seminars not included in FY84 Report

30 August 1984	Dr. R. Lee Panetta "Stationary External Rossby Waves" Global Scale Anomalous Circulation in the Atmosphere and Blocking Conference, Rome, Italy
12 September 1984	Dr. R. Lee Panetta Stationary External Rossby Waves" University of Reading, England
17 September 1984	Dr. Jorge L. Sarmiento "A New 3-D Seasonal Model of the North Atlantic" SCOR Working Group 68 Meeting, Princeton University
1985 3 October 1984	Dr. Jerry D. Mahlman "The Role of 3-D Models in the Design and Interpretation of Chemical Climatology Networks" Planning Conference on Global Chemical Climatology, Atlanta, Georgia
8 October 1984	Mr. Jeffrey J. Ploshay "Re-analysis of FGGE-IIIb Data Sets during the SOPS" FGGE Tropics Seminars, Tallahassee, FL
8 October 1984	Dr. Kikuro Miyakoda "Numerical Experimentation at GFDL", FGGE Tropics Workshop, Florida State University, Tallahassee, FL
11 October 1984	Dr. Stephen B. Fels "The Semi-diurnal Tide in the Venus Mesosphere" American Astronomical Society Meeting, Div. of Planetary Sciences, Kona, Hawaii
16 October 1984	Dr. Roxana Wajsowicz "Adjustment of the Ocean under Buoyancy Forces" Woods Hole Oceanographic Institution, Woods Hole, MA
17 October 1984	Dr. Roxana Wajsowicz "Behavior of Planetary Waves Propagating on a Finite-Difference Grid" Woods Hole Oceanographic Institution, Woods Hole, MA
17 October 1984	Dr. Jerry D. Mahlman "Role of Chemically Active Trace Gases in Future Climate Change" National Academy of Sciences, Washington, DC

17 October 1984	Dr. Hiram Levy II "Global Tropospheric Chemistry: A Plan for Action-Global Distributions, Long-Range Transport and Modeling the Tropospheric Chemical System" National Academy of Sciences Press Conference on Global Tropospheric Chemistry: A Plan for Action, Washington, D. C.
18 October 1984	Dr. Raymond T. Pierrehumbert "Mechanisms of Circulation Change during Lee Cyclogenesis" American Meteorological Society's Mountain Meteorology Meeting, Portland, Oregon
22 October 1984	Dr. Raymond T. Pierrehumbert "Feedback of Synoptic Eddies on Persistent Anomalies" University of Washington, Seattle, Washington
22 October 1984	Mr. Joseph J. Sirutis "Monthly Forecast Experiments with Sea Surface Temperature Anomaly Forcings: Preliminary Results" Ninth Climate Diagnostics Workshop, Corvallis, Oregon
24 October 1985	Mr. Antonio Navarra "A Baroclinic, Primitive Equation Anomaly Model" Ninth Climate Diagnostic Workshop, Corvallis, Oregon
28 October 1984	Mr. Frank Bryan "Water Mass Transformations in a Model of the North Atlantic" NATO/ARW Water Mass Formation in the Upper Ocean Conference, Venice, Italy
29 October 1984	Mr. Sydney Levitus "Annual Cycle of Salinity in the World Ocean" NATO Advanced Research Workshop on Water Mass Formation in the Upper Ocean Conference, Venice, Italy
29 October 1984	Dr. Kirk Bryan "Water Mass Formation in an Eddy-Resolving Model" NATO Advanced Research Workshop on Water Mass Formation in the Upper Ocean Conference, Venice,Italy
30 October 1984	Dr. Abraham Oort "Variability of the Hydrological Cycle over the Globe" International Symposium "Relationships between Climate of China and Global Climate: Past, Present and Future" sponsored by Academia Sinica, Beijing, China
31 October 1984	Dr. George Philander "Predictability of Tropical Oceans and Atmospheres" Massachusetts Institute of Technology, Cambridge, Massachusetts

8 November 1984	Dr. Syukuro Manabe 1) "CO_2 and Climatic Change" and 2) "Simulation of an Ice Age Climate" University of Washington, Seattle, Washington
8 November 1984	Mr. David G. Dritschel "The Nonlinear Stability of Uniform Vortices" University of Cambridge, Cambridge, England
12 November 1984	Mr. David G. Dritschel "A New Class of Instabilities on a Columnar Vortex" University College, London, England
12 November 1984	Dr. Isidoro Orlanski "Explosive Cyclogenesis" University of Buenos Aires, Buenos Aires, Argentina
15 November 1985	Prof. George L. Mellor "Model, Data Comparison for the Hudson/Raritan Estuary and Lessons Learned" Middle Atlantic Bight Physical Oceanography Workshop, University of Delaware, Newark DE
14-21 November 1984	Dr. Kikuro Miyakoda 1) "Ocean-Atmosphere Interaction" 2) "Feasibility of Monthly Forecasts" 3) "FGGE Data Assimilation at GFDL" WMO/CAS Experts Meetings, Geneva, Switzerland
16 November 1984	Dr. Raymond T. Pierrehumbert "Small Scale Transition" Workshop on Free Shear Layers Providence, Rhode Island
19 November 1984	Dr. George Philander "Status of Indian Ocean Models" Indian Ocean Workshop, Miami, Florida
26 November 1984	Dr. Charles T. Gordon "The Specification or Prediction of Radiatively Constrained Clouds in GCM's: Methodology and Some Preliminary Results" European Centre for Medium Range Weather Forecast Workshop on Cloud Cover and Radiative Fluxes, Reading, England
27 November 1984	Dr. Saburo Miyahara "Suppression of Stationary Planetary Waves by Internal Gravity Waves in the Mesosphere" MAP Symposium, Kyoto, Japan
27 November 1984	Dr. Yoshikazu Hayashi "Effects of Rayleigh and Newtonian Damping on Wave-Mean Flow Interaction" International MAP Symposium, Kyoto, Japan

27 November 1984	Dr. Hiram Levy II "Monitoring vs. Research Measurements" ERL Air Quality "Bin Review" Oak Ridge, Tennessee
27 November 1984	Dr. Jerry D. Mahlman "Major Problems and Challenges in Dynamics and Transport Processes" ERL Air Quality "Bin Review" Oak Ridge, Tennessee
28 November 1984	Dr. Hiram Levy II "Tropospheric Ozone" Georgia Institute of Technology, Atmospheric Chemistry Department, Atlanta, Georgia
28 November 1984	Dr. Abraham H. Oort "Physics of Climate" University of Pennsylvania, Department of Physics, Philadelphia, PA
30 November 1984	Dr. Syukuro Manabe "Recent GCM Results on the CO_2-Induced Climate Change" Meeting of the Climate Research Committee of the National Research Council, National Academy of Science, Washington, DC
3 December 1985	Dr. Saburo Miyahara "Gravity Wave-planetary Wave Interaction in the High Resolution GFDL "SKYHI" Model" GRATMAP Workshop, Kyoto, Japan
10 December 1985	Dr. Jorge L. Sarmiento "Trace Modeling Projects at Princeton University" U.S. WOCE Working Group on Numerical Modeling, NCAR, Boulder, CO
11 December 1984	Dr. Jerry D. Mahlman "DOC Science Management: Going the Wrong Way?" Federal Executive Forum, Dept. of Commerce, Washington, DC
14 December 1984	Dr. Ngar-Cheung Lau "Response of a GFDL GCM to SST Fluctuations Observed in the Tropical Pacific" University of Maryland, Dept. of Meteorology, College Park, MD
14 December 1984	Dr. Kikuro Miyakoda "Review of Extended Range Forecasts" Joint GLA/NMC/UMD Seminar, National Meteorological Center, Washington, DC
10 January 1985	Dr. George Philander "El Nino: Is it Predictable?" Naval Postgraduate School, Monterey, CA

18 January 1985	Dr. In-Sik Kang "Atmospheric Linear Response to Tropical SST Anomalies" Tokyo University, Japan
21 January 1985	Dr. Abraham H. Oort "Annual and Interannual Variations in the Water Vapor Budget over the Asian Monsoon Region" Workshop on "Interannual Variability of Monsoons" sponsored by Indo-US Science and Technology Initiative, New Delhi, India
21 January 1985	Dr. Kirk Bryan 1)"Ocean Circulation Models for WOCE" and 2)"Technical Aspects of Ocean Modeling" Texas A & M University, Dept. of Oceanography, College Station, TEXAS
22 January 1985	Dr. In-Sik Kang "The Maintenance of Upper Tropospheric Monsoon Circulation" Seoul National University, Korea
23 January 1985	Dr. Syukuro Manabe "CO_2-Induced Change of the Coupled Ocean-Atmosphere System and its Paleoclimatic Implication" Yale University, Dept. of Geology and Geophysics, New Haven, CT
8 February 1985	Dr. Yoshio Kurihara "Some Promising Results from the GFDL Hurricane Model" NMC Hurricane Panel Meeting, National Meteorological Center, Washington, DC
11 February 1985	Mr. Michael D. Cox "Numerical Models of the Ventilated Thermocline" Australian Physical Oceanography Conference, Hobart, Tasmania, Australia
19 February 1985	Mr. J. David Neelin "Simple Models of Low Level Flow in the Tropics" NATO Advanced Study Institute on Large Scale Transport Processes in Ocean and Atmosphere, Les Houches, France
20 February 1985	Dr. George Philander "Global Ocean Modeling" NOAA Marine Observations and Predictions Review, Washington, DC
20 February 1985	Dr. Stephen B. Fels "Tides in the Atmosphere of Venus" SUNY, Stony Brook, New York
21 February 1985	Dr. Isidoro Orlanski "Local Baroclinicity - Source of Meso-Cyclones" McGill University, Dept. of Meteorology, Montreal, Canada

27 February 1985	Dr. Bin Wang "Moist Instability of the Mid-Latitude Zonal Flow with Application to Explosive Cyclogenesis" Florida State University, Tallahassee, FL
27 February 1985	Dr. Rui-Xin Huang "Ideal Fluid Thermocline and Current Structure in Subtropical/Subpolar Basin" University of Rhode Island, Rhode Island
1 March 1985	Prof. George L. Mellor "Physical Oceanography of Delaware Bay" Estuarine Seminar Series - U.S. Department of Commerce, Washington, DC
4 March 1985	Dr. Raymond T. Pierrehumbert "Scattering of a Rossby Wave Train from an Isolated Mountain" American Meteorological Society Waves and Stability Conference, New Orleans, LA
6 March 1985	Mr. David G. Dritschel "A New Class of Instabilities on a Columnar Vortex" 5th Conference on Atmospheric and Oceanic Waves and Stability, New Orleans, LA
6 March 1985	Dr. Bin Wang "Linear Dynamics of the Transient Planetary Waves in the Presence of Damping" 5th Conference on Atmospheric and Ocean Waves and Stability, New Orleans, LA
7 March 1985	Dr. Rui-Xin Huang "Ideal Fluid Thermocline" Lamont-Doherty Geological Observatory, Palisades, NY
11 March 1985	Dr. Jerry D. Mahlman "Role of Global Dynamics Research in Relation to RITS" 1st Meeting of ERL RITS Committee, Boulder, CO
12 March 1985	Dr. Stephen B. Fels "Tides in the Atmosphere of Venus" Harvard University, Cambridge, MA
13 March 1985	Dr. George Philander "Predictability of El Nino" University of South Florida, St. Petersburg, Florida
13 March 1985	Dr. Isidoro Orlanski "Numerical Simulation of the Evolution of a Cold Front" Courant Institute, New York, NY

15 March 1985	Mr. Morris Bender "Numerical Simulation of the Landfall of Tropical Cyclones" Rutgers University, Dept. of Meteorology New Brunswick, NJ
18 March 1985	Dr. Ngar-Cheung Lau "Response of the GFDL GCM to SST Anomalies in the Tropical Pacific" Royal Hong Kong Observatory, Hong Kong
19 March 1985	Dr. Kikuro Miyakoda "Extended Weather Forecasting" Geological and Geophysical Sciences/IEEE Power Engineering Society Colloquium, Princeton University
19 March 1985	Dr. George Philander "El Niño" TOGA Meeting, Washington, DC
20 March 1985	Dr. Abraham H. Oort "Some Unresolved Issues in Climate" Goddard Space Flight Center, Greenbelt, MD
21 March 1985	Mr. William Stern "Comparison of the NMC and GFDL Models' Performance" National Meteorological Center, Washington, DC
22 March 1985	Dr. Abraham H. Oort "Physics of Climate" United States Dept. of Commerce, National Bureau of Standards, Gaithersburg, MD
22 March 1985	Dr. Charles T. Gordon "Preliminary 30-Day Integrations with Specified and Model-Predicted Clouds" Colorado State University, Fort Collins, CO
26 March 1985	Dr. Rui-Xin Huang "Ideal Fluid Thermocline" Scripps Institution of Oceanography, La Jolla, CA
28 March 1985	Dr. Ngar-Cheung Lau "On the Structure and Propagation Characteristics of Transient Disturbances in Observed and Simulated Atmospheres" Chinese Meteorological Society's Symposium on the Atmospheric Circulation, Guilin, Peoples Republic of China
29 March 1985	Dr. Rui-Xin Huang "Ideal Fluid Thermocline" Oregon State University, Corvallis, OR

1 April 1985	Mr. David Dritschel "The Nonlinear Stability of Uniform Vortices" University of California, Berkeley, Berkeley, CA
2 April 1985	Dr. Jorge L. Sarmiento "Natural Variations in Atmospheric CO_2 Driven by Changes in Ocean Circulation" Center for Energy and Environmental Studies, Princeton University
3 April 1985	Dr. Rui-Xin Huang "Ideal Fluid Thermocline" University of Washington, Seattle WA
4 April 1985	Dr. Roxana Wajsowicz "Behavior of Planetary Waves in Finite-difference Models" Florida State University, Tallahassee, FL
5 April 1985	Dr. Roxana Wajsowicz "Adjustment of the Ocean under Buoyancy Forces" Florida State University, Tallahassee, FL
8 April 1985	Dr. Roxana Wajsowicz "Adjustment of Planetary Waves in Finite-difference Models" NORDA/NSTL New Orleans, LA
9 April 1985	Dr. Stephen B. Fels Dynamics of the Venus Atmosphere" University of British Columbia, Vancouver, British Columbia
11 April 1985	Dr. Jorge L. Sarmiento "On the Control of Atmospheric pCO_2 by High Latitude Deep Water Formation Regions" Brookhaven, NY
11 April 1985	Dr. R. Toggweiler "On the Possible Role of Dissolved Organic Carbon in Atmospheric pCO_2 and Ocean Oxygen Variations" Brookhaven, NY
12 April 1985	Dr.Jack J. Katzfey "Numerical Modelling and the President's Day Snowstorm of February 18-20, 1979" State University College at Oswego, Oswego, New York
12 April 1985	Dr. Isidoro Orlanski "Numerical Weather and Climate Prediction" Workshop on "Numerical Fluid Dynamics" sponsored by Georgia Tech. IMACS, Atlanta, Georgia
16 April 1985	Dr. Jorge L. Sarmiento "Tritium Transient Tracers and Ocean Circulation" Dalhousie University, Halifax, Nova Scotia

16 April 1985	Dr. Kirk Bryan "Robust Diagnostic Models" Meeting on "Data Assimilation and Inverse Modeling" sponsored by the World Ocean Circulation Experiment, Miami, Florida
17 April 1985	Dr. Jorge L. Sarmiento "Role of Deep Ocean Circulation in Determining Atmospheric CO_2" Bedford Institute of Oceanography, Florida State University, Tallahassee, FL
19 April 1985	Dr. Rui-Xin Huang "Analytical and Numerical Simulation of Outcropping Phenomenon in Subtropical/Subpolar Gyres" Department of Physical Oceanography, Florida State University, Tallahassee, FL
23 April 1985	Dr. Bin Wang "Moist Instability of a Baroclinic Zonal Flow with Conditionally Unstable Stratification" Fifth Extratropical Cyclone Workshop Conference Center, University of Maryland, MD
23 April 1985	Dr. Jerry D. Mahlman "Current Results from the GFDL SKYHI Model: Effects of Resolution" Fifth Conference on the Stratosphere and Mesosphere, Boulder, CO
23 April 1985	Dr. Jerry D. Mahlman "Numerical Simulation of Large-Scale Transport" Fifth Conference on the Stratosphere and Mesosphere, Boulder, CO
25 April 1985	Dr. Rui-Xin Huang "Partial Solution of Inertial Western Boundary Current with Continuous Stratification" Poster presentation - Gulf Stream Workshop, University of Rhode Island, Kingston, RI
29 April 1985	Dr. Kirk Bryan "The Implications of Ocean Models on Sea Level Predictions" National Academy of Science Committee Meeting on Engineering Implications of Changes in Relative Mean Sea Level, Washington, D.C.
29 April 1985	Dr. Syukuro Manabe "Climatic Influence of Continental Ice Sheets during the Last Glacial Maximum" University of Maine, Department of Geological Sciences, Orono, Maine

2 May 1985	Dr. R. Toggweiler "A Preliminary Discussion of a Model for Nutrient and Particle Cycling in the Oceans" Princeton University Princeton, NJ
7 May 1985	Mr. Lawrence J. Lewis "Site Report for GFDL" Spring Meeting of Meteorological Users of 205's Systems Representatives, NASA-Goddard, Greenbelt, Maryland
7 May 1985	Mr. William Stern "Current and Future Work in Modeling at GFDL" Scientific Services Divisions Conference, National Meteorological Center, Washington, DC
8 May 1985	Mr. Mitsuhiro Kawase "Circulation and Nutrients in the Mid-Depth Atlantic Ocean" Massachusetts Institute of Technology, Cambridge, MA
9 May 1985	Dr. R. Toggweiler "An Update of the PBH Model for Low Atmospheric CO_2 Levels during the Last Ice Age" University of California, Los Angeles, Lake Arrowhead, CA
14 May 1985	Mr. Morris A. Bender "A Numerical Study of the Effect of a Mountain Range on a Landfalling Tropical Cyclone" Sixteenth Conference on Hurricane and Tropical Meterology, Houston, Texas
24 May 1985	Prof. G. Mellor "A Three-Dimensional Model for Forecasting Estuarine Tides, Currents and Salinities" APL-NOS Conference on Real Time Applications of Numerical Models. Applied Physics Laboratory, MD
27 May 1985	Dr. Kikuro Miyakoda "Assessment of Results from Different Analysis Schemes" World Meteorological Organization Conference on the Results of the Globl Weather Experiments and Their Implications for the World Weather Watch, Geneva, Switzerland
28 May 1985	Dr. Raymond T. Pierrehumbert "On the Absence of Gravity Waves over the Alps" National Academy of Sciences Workshop on the Alpine Experiment, New Haven, CONN
3 June 1985	Dr. Isidoro Orlanski "The Structure and Dynamics of an Observed Moist Front" Second Conference on Mesoscale Processes sponsored by the American Meteorological Society, State College, PA

6 June 1985	Dr. Norman Crook "A Numerical and Analytical study of Atmospheric Undular Bores" Second Conference on Mesoscale Processes, American Meteorological Society, University Park, PA
14 June 1985	Dr. Jerry D. Mahlman "ERL 'RITS' Research Plan for FY87", NOAA Budget Briefing, Department of Commerce, Rockville, MD
17 June 1985	Mr. Jeffrey J. Ploshay "Studies Involving GFDL's Post-FGGE Data Assimilation System" American Meteorological Society's Seventh Conference on Numerical Weather Prediction, Montreal Canada
17 June 1985	Mr. William F. Stern "High Resolution Spectral Models for Extended Range Prediction" American Meteorological Society's Seventh Conference on Numerical Weather Prediction Montreal, Canada
21 June 1985	Dr. Jerry D. Mahlman "Climate Modeling at GFDL" Climate Modeling Meeting, U.S. Congress Office of Technology and Assessment, Washington, DC
15 July 1985	Dr. Frank B. Lipps "Numerical Modeling of a Line of Towering Cumulus on Day 226 of GATE" International Cloud Modeling Workshop Conference sponsored by the Weather Modification Programme of the World Meteorological Organization Irsee, Federal Republic of Germany
15 July 1985	Dr. Isaac M. Held "Climate Sensitivity" National Climate Program Workshop, Woods Hole, MA
24 July 1985	Dr. Roxana Wajsowicz "The Behavior of Planetary Waves in Finite-Difference Numerical Models, NCAR Boulder, CO
29 July 1985	Dr. Abraham H. Oort "Diagnosis of Historical ENSO Events" First WMO Workshop on the "Diagnosis and Prediction of Monthly and Seasonal Atmospheric Variations over the Globe" College Park, MD

29 July 1985	Dr. Yi Hong Pan "Diagnosis of Historical ENSO Events" First WMO Workshop on "Diagnosis and Prediction of Monthly and Seasonal Atmospheric Variations over the Globe" College Park, MD
29 July 1985	Dr. Kikuro Miyakoda "Monthly Forecast Experiments: Part I. Without Anomaly Boundary Forcings; Part II. With Sea Surface Temperature Anomaly Forcings" First World Meteorological Organization Workshop on the Diagnosis and Prediction of Monthly and Seasonal Atmospheric Variations over the Globe, University of Maryland College Park, MD
29 July 1985	Mr. Anthony J. Rosati "A Simulation of 1982-83 El Nino Using an Ocean GCM" First World Meteorological Organization Workshop on the Diagnosis and Prediction of Monthly and Seasonal Atmospheric Variations over the Globe, University of Maryland, College Park, MD
29 July 1985	Dr. Jerry D. Mahlman "Modeling the Middle Atmosphere" Goddard Laboratory for Atmospheres, Greenbelt, MD
30 July 1985	Mr. Ronald C. Pacanowski "Seasonal Cycle of the Tropical Atlantic Ocean... Periodic or Initial Value Problem" SEQUAL/FOCAL Meeting, New York City, NY
31 July 1985	Dr. George Philander "Simulation of the Seasonal Cycle of the Tropical Atlantic" Tropical Atlantic Ocean Circulation Meeting, Columbia University, New York, NY
31 July 1985	Dr. Raymond T. Pierrehumbert "Response of a Baroclinic Atmosphere to Localized Temporally Varying Forcing" First International Workshop on Monthly and Seasonal Forecasting, University of Maryland, College Park, MD
5 August 1985	Dr. Jorge L. Sarmiento "The Role of Seasonality in Ocean Ventilation" IAMAP/IAPSO Conference, Honolulu, Hawaii
5 August 1985	Dr. Syukuro Manabe "CO_2 Induced Change in a Coupled Ocean-Atmosphere Model and its Paleoclimatic Implications" IAMAP/IAPSO Joint Scientific Assembly, Honolulu, Hawaii

5 August 1985	Dr. Ngar-Cheung Lau "Modeling the Seasonal Dependence of the Atmospheric Response to Observed El Ninos in 1962-1976" IAMAP/IAPSO Joint Assembly Meeting, Honolulu, Hawaii
5 August 1985	Dr. Isaac M. Held "Mid-Latitude Effects of Tropical Forcing" IAMAP/IAPSO Joint Assembly Meeting, Honolulu, Hawaii
6 August 1985	Mr. Antonio Navarro "Simulation of the January 1983 Atmospheric Anomalies using and Anomaly Model" IAMAP/IAPSO Joint Assembly Meeting, Honolulu, Hawaii
8 August 1985	Mr. Michael D. Cox 1. "An Eddy-Resolving Numerical Model of the Ventilated Thermocline" 2. "Four-Year Waves in a Numerical Model of the Subtropical Thermocline" IAMAP/IAPSO Joint Assembly Meeting, Honolulu, Hawaii
12 August 1985	Dr. Hiram Levy II "Role of HxOy Measurements in Future Development of Atmospheric Chemistry, NASA Workshop on HxOy Measurements, Palo Alto, CA
13 August 1985	Dr. Jorge L. Sarmiento "A Model Study of Seasonal Variations in Heat Transport and Surface Flux in the North Atlantic" and "On the Control of Atmospheric CO_2 by Ocean Circulation" IAMAP/IAPSO Conference, Honolulu, Hawaii
15 August 1985	Dr. Bin Wang "Moist Stability of a Baroclinic Zonal Flow with Conditionally Unstable Stratification" IAMAP/IAPSO Conference, Honolulu, Hawaii
15 August 1985	Prof. G. Mellor "Ice-Seawater Turbulent Boundary Layer Interaction with Melting or Freezing" IAMAP/IAPSO Conference, Honolulu, Hawaii
26 August 1985	Dr. George Philander "Coastal Currents and Undercurrents" Coastal Oceanography Workshop, Buenos Aires, Argentina
27 August 1985	Prof. G. Mellor "Some Questions Concerning Second Moment Turbulence Closure Models and an Application to Estuarine Modeling" IUTAM Symosium on Mixing in Stratified Fluids, University of Western Australia, Margaret River, Western Australia

9 September 1985	Dr. George Philander "Low Frequency Variability of the Tropical Atlantic Ocean" Meeting on Interannual Variability in the Tropical Atlantic, Rio de Janeiro, Brazil
13 September 1985	Dr. Jerry D. Mahlman "An Overview of Research Activities at GFDL" Environmental Research Laboratories, Boulder, CO
15 September 1985	Dr. Jorge L. Sarmiento "Modeling Oceanic Transport of Dissolved Constituents" NATA/ASI on Air-Sea Exchange, Bordeaux, France
16 September 1985	Dr. Jorge L. Sarmiento "Modeling Oceanic Transport of Dissolved Constituents" NATO/ASI on Air-Sea Exchange, Bordeaux, France

APPENDIX F

List of Acronyms

APPENDIX F

ACRONYMS

ALPEX	ALPine EXperiment
ANMRC	Australian Numerical Meteorology Research Centre
A2,E2,E4,F,M.	Five physical parameterization packages in use at GFDL, in increasing order of sophistication. E4 physics includes a high-order closure scheme for sub-grid turbulence, F physics includes Arakawa-Schubert convective parameterization, and M physics include envelope orography.
CAC	Climte Analysis Center (NOAA)
CDC	Control Data Corporation
CLIMAP	Climate: Long Range Investigation, Mapping and Prediction
CODE	Coastal Ocean Dynamics Experiment
ECMWF	European Centre for Medium-Range Weather Forecasting
ENSO	El Niño - Southern Oscillation
FGGE	First GARP Global Experiment- Dec.1978 - Nov.1979 IIb - Data set analyzed on a spatial grid. 4D- Analysis system taking into account both space and time variation of the data. SOP1 - First Observing Period, Jan.5 - Mar.5,1979 SOP2 - Second Observing Period May 1 - June 30, 1979
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GCM	General Circulation Model
HIBU	Hydrological Institute, Belgrade University
ITCZ	Intertropical Convergence Zone
LGM	Last Glacial Maximum
LIMS	Lim Infrared Modulated Sensor
MAC/BES	Meso-alpha coarse model/meso-Beta scale model
MCS	Mesoscale Convective System

Meso α, β, or γ	Three classes of mesoscale atmospheric motion, in descending order of spatial scale.
NOS	National Ocean Service
NMC	National Meteorological Center (USA)
PU	Princeton University
SESAME	Severe Storms & Mesoscale Experiment
SKYHI	The GFDL Troposphere-Stratosphere-Mesosphere GCM
SST	Sea Surface Temperature
TTO	Transient Tracers in the Ocean
WOCE	World Ocean Circulation Experiment

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