GEOPHYSICAL FLUID DYNAMICS LABORATORY

ACTIVITIES – FY83
PLANS – FY84

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

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Geophysical Fluid Dynamics Laboratory
Princeton, New Jersey

UNITED STATES DEPARTMENT OF COMMERCE

Malcolm Baldrige, Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

John V. Byrne, Administrator

Environmental Research Laboratories

Vernon E. Derr
Acting Director

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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 the four major research areas that correspond to NOAA's mission in oceanography and meteorology: Weather Observation and Prediction; Climate; Air Quality; and Marine Environmental Quality. These are four 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; 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 1983; a bibliography of the most 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 FY84; a listing of seminars presented at GFDL during Fiscal Year 1983; a list of seminars and talks presented during Fiscal Year 1983 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.

The FY83 Annual Report was edited by Raymond T. Pierrehumbert.

September 1983

TABLE OF CONTENTS

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:

- o the predictability of weather, large and small scale;
- o the particular nature of the Earth's atmospheric general circulation within the context of the family of planetary atmospheric types;
- o the structure, variability, predictability, stability and sensitivity of climate, global and regional;
- o the structure, variability and dynamics of the ocean over its many space-and-time scales;
- o 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 FY83

and

IMMEDIATE OBJECTIVES

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 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 but quantitative precipitation forecasts remain elusive. As regards phenomena with small 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 and growth 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 it 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.

Recent results, and plans for the next year, are briefly summarized below. For details, see the cited sections of Part B of the report.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY83)

Accomplishments over the past year (FY83) include the following:

* For the past several years, GFDL has been engaged in the production of a Level III-b gridded analysis of data from the First GARP Global Experiment (FGGE). The analysis was performed using an experimental continuous data assimilation scheme. In FY83, the operational production of the analyzed data set was completed, and the products were archived at the two World Data Centers (3.4.1).

* Monthly forecast experiments with a GCM were conducted for four winter cases, and some skill in the 10 day and 20 day mean height prognosis was demonstrated. The experiment revealed that the quality of a GCM as well as that of the initial conditions are crucial for a successful simulation of planetary scale circulation patterns and blocking phenomena. This implies that, in the development of models for use in forecasting on the monthly time scale, internal dynamics must be treated carefully before the effects of the anomaly components of external forcing can be included (3.1.1).

* The impact of subgrid-scale processes on GCM performance has emerged clearly in recent prediction studies. Simulation of tropical precipitation was improved by a sophisticated cumulus parameterization, and the condensational heating appears to exert an appreciable effect on the formation of midlatitude planetary waves. Mountain peaks also exhibit appreciable impact on the large-scale flow; a theory characterizing the extent to which

a mountain acts as a barrier to the oncoming flow was developed. The theory has important implications concerning the representation of mountains in GCM's (3.2).

* Several cases of blocking were successfully simulated by a GCM. In parallel, a new theory was developed in which blocking appears as a non-linearly amplified response to a weak localized forcing (3.3.2).

* Analysis of a 15 year series of observed geopotential height maps has revealed that the zonal winds averaged over certain longitude ranges have distinct meridional profiles associated with the teleconnection patterns classified by Wallace and Gutzler. The patterns were reproduced to a considerable extent when the appropriate zonal wind profiles were used in a linear barotropic model. Thus, the zonal wind profile emerges as a key factor in determining the character of the teleconnection pattern (3.3.1).

* The structure and dynamics of convection associated with fronts has been clarified using numerical simulations and stability analyses. The simulation of an observed moist cold front system produced a mature frontal squall line which shows a dual-updraft structure very similar to that observed in an Oklahoma squall line. A linear, two-layer, dry model was shown to reproduce this dual-updraft structure for certain low-level wind intensities without requiring microphysics. Also, a stability analysis of narrow cold-frontal rainbands has revealed a barotropic mechanism by which horizontal shear can organize the rainband convection into the regularly spaced cellular structure observed by radar (8.1.1).

* Results from a limited-area model nested in a global spectral model suggest that differences in the lateral boundary conditions taken from the global forecast predominate over initial condition differences in determining the position and strength of the synoptic as well as mesoscale features in the limited-area solution after only a few simulation hours (8.2.1).

* A 24-h meso-β simulation of the severe storm outbreak of 10-11 April 1979 (SESAME Day I) over Oklahoma and Texas wherein initialized and boundary data were used from a dense network of observations shows good agreement with the observed precipitation patterns as well as the mesoscale environment in which severe storms first developed (8.3.1).

* Calculations of deep moist convection representative of continental conditions give a maximum vertical velocity slightly larger than 20 m/sec at 7.5 km and a maximum disturbance potential temperature of 5.5°C near 8.5 km. At the surface 1.5 cm of rain fell in one-half hour and the downdraft outflow was cooler than its environment by 6°C (9.1).

* The decay process of tropical cyclones after the simulated landfall was investigated. A major cause for decay of a storm is the reduction of water vapor supply to a storm system. The low land surface temperature made a large contribution to decay through the suppression of evaporation, the alteration of the boundary layer wind and the reduction in conditional instability (7.1).

* The mechanism of comma vortex formation in the tropical cyclone model was studied. The tail of comma pattern tends to develop at the high wind side of disturbances. The β-effect retards the development of a comma vortex in the case of easterly basic flow and enhances it in the case of westerlies. The air-sea interaction is a necessary ingredient for the formative process of the distinct comma vortex (7.1).

* A numerical study on the transformation of a tropical easterly wave revealed that the heating effect is required for the growth of the wave. The nonlinearity effect, if and only if it is combined with the heating effect, accounts for the formation of a distinct vortex at a trough region of a wave (7.1).

PLANS FOR FY84

Plans for the next year include the following:

A study involving 4 monthly forecast cases will be completed, and the historically anomalous 1982-83 winter case will be tested.

A comparative study of A, E and F physics will be finalized.

The construction of the R42L18-F model will be completed.

The generation of transients in local baroclinic zones, the distribution of the consequent eddy fluxes, and the effects of the fluxes on blocking will be investigated.

Simulation of the Pacific comma cloud and the mid-west summer mesoscale convective complex will be attempted.

Research on the development of cellular structure in frontal rainbands will be completed.

Further investigation will be made of the impact of initial and boundary data on the simulation of mesoscale convective systems.

Further investigations will be made of the value of an explicit formulation of moist convection as a means of representing convective processes in a meso-beta scale model.

An attempt will be made to nest a cloud model within a meso-beta scale solution.

The vertical momentum transfer and kinetic energy transformation associated with the interaction of vertical wind shear and deep moist convection will be examined.

A study of hurricane landfall simulation will continue with a new model to investigate the effect of topography on landfall.

Research on the comma vortex formation in hurricanes and on the transformation of easterly waves will be finalized.

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 millenia; and to evaluate the impact on climate, 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, with a period of a few weeks, and their role in the general circulation of the atmosphere; the seasonal cycle which must be known before departures from the seasonal cycle (interannual variability) can be appreciated; interannual variability associated with phenomena such as the Southern Oscillation/El Nino; a very long-term variability which includes the ice ages for example; and the meteorologies of various planets, the study of which enhances 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; and mathematical models are constructed to study and simulate the ocean, the atmosphere, the coupled ocean, atmosphere and cryosphere system, and various planetary atmospheres.

Recent results, and plans for the next year, are briefly described below. For more details see the cited sections of Part B of the report.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY83)

Accomplishments over the past year include the following:

* The CO_2-induced change in hydrology has been the subject of continued investigation by use of an atmosphere-mixed layer ocean model. It was found that, in winter, soil moisture in the subtropical steppe belt tends to decrease with increased CO_2-concentration due to the poleward shift of the middle latitude rainbelt (1.1.1).

* The transient response of climate to an increase of the atmospheric concentration of CO_2 has been investigated by use of a coupled ocean-atmosphere general circulation model with idealized geography. It is shown that zonal mean response of surface air temperature over continents precedes slightly the corresponding response over oceans having large thermal inertia (1.1.3).

* The results from a model experiment indicate that a large scale soil moisture anomaly in the middle latitude rainbelt tends to persist longer than a similar anomaly in the subtropics from where moisture is exported to the neighboring rainbelts (1.3.1).

* A study of climatic effect of the massive continental ice sheets of an ice age has been continued. The model results indicate a significant reduction of soil moisture in a zone located to the south of the ice sheets in North America and Eurasia. This is consistent with some of the geological evidence from the last glacial maximum (1.2.1).

A linear, baroclinic stationary wave model has been found to reproduce very accurately the stationary eddies in the wintertime upper troposphere of a general circulation model. The linear simulation allows one to dissect the stationary wave field into parts resulting from different features in the mean diabatic heating field and in the surface topography (1.4.1).

* The theoretical justification for barotropic models of planetary-scale stationary eddies forced by topography has been clarified by studying the extent to which the stationary eddy field is dominated by external Rossby waves and by demonstrating how to design a barotropic model which satisfactorily captures the external Rossby wave part of the solution (1.4.1).

* The effects of wave-wave interactions on midlatitude transient ultra-long waves have been examined by eliminating some selected wavenumber components from a spectral general circulation model (1.4.2).

* The GFDL troposphere-stratosphere-mesosphere GCM (SKYHI) has achieved a simulation of the equatorial semi-annual oscillation (SAO) which agrees well with observations. The westerly acceleration phase of the SAO is driven by absorption of dissipating Kelvin waves. The easterly acceleration phase on the summer hemisphere side of the equator is provided by advection of easterly angular momentum by the cross-equatorial mean meridional acceleration. On the winter hemisphere side, the easterly acceleration is provided by absorption of winter planetary waves propagating into low latitudes (2.2.4).

* A detailed space-time spectral analysis of the SKYHI GCM has achieved some remarkable new results on the structure of equatorial Kelvin waves. All classes of identified Kelvin waves have zonal wavenumber 1-2, an eastward phase velocity and an upward flux of eastward momentum. In addition to the "traditional" Kelvin wave (period 10-30 days, vertical wavelength ($L_z \sim 10$km), there have been identified "fast" Kelvin waves (periods 5-7 days, $L_z \sim 20$km), and "ultra-fast" Kelvin waves (periods 3-4 days, $L_z \sim 40$km). These waves agree well with their recently discovered observational counterparts (2.2.3).

* A coupled ocean-atmosphere model that simulates the amplification of modest initial perturbations during El Niño/Southern Oscillation Events was developed. The model reproduces the simultaneous growth of perturbations in the atmosphere and ocean (4.3).

* Global atmospheric circulation statistics for May 1958 through April 1973 have been published as NOAA Professional Paper No. 14 with more than 8000 maps and cross sections on microfiche. The mean climate and its year-to-year variability are shown for the monthly, seasonal and annual time scales (6.1.1).

* The global cycles of angular momentum, energy and water substance in the atmosphere-ocean-solid earth system and some of the regional variations have been documented and published (6.1.2).

* A high correlation was discovered between the monthly-mean, hemispheric temperature averaged over the entire troposphere and the sea surface

temperature in the eastern Equatorial Pacific Ocean. Increased convection in the Tropics during El Niño conditions (warm episodes) apparently leads to an overall warm atmosphere with a lag of about 6 months (6.1.1).

* Observed transient eddy heat and vorticity fluxes tend to destroy zonal asymmetries in the time-mean circulation. Disturbances with time scales longer than 10 days dominate this process (6.1.1).

* Midlatitude disturbances accompanying cold air outbreaks over East Asia show a typical life cycle with baroclinic growth during the polar outbreaks followed by a decay dominated by barotropic processes (6.1.1).

* A model of Jupiter's Great Red Spot and Large Ovals, based on intermediate-geostrophic (IG) dynamics, succeeded in providing an explanation of the structure, longevity, and possibly of the origin of these solitary and isolated forms of vortex. IG motions occur on scales greater than those of quasi-geostrophic ones. The longevity of some planetary scale patterns in the Earth's atmosphere may be due to the stability of IG scale motion, as suggested by the theory.

PLANS FOR FY84

Plans for the next year include the following:

A global ocean-atmosphere model with realistic orography will be constructed by combining a spectral model of the atmosphere with a finite difference model of the oceans.

The study of transient and equilibrium responses of climate to a CO_2-increase will be continued by use of a newly-developed ocean-atmosphere model with realistic geography.

The response of an idealized 9-level atmospheric GCM to successive decreases in the solar constant, Q, will be examined to see if sensitivity increases monotonically as Q is lowered, as predicted by simple energy balance models, or if the sensitivity has the more complex dependence on Q found with a 2-level primitive equations model.

Comparison of linear stationary wave models with GCM's will be actively pursued by continuing the analysis of the wintertime stationary waves already begun, extending this analysis to the seasonal variation of the stationary waves, and by examining the extent to which monthly or seasonal mean anomalies from the mean GCM climate can be understood as being due to anomalies in the forcing of stationary waves.

Theoretical and numerical studies will be made of the effects of transient eddies on the mean zonal flow.

The analysis of equatorial Kelvin wave structure will be completed.

Analysis of seasonal integrations of the SKYHI model will continue.

The study of unstable interactions between the ocean and atmosphere will be continued, and CISK processes will be included.

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. 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.

Ongoing work that will be completed within the next 5 years includes analyses of atmospheric nitrous oxide, reactive nitrogen (natural plus anthropogenic), and tropospheric ozone. Capability will be developed to solve for a number of trace constituents simultaneously. Using this capability, interdependent experiments will be run involving ozone and its precursors, partitioned components of total reactive nitrogen, carbon monoxide, etc. Also, development of a dynamically active ozone photochemistry will be completed for inclusion into the GFDL into the GFDL troposphere-stratosphere-mesosphere GCM.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY83)

Accomplishments over the past year are described below. For details, see the cited sections of Part B of the report.

* Comparison of analysis results from the 3-D "classical ozone" model of the troposphere against available observations and against a comprehensive ozone photochemical model has led to some surprising, but tentative, conclusions. To explain the summertime behavior of ozone in the Northern Hemisphere, net photochemical destruction of ozone may be required in high latitudes, while net production may be necessary in midlatitudes. These conclusions are quite sensitive to assumptions about the highly uncertain NO_x amounts in the troposphere (2.1.3).

* Preliminary experiments have been carried out to examine the mixing of a passive tracer due to deep moist convection. The initial tracer is confined to a surface layer 1750 m deep. After the mixing associated with a one-hour convective shower cloud, the horizontal average tracer has a bimodal distribution in the vertical. The primary maximum is in the boundary layer and the secondary maximum at 10 km is in the layer of convective outflow. A well-defined minimum in tracer concentration is found at mid-levels. These results illustrate the well-known non-local character of moist convection mixing (9.1).

PLANS FOR FY84

Plans for the next year include the following:

The study of the convective mixing of a passive tracer will continue. Downward advection of tracer from the upper atmosphere will be examined in addition to the boundary layer source treated previously. The effect of water solubility will be included.

Efforts will continue on the tropospheric "Combustion Nitrogen" and "Maximum Insight" experimental series. Final steps of the atmospheric N_2O and "Classical Ozone" model experiments and their corresponding observational comparisons will be completed.

Efforts to develop a self-consistent two-dimensional tracer transport model will continue.

IV. MARINE QUALITY

GOALS

Research at GFDL related to the quality of the marine environment has as its objective the simulation of oceanic conditions in coastal zones and in estuaries, and the modeling of the dispersion of geochemical tracers (tritium, radon...) in the world oceans. Over the next few years two and three-dimensional models of estuaries such as the Hudson-Raritan and Delaware Estuaries will be 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.

ACCOMPLISHMENTS OVER THE PAST YEAR (FY83)

Results obtained over the past year include the following: For details see the cited sections of Part B of the report.

* During FY83 the marine geochemistry group began to consider how to model nutrient cycling in the ocean. This is the major first step in predicting the role of the oceans in determining atmospheric CO_2. Preliminary box model calculations suggest a mechanism for predicting the lower glacial pCO_2 levels that requires either a more efficient nutrient uptake by organisms in high latitude waters and/or less efficient mixing of nutrients into the mixed layer (4.3).

PLANS FOR FY84

Plans for the next year include the following:

Nutrient cycling parameterizations will be tested in a coarse resolution sector model, and then in the North Atlantic model.

Analysis of Cs-137/Sr-90 Weathership and other observations will be completed.

Data from the Transient Tracers in the Oceans observations in the North Atlantic will be analyzed.

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 Somali Current after the 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 (FY83)

Results obtained over the past year include the following. For details see the cited sections of Part B of the report.

* A three-dimensional ocean circulation calculation with high vertical resolution was carried out on the CYBER-205 to provide a detailed check on analytic theories of the thermocline. The model was successful in showing how convection and wind stress act together to inject low potential vorticity water along density surfaces. Of particular interest is the simulation of subtropical mode water near the western boundary. An age map based on the time elapsed along trajectories from the surface was prepared (4.1).

* A Climatological Atlas of the World Ocean describing the annual mean and seasonal structure of the oceans has been published as NOAA Professional Paper No. 13. The basic analyses are already widely used in the U.S.A. and abroad (6.2.1).

PLANS FOR FY84

Plans for the next year include the following:

A high resolution model of the tropical Pacific Ocean will be developed and will be used to study the seasonal and interannual variability, including simulation of the El Niño phenomenon.

Eddy resolving models will be extended to a more realistic geometry, and the results analyzed to assess the role of eddies in the transport of water mass properties.

Work with the coupled ice pack/ocean model will continue using a higher resolution model. The model will be used to identify the areas of maximum ice growth, and examine the effect on the heat and salinity budget of the Arctic Ocean.

The study of heat and salt water balances over individual oceans will continue.

The year-to-year variability in subsurface heat storage will be investigated over data-rich areas in the North Atlantic Ocean.

PROJECT ACTIVITIES FY83

PROJECT PLANS FY84

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-CLIMATE SENSITIVITY STUDY

K. Bryan
S. Fels
F. Komro
S. Manabe
D. Schwarzkopf
M. Spelman
R. Stouffer
R. Wetherald

ACTIVITIES FY83

1.1.1 Hydrology Response

During the last several years, the hydrological response to an increase in atmospheric CO_2 has been investigated by coupling a general circulation model (GCM) of the global atmosphere to a static model of the mixed layer ocean. As discussed in (473), the following CO_2-induced changes are identified to be statistically significant.

o The annual mean rate of runoff markedly increases in high latitudes.

o During summer, zonal mean soil wetness reduces in two separate belts in middle and high latitudes. In addition, the following hydrologic change has been recently identified upon further examination of results from the model experiments.

o In winter, zonal mean soil moisture reduces in the subtropics due to the poleward shift of the middle latitude rainbelt. According to a signal to noise ratio analysis, it is much more difficult to detect these hydrologic changes than the CO_2-induced change in surface air temperature. Comprehensive discussions of these results are contained in (532).

1.1.2 Cloud Cover

The influence of cloud cover variation upon the sensitivity of climate to an increase in the atmospheric CO_2 has been investigated by use of the atmosphere-mixed layer ocean model with global computational domain and realistic geography. This is done by comparing the results from two versions of the model, one with fixed and another with predicted cloud cover. It is (420) using a model with idealized geography and limited computational domain.) The physical mechanisms for this enhancement of sensitivity are under investigation.

1.1.3 Transient Response

In collaboration with the ocean circulation group of the laboratory, the transient response of climate to an increase of atmospheric CO_2 has been investigated during the last several years (484). The model used for this study is a coupled ocean-atmosphere GCM with limited computational domain and idealized geography. Fig. 1.1 illustrates some of the recent results from this project. It shows separately for oceans and continents the response of area mean surface air temperature of the model to a sudden quadrupling of the CO_2 concentration in the atmosphere. (The ordinate indicates the transient response of area mean surface air temperature normalized by the total equilibrium response and the abscissa indicates the time elapsed after the sudden CO_2-increase.) According to this figure, the normalized response of surface

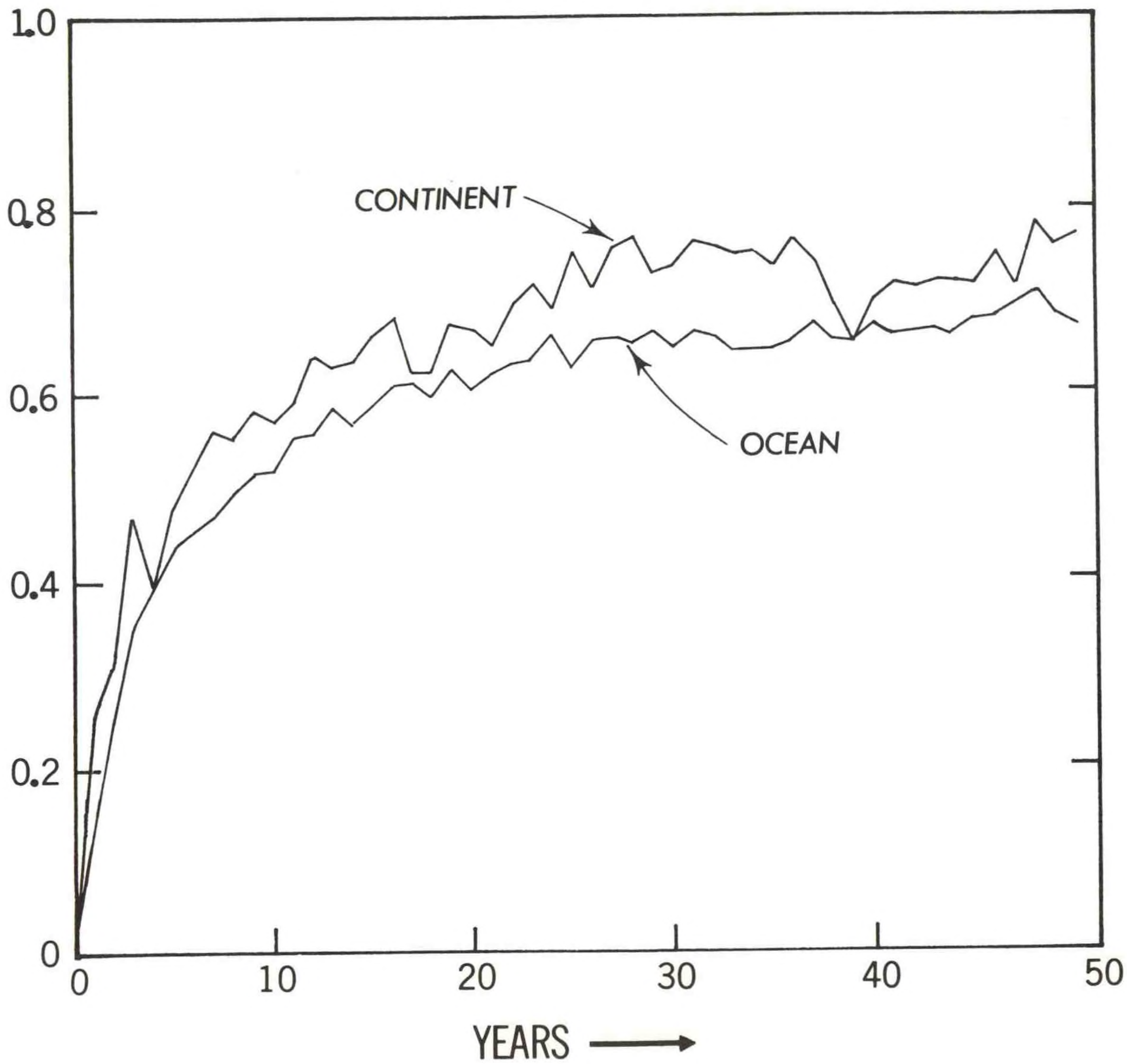


Fig. 1.1-- The transient response of area averaged, annual mean surface air temperature normalized by the total equilibrium temperature response over the continent and the ocean. The abscissa indicates the time elapsed after a sudden fourfold increase of atmospheric CO_2 in a coupled ocean-atmosphere model with limited computational domain.

air temperature over continents precedes slightly the corresponding response over oceans which have a large thermal inertia.

1.1.4 Oceanic Heat Transport and Equilibrium Response

As noted in the GFDL report of the previous fiscal year, the influence of oceanic heat transport upon the sensitivity of climate was investigated by use of a coupled ocean-atmosphere model with idealized geography (o). The study concluded that the poleward heat transport by ocean currents significantly reduces the sensitivity of climate. Recently, a code error was discovered in the computer program used for this study. Therefore, it was necessary to repeat the entire experiment during this fiscal year. The basic conclusions of the study remain unchanged.

The analysis of the equilibrium response of the model ocean also indicates that the temperature change in the deep ocean is as large as the change in the surface ocean layer of high latitudes where the CO_2-induced warming is particularly large. This is because bottom water forms due to the sinking of relatively cold, dense water in polar regions.

The results described above may have paleoclimatic implications. It has been suggested that the CO_2-concentration in the atmosphere during the Cretaceous epoch was several times larger than the modern concentration. According to the results from isotopic analysis of deep sea cores, the temperature of the deep ocean has decreased markedly during the last 100 million years. A reduction of almost the same magnitude also occurred in the ocean surface temperature in high latitudes. The qualitative similarity between isotopic temperature variation during the Tertiary and the equilibrium response of the model ocean to a CO_2-change suggests that a similar mechanism (i.e., sinking of cold water in high latitudes) is involved in both cases. The present results may partly explain why the cooling of the deep ocean during the last 100 million years has been much larger than the cooling of the surface ocean layer in low latitudes.

1.1.5 Review

The relationship between climate and atmospheric CO_2 has been the subject of continuous study at GFDL during the last 20 years. The results from this long term project have been published as a chapter of a book titled "Theory of Climate" (532).

1.1.6 Radiative Forcing Intercomparison

As part of a long-range study of CO_2-climate sensitivity, the Department of Energy has carried out an investigation of the purely radiative forcing due to a doubling of CO_2. Changes in IR fluxes at the surface, tropopause and at the top of the atmosphere were computed by various U.S. participants. The transmission function tables calculated in (441) were used to produce accurate standard values to which more heavily parameterized models can be compared.

PLANS FY84

Transient and Equilibrium Response

The coupled ocean-atmosphere GCM used for the CO_2-climate problem has a limited computational domain and idealized geography. During the next fiscal year, a coupled model with global computational domain and realistic geography will be completed. (See Section 1.5.2). In collaboration with the ocean circulation group of the GFDL, a study of transient and equilibrium response of climate to a CO_2-increase will begin by use of this global model.

Oceanic Heat Transport

The revised version of the manuscript which discusses the influence of oceanic heat transport upon the sensitivity of climate will be resubmitted.

Equilibrium Response

The equilibrium response of the coupled ocean atmosphere model to large changes in the concentration of atmospheric CO_2 (150 ppm - 2400 ppm) will be investigated. This study may be useful for identifying the mechanism responsible for the large climatic change from Mesozoic to Cenozoic epochs.

1.2 ICE AGES

A. Broccoli	I. Held
K. Bowman	S. Manabe
D. Hahn	P. Phillips

ACTIVITIES FY83

1.2.1 Simulation of an Ice Age Climate

During the last three years, the climatic effect of the massive continental ice sheets of an ice age has been investigated by conducting a set of numerical experiments with a mathematical model of climate. This is part of a long-term research effort towards understanding how a cold climate of an ice age is maintained. Successful simulation of an ice-age climate increases our confidence in a climate model as a tool for the study of climate variation.

The model used here consists of an atmospheric general circulation model coupled with a static mixed-layer ocean model. Simulated climates are obtained from each of two versions of the model: one with the modern land-ice distribution and the other with the ice distribution which existed 18,000 years ago (18K B.P.). The climatic effect of the 18K B.P. ice sheet is evaluated by comparing these two climates.

In the Northern Hemisphere, the flow field in the lower troposphere is strongly influenced by the Laurentide ice sheet and features a split jet stream straddling the ice sheet. The northern branch of the flow brings very cold air over the North Atlantic Ocean where thick sea ice is maintained. The distribution of sea surface temperature (SST) difference between the two experiments resembles the difference between the present and 18K B.P. SST as estimated by CLIMAP.

In the Southern Hemisphere, the 18K B.P. ice sheets have little influence on temperature. This is because only a small change in the interhemispheric heat exchange takes place, as the *in situ* radiative compensation in the Northern Hemisphere offsets the reflection of solar radiation by continental ice sheets. These results suggest that other changes in the earth's heat balance, besides those caused by ice sheets, are needed to explain the cold ice-age climate in high southern latitudes. Such changes may include a reduction in atmospheric CO_2-concentration or a change in the intensity of interhemispheril thermohaline circulation in the oceans.

Hydrologic changes in the model climate are also found, with statistically significant decreases in soil moisture occurring in a zone located to the south of the ice sheets in North America and Eurasia. These findings are consistent with some geological evidence of regionally drier climates at the last glacial maximum.

The preliminary results from this study are summarized in a manuscript submitted to the Annals of Glaciology (vv). A paper which contains a comprehensive discussion of the results from this study is almost completed.

1.2.2 Influences of Ice Sheets on Climate Sensitivity

A two-level, seasonal, energy balance climate model has been used to study the effects of large ice sheets on the sensitivity of climate. Earlier experiments with a simple annual-mean energy balance model indicated that ice sheets reduce the sensitivity of climate to perturbations in the solar constant when compared to a model with snow cover (522). The annual-mean model treated the snow budget and the mass budget of the ice sheet in a highly simplified manner. In the seasonal model it is possible to calculate the mass budget of the ice sheet explicitly if the precipitation is known. Sensitivity experiments have been conducted using several different assumptions about the distribution of precipitation over the Earth. High melt rates in the ablation zone of the ice sheet keep the ice margin closely coupled to the permanent snowline. For this reason the model with the ice sheet is only slightly less sensitive than in control experiments with snow cover only.

1.2.3 Influence of Orbital Parameters on Climate

The Southern Hemisphere's response to orbital parameter variations has been examined with a variety of energy balance models. The rationale for this work is twofold. Firstly, since the model predicts only the zonal mean temperature field, it seems better suited to studying the more zonally symmetric climate of the Southern Hemisphere, rather than the more asymmetric climate in the North. Secondly, the paleoclimatic record suggests that climatic variations in the two hemispheres are in phase on the 20,000-year perihelion cycle time scale. If the two hemispheres responded similarly to insolation anomalies, one would expect the response to the perihelion cycle in the South to be exactly out of phase with that in the North. Therefore, a model similar to that described in (377) has been constructed with idealized Southern Hemisphere geometry (all land poleward of 70°, all ocean equatorward of 70°). The sensitivity of the response to the details of the sea-ice model and the heat flux parameterization are currently being examined. Preliminary results suggest that such a model cannot explain the phase of the response inferred from paleoclimatic indicators. The implication is that the climate in high Southern latitudes is strongly coupled to that in high Northern latitudes on these time scales. Calculations have also been performed with several energy balance models, and with a two-layer primitive equation model, testing the sensitivity of high Southern latitudes to large albedo variations in high Northern latitudes. These strongly suggest that meridional heat transport in the atmosphere is incapable of providing this coupling. The GCM experiment discussed in Section 1.2.1 is consistent with this result.

Work towards constructing a 2-dimensional latitude-longitude energy balance model by coupling the 1-dimensional model with a linear forced wave model for the zonal asymmetries has been postponed pending further analysis of the linear stationary wave model.

PLANS FY84

Simulation of Ice Age Climate

A manuscript which describes the details of the ice sheet experiment will be completed.

A new set of numerical experiments will be conducted to evaluate the influence of other factors on the climate of an ice age. Other factors to be considered are the reduced concentration of atmospheric CO_2 and the increased albedo of continental surface outside ice sheets.

Ice Sheets and Climate Sensitivity

The study of the influence of ice sheets on climate sensitivity will be continued by use of an energy balance model of climate. A new parameterization of the meridional transport of water vapor by the atmosphere also makes it possible to study the effects of changes of the solar constant on the hydrological cycle. The intensity of the hydrological cycle in the energy balance model responds in a manner similar to that predicted by general circulation models. The water vapor transport parameterization is used to predict precipitation in the model. Sensitivity studies will be carried out in which the entire mass budget of the ice sheet (snowfall minus ablation) is calculated internally by the model.

Orbital Parameters

The calculations of the Southern Hemisphere's response to orbital parameter variations will be pursued, and a manuscript prepared on the results obtained.

Sensitivity of GCM to Solar Constant

The sensitivity of an idealized 9-level atmospheric GCM to a decrease in solar constant will be examined. The solar constant will be lowered to the point that the high-albedo snowcover expands to cover the entire surface of the model. For efficiency, a hemispheric model with three-fold symmetry around a latitude circle, and with a "swamp" (saturated, zero heat capacity) surface boundary condition will be utilized. Simple energy balance models generally predict monotonically increasing sensitivity as the solar constant decreases, owing to stronger albedo feedback from larger snowcover. However, the two-layer model described in (323) predicts an initial increase in sensitivity as the solar constant is lowered, but this sensitivity reaches a maximum and then dips to a minimum after the snowcover boundary passes through the midlatitude maximum in baroclinic activity. After this the sensitivity increases again, leading finally to the familiar large icecap instability. An explanation for this behavior was offered in (468). The experiments planned for the coming year will determine if the behavior of the 9-level model is similar to that of the 2-level model or the simplest energy balance models.

1.3. CLIMATE VARIABILITY

D. Hahn
N. C. Lau
S. Manabe
R. Wetherald
T. C. Yeh

ACTIVITIES FY83

1.3.1 Land Surface Anomaly

The GFDL report of the preceding year describes briefly the results from a modeling study which assesses the interaction between climate and a large scale soil moisture anomaly created by saturation of soil with water (i.e., irrigation). During this fiscal year, the results from this study have been extensively analyzed and are described in a manuscript to be resubmitted for publication (bb).

The model used for this study is an atmosphere-mixed layer ocean model with a limited computational domain and an idealized geography. In three separate numerical experiments, the soil in each of three latitude bands (i.e., 30N-60N, 0-30N, and 15S-15N) is initially saturated with water. The temporal variation of soil moisture after the time of irrigation is observed. It is found that the anomaly of soil moisture resulting from this large scale irrigation can persist at least several months. If an irrigation region is located under a rainbelt, precipitation over the region is enhanced. On the other hand, if an irrigated region is located outside a rainbelt much of the additional moisture from irrigation is exported to rainbelts outside this region. Thus, the soil moisture anomaly under the middle latitude rainbelt tends to persist longer than the corresponding anomaly in the subtropics.

This study suggests that a large scale soil moisture anomaly induced by a natural fluctuation of climate may also persist over an interseasonal time scale and may have significant impact upon the hydrological behavior of the atmosphere.

1.4 WAVE DYNAMICS AND CLIMATE

D. Golder
Y. Hayashi
I. Held
N. C. Lau
S. Nigam
J. Osinga
L. Panetta
P. Phillips
R. Pierrehumbert
T. Yamagata

ACTIVITIES FY83

1.4.1 Stationary Planetary Waves in the Troposphere

(A) Research in the past three decades has demonstrated the qualitative value of the theory of linear stationary waves forced by orography and heating for explaining the extratropical stationary eddy field. Testing of the theory has been hindered in part by the lack of data on the detailed distribution of diabatic heating, particularly latent heat release, in the atmosphere. By comparing linear wave theory with the stationary eddies produced by a GCM one can circumvent this problem, to the extent that one accepts the GCM as an adequate surrogate atmosphere. Thus, comparisons have been made between a linear primitive equation model on the sphere and the winter climatologies produced by 15-year integrations of two GCM's, one with and one without surface orography. As illustrated in Fig. 1.2 the results are very encouraging. The figure shows the wintertime mean Northern Hemisphere stationary eddy (deviation from zonal mean) geopotential height fields at 300 and 700 mb as produced by the "no-mountain" GCM, and the result from a linear model forced by the diabatic heating produced by the GCM. The excellent agreement in the upper troposphere persists down to 500 mb, below which the solution deteriorates significantly. A similar comparison with the "mountain" GCM shows broadly similar results. The following are some of the conclusions drawn from these comparisons:

- The linear model result in Fig. 1.2 is forced by diabatic heating in the Northern Hemisphere only. If this linear model is forced by global heating, the result in the Northern Hemisphere deteriorates badly. Evidently, the linear model allows waves generated south of the equator to pass through the tropics into the Northern Hemisphere to a much greater extent than does the GCM. This difference between hemispheric and global forcing is less pronounced in the "mountain" model comparison.

- There are substantial differences in the thermally forced eddies in the linear simulations of the "mountain" and "no-mountain" models. Thus, the effect of mountains on the wintertime heating distribution is important for the thermally forced waves.

- The thermally forced eddies in the linear models can be split into parts forced by zonal asymmetries in sensible, latent, and radiative heating. Latent heating, located primarily in the mid-latitude oceanic storm tracks, is found to be by far the dominant component.

(B) Linear, inviscid, stationary wave theory breaks down near "critical latitudes," where one finds transitions from mean westerlies to easterlies. Whether or not this breakdown results in significant reflection of incident Rossby waves is one of the key problems in stationary wave theory. A barotropic model on a sphere has been used to study the effects of a critical latitude in the tropics on Rossby waves forced by tropography in mid-latitudes. High resolution linear and "quasi-linear" calculations have been performed; in the latter, the zonal asymmetries are allowed to interact non-linearly with the zonal flow but not with themselves. In the quasi-linear model, a wavetrain originally generated by the Himilayas reflects off of the tropical winds in the Pacific and then propagates eastward and northward across the North American continent. This wavetrain can be isolated by taking the difference between the quasi-linear and linear solutions, as indicated in Fig. 1.3. Since the reflection does not occur in the linear model, the wind structure responsible for the reflection is generated by the waves themselves. These calculations have been analyzed in a paper submitted for publication (kk).

(C) The utility of barotropic models for studying the stationary response to topography on planetary scales has been evident since the pioneering work of Charney and Eliassen, and barotropic models remain invaluable for gaining insights into aspects of the theory (see above and Sec. 3.3.1). In order to provide theoretical justification for the use of barotropic models, a comparison has been made between the stationary responses to localized forcing in a barotropic model and in a series of baroclinic, quasi-geostrophic models.

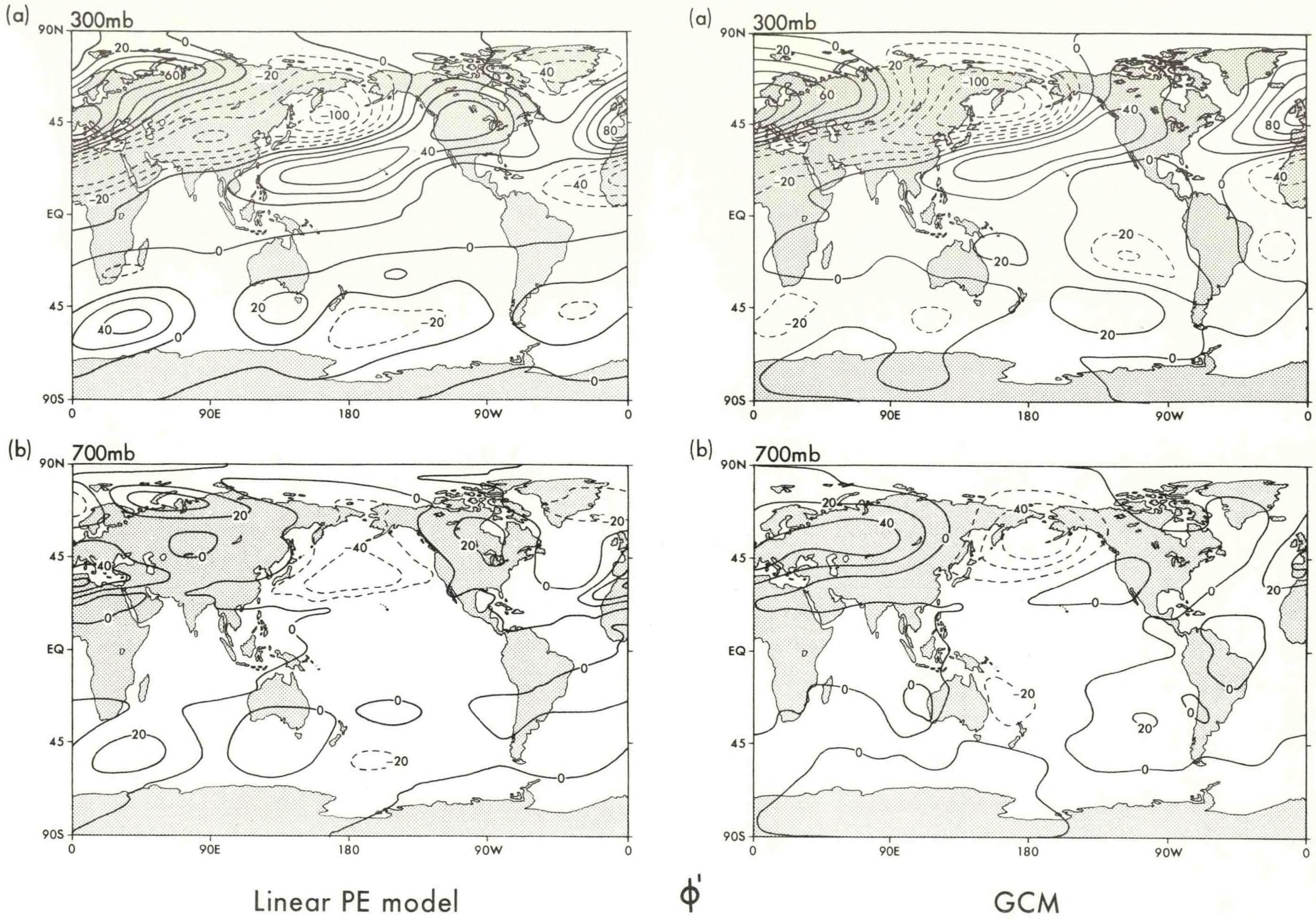


Fig. 1.2-- Stationary wintertime eddy geopotential field predicted by the "no mountain" GCM (right) and by a linear stationary wave model forced by the diabatic heating distribution generated by the GCM (left), at 300 mb and 700 mb. Units are geopotential meters.

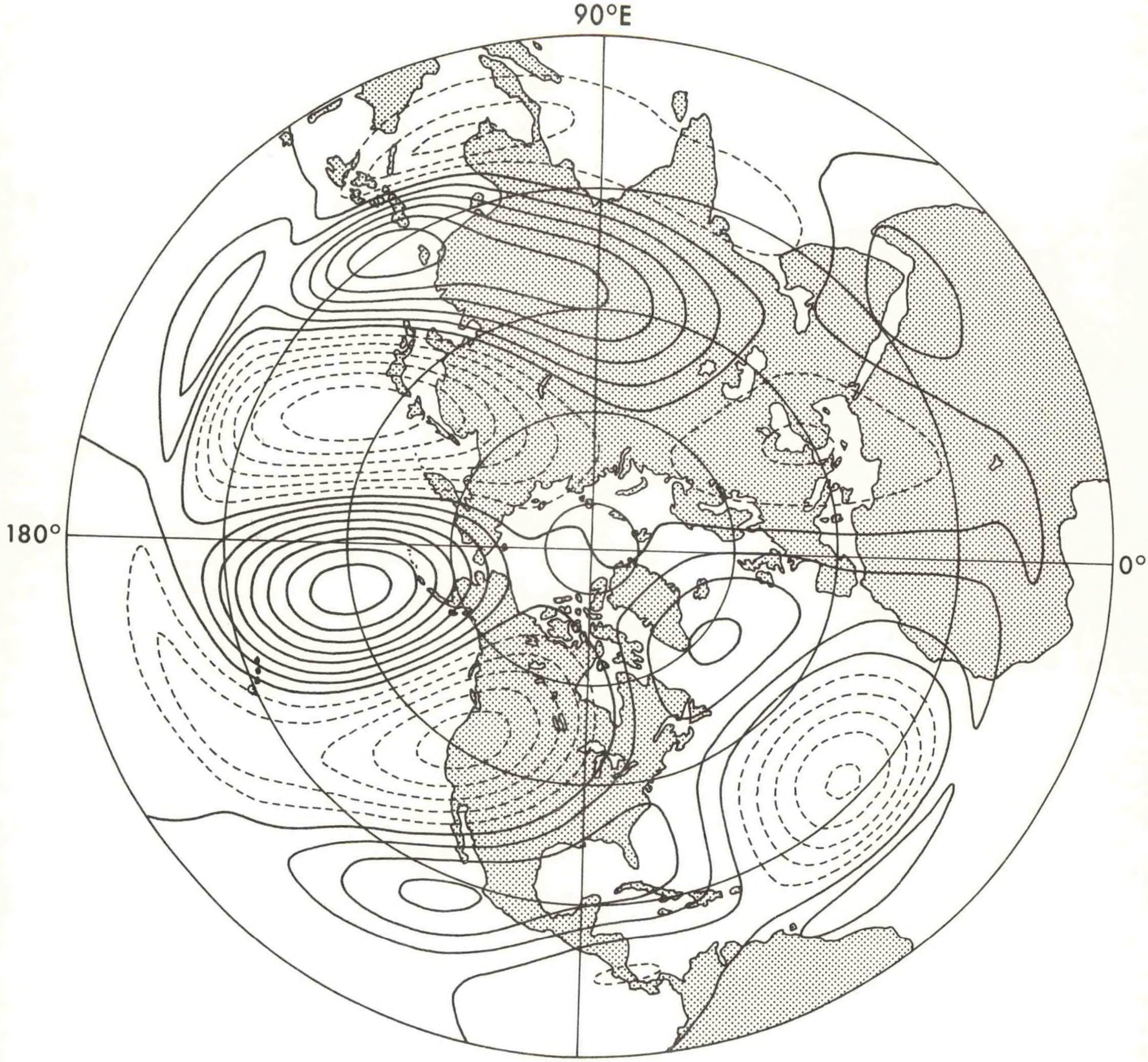


Fig. 1.3-- The difference between the eddy streamfunctions forced by topography in "quasi-linear" and linear barotropic models, showing the wave-train originating in the far western Pacific that is generated by reflection in the nonlinear model. Contour interval is 1.5×10^6 m^2/s; negative contours are dashed.

The response in the baroclinic models far from the source is dominated by the stationary "external Rossby wave," and one can mimic the far-field solution with a suitably designed barotropic model. The strength of the topographic stretching and the height at which one should select the mean wind field for use in a barotropic model are unambiguously determined by the vertical structure of the external mode obtained from the baroclinic model. Some of the results obtained from this study are that

1) the height from which one must select the mean wind field for use in a barotropic model increases as the vertical shear increases, and

2) the horizontal group velocity of the external mode becomes infinite in the presence of positive vertical wind shear as the surface wind approaches zero, a result that has no analogue in the barotropic model.

1.4.2 Transient Planetary Waves

A. Planetary waves in middle latitudes

The effects of wave-wave interactions on mid-latitude transient ultralong waves were examined by comparing a spectral general circulation model with 21 zonal wavenumbers to a number of experiments in which the model retains only a single wavenumber or a combination of wavenumbers (ggg). It was found that the wavenumber 1 component is maintained primarily through the process of wave-wave energy transfer and does not grow by itself, while wavenumber 3 component is maintained primarily through the zonal-wave energy transfer and can grow by itself to a great extent. The wavenumber 2 component is maintained primarily through the zonal-wave energy transfer and, to some extent, through the wave-wave energy transfer. This component, however, only grows to a small extent without wave-wave interactions. It is suggested that even a moderate increase in the growth rate due to the wave-wave energy transfer results in a dramatic increase in the energy of low wavenumbers, since the surface friction is not effective in damping low wavenumber components.

B. Tropical waves

A simple linear model was constructed to diagnose the response of the tropical troposphere to a localized heat source pulsating with the observed 40 day periodicity. This model suggests that the atmospheric response may be interpreted as a standing wave in the region of heating and traveling waves elsewhere. It may be worthwhile, in the future, to simulate and analyze these waves by the use of a general circulation model of the atmosphere.

1.4.3 Transient Eddy Flux Parameterization

In (438) it was argued that the fluxes due to baroclinic eddies in a forced, dissipative quasi-geostrophic flow should be relatively easy to study when the meridional scale of the forcing is much larger than the relevant radius of deformation. It was hypothesized that for sufficiently large forcing scale the eddy statistics would become horizontally homogeneous and dependent primarily on the local time mean flow. This hypothesis is being tested using a 2-layer model on a beta-plane with a severely truncated zonal spectrum (zonal flow plus one non-zero zonal wavenumber) but with sufficient meridional resolution so as to allow for an enstrophy cascade to small scales.

Statistically steady states for a wide range of parameters have been obtained and are currently being analyzed. Preliminary results suggest that the approach towards the homogeneous limit as the scale of the forcing increases may be faster for some statistics than for others.

PLANS FY84

Stationary Planetary Waves

The comparison of linear stationary wave models with GCM's will be actively pursued by 1) extending the wintertime comparison to an analysis of the seasonally varying stationary waves, and 2) examining the extent to which monthly or seasonal mean anomalies from the 15-year mean can be understood as anomalies in the forcing of the stationary wave field.

A manuscript will be prepared for publication on the comparison of barotropic and baroclinic stationary wave responses to localized forcing and the implications of this comparison for the proper design of barotropic models.

The problem of the interaction of Rossby waves with the mean flow near the transition from mean westerlies to easterlies will be readdressed in a model in which the mean flow is maintained against the Rossby wave stresses by a Hadley circulation. Interpretation of previous work on this issue has been hampered by the rather arbitrary methods used to maintain realistic mean flows in the tropics. A fully non-linear, high resolution barotropic model will also be used to study the effect of wave-wave interactions and zonally asymmetric tropical flow on Rossby waves incident from midlatitudes, as well as non-linear aspects of the stationary response to tropical vorticity sources.

The theory of the linear, dissipative critical latitude in the presence of baroclinicity will be examined with a two-layer quasi-geostrophic model.

Transient Planetary Waves

Space-time spectral analysis will be made of the nonlinear energy transfer of stationary and transient planetary waves in the middle latitudes and tropics simulated by general circulation models with and without topography. Theoretical and numerical studies will be made of the effect of transient eddies on the mean zonal flow.

Eddy Flux Parameterization

Analysis of the 2-layer channel model and the doubly-periodic model will be continued to study the homogeneous limit and other aspects of the eddy flux parameterization problem.

1.5 MODEL IMPROVEMENTS

D. Daniel	M. Spelman
D. Hahn	R. Stouffer
L. Holloway	

ACTIVITIES FY83

During this fiscal year, major emphasis has been placed upon the conversion and optimization of climate model programs for their operation on the new

CDC Cyber 205 computer. The programs for the following climate models have been converted and are performing satisfactorily: energy balance model; radiative, convective model; spectral GCM of the atmosphere with various computational resolutions; atmosphere-mixed layer ocean model; coupled ocean atmosphere GCM with limited computational domain.

Research aiming at the improvement of these models has been resumed. Brief descriptions of some of this research activity follows.

1.5.1 Atmospheric GCM

A spectral model of atmosphere used by the climate dynamics project employs "the transform technique" for the sake of computational economy. In this approach, a time derivative of a prognostic variable computed at each grid point is represented by a limited number of spherical harmonics. Thus, high wave components are removed. This spectral truncation has a particularly large impact upon the moisture field which varies markedly by substantial factors from one geographical location to another, and it generates large areas of negative moisture and super-saturation, which results in a fictitious precipitation. Because of the non-local influence of the spectral truncation, a spectral model with the transform technique often over-estimates the precipitation rate in regions of meagre precipitation, such as Siberia and Canada during winter.

In order to avoid this difficulty, an attempt has been made to construct a modified version of the model in which dynamical equations are evaluated by the spectral transform technique but the moisture equation is computed by use of a finite difference method. Preliminary results of test experiments indicate that this hybrid model produces a significantly more realistic distribution of precipitation than the original model in the regions of meagre precipitation.

1.5.2 Global Ocean Atmosphere Model

The coupled ocean atmosphere model with limited computational domain, which has been used extensively, has been converted to a global model with realistic geography. This version of the global model consists of the spectral GCM of the atmosphere and the finite-difference model of the oceans. A numerical integration of this model has been successfully executed.

PLANS FY84

Atmospheric GCM

The research aiming at the improvement of a spectral GCM of the atmosphere will be continued. Most of the spectral GCM's used by the Climate Dynamics Group have a relatively low computational resolution. Special emphasis will be placed upon a performance assessment and improvements of spectral GCM's with relatively high computational resolution.

Global Ocean-Atmosphere Model

The global model of the coupled ocean atmosphere system discussed in Section 1.5.1 will be improved by the incorporation of (a) new parameterization of oceanic surface layer (477) and (b) the hybrid GCM of the atmosphere described in Section 1.5.1. The performance of this model will be evaluated throughout the next fiscal year.

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 TRACER STUDIES

J. Bacmeister
P. L. Baker
H. Levy II
J. D. Mahlman
W. J. Moxim
R. A. Plumb

2.1.1 Atmospheric N_2O Tracer Experiments

Final work has been completed on the series of experiments designed to test the sensitivity of stratospheric N_2O (nitrous oxide) to various photodestruction hypotheses. The model analysis reveals that the horizontal "topography" of time-mean mixing ratio surfaces should be essentially the same for a wide class of long-lived trace constituents. This relationship is predicted to hold as long as the chemical destruction time scale is long compared to an appropriate transport time scale. This result has allowed development of a simple theory which predicts the amount of temporal tracer variability in terms of its local time-mean vertical mixing ratio gradient. Both of these predictions are being tested against observational data (see 2.1.7).

2.1.2 Reactive Nitrogen in the Troposphere

Analysis has continued on the set of preliminary experiments which examine the global impact of the U.S. combustion source on the global reactive nitrogen budget. Detailed analysis programs have been constructed in preparation for future more realistic experiments.

2.1.3 Examination of the Classical Theory for Tropospheric Ozone

Final analysis has been completed on the two numerical experiments designed to examine the classical "no-chemistry" theory for tropospheric ozone. A more detailed analysis of model-generated vertical ozone profiles against available observations has been completed and show good qualitative agreement in both profile means and variances. In general, the model seasonal variations also show reasonable agreement with observations. An important exception occurs in Northern Hemisphere midlatitudes. The model shows a well defined spring ozone peak near the surface, while observations suggest a broad peak lasting well into the summer season. A preliminary analysis of surface strontium-90 data suggests that a portion of the summer peak may indeed be transport induced. If so, this could identify a significant defect in the transport model.

A careful re-analysis of the observations suggests that the model predicts too much midtropospheric ozone north of 40°N. In the Southern Hemisphere, the agreement is rather good, but observations are quite limited.

2.1.4 Tropospheric Photochemistry

A photochemical model (O-D) has been developed to study the purely chemical behavior of tropospheric ozone. Diurnal photochemical calculations for 500 mb have been carried out for winter and summer conditions at 15° and 45° latitude. Ozone overburden and water vapor mixing ratios are specified, methane chemistry is neglected and NO_x volume mixing ratios are varied systematically from 10 ppt to 1 ppb.

For the summer, the photochemical equilibrium value of ozone for a specified NO_x level is nearly independent of latitude. For winter, the 15° latitude values are nearly unchanged, while at 45° latitude, the photochemistry is very weak. By utilizing previous estimates of NO_x levels resulting from stratospheric injection (414,433), the model predicts that net ozone photochemical destruction should be present.

However, some previous measurements in the continental middle troposphere find summertime NO_x levels considerably higher than those expected solely from the stratospheric NO_x source. For such high NO_x levels, the model predicts a net photochemical production. This would then be added to the already too large transport-determined ozone values in mid- and high latitudes (2.1.3).

The results of the classical ozone study (2.1.3) combined with this photochemical model suggests that net photochemical destruction may take place in summer high latitudes, while some net production may occur in summer midlatitudes. These conclusions are critically dependent upon highly uncertain assumptions about the amount of NO_x present in the atmosphere (2.1.2).

2.1.5 "Maximum Insight" Tracer Experiments

Final analysis is underway on the two tracer experiments designed to allow an increased mechanistic understanding of tracer transport and dispersion. Case studies are being prepared to demonstrate the character of disturbance-induced dispersion of tracers. The analysis shows how much more efficient this process is in the troposphere compared to the stratosphere. A manuscript derived from this work is now in press (eee).

2.1.6 Development of a 2-D Transport Model

Statistics from the above 3-D "Maximum-Insight" experiments are being used to evaluate the scientific feasibility of a self-consistent 2-D tracer transport model. In principle, the two experiments provide all the transport coefficients and advective velocities required to satisfy the constraints of the recent "generalized diffusion tensor" theories. Work on this problem is in the preliminary stage.

2.1.7 Observational Analysis of Long-Lived Tracers

The previous modeling research on atmospheric N_2O has led to several hypotheses on the generalized behavior of a large class of long-lived trace gases (see 2.1.1). To examine the validity of these hypotheses, an analysis of the structure of observed N_2O, CF_2Cl_2 and $CFCl_3$ has been undertaken. The data source is the series of balloon samples gathered at diverse sites by scientists from the Aeronomy Laboratory/NOAA.

Work completed to date includes: data quality control; analysis algorithm choices; data processing; and method of data averaging. Careful tests of the applicable hypotheses are currently underway.

2.1.8 Model Development

During FY83 a major effort was expanded to convert many of the tracer model and analysis codes to the CYBER 205 computer. This required considerable attention to the optimization of code, as well as to the usual mechanical conversion problems. In addition, the 3-D tracer model has been completely restructured to allow for the possibility of simultaneous solution of multiple species chemistry/transport problems.

PLANS FY84

Efforts will continue on the tropospheric "Combustion Nitrogen" and "Maximum Insight" experimental series. The final wrapups of the atmospheric N_2O and "Classical Ozone" model experiments and their corresponding observational comparisons should be completed. Significant effort to develop a self-consistent 2-D tracer transport model will continue. Some early multiple tracer experimental testing on the CYBER 205 should be underway.

2.2 MODELS OF THE TROPOSPHERE-STRATOSPHERE-MESOSPHERE

S. B. Fels
D. G. Golder
D. S. Graves
Y. Hayashi
J. D. Mahlman
M. L. Salby
L. J. Umscheid

ACTIVITIES FY83

2.2.1 Model Improvements

This past fiscal year has been unusual in that a large amount of time has been spent in converting the 40-level troposphere-stratosphere-mesosphere GCM (designated as SKYHI) to the CYBER 205 computer. In particular, a significant effort was required in code optimization before the speed potential of the computer began to be realized.

Several improvements in the physical parameterizations have been added, particularly in the surface-atmosphere interface. Also, testing of the impact of "rougher" topography has been underway. A higher horizontal resolution (N30) version of SKYHI has been coded and checked. This model is currently undergoing examination through analysis of an extended integration.

2.2.2 "Low Diffusion Medium Resolution (N18) Experiment"

The final work on this previously reported SKYHI annual mean insolation experiment has been completed and the manuscript is in press (nn). This work has utilized the "transformed Eulerian" zonal momentum analysis in which the traditional "eddy" terms are replaced by the so-called "Eliassen-Palm flux divergence" (EPFD), while the paths of wave activity are closely approximated by the Eliassen-Palm flux vector.

As pointed out earlier, these diagnostics generally predict a qualitatively opposite conclusion about the force exerted by the eddies on the zonal flow than that provided by traditional balances. A test of which diagnostic approach is the more meaningful for determining the role of eddies has been devised through a companion model experiment in which all eddy quantities are strongly damped in the lower stratosphere. The results show that the transformed diagnostics provide a far better predictor of the subsequent change in mean flow than do the traditional balance equations.

2.2.3 Analysis of Equatorial Waves in the SKYHI Model

A space-time spectral analysis has been made of equatorial middle atmosphere Kelvin and gravity waves as simulated by the SKYHI annual mean insolation model (2.2.2).

The model Kelvin waves are associated with zonal wavenumbers 1-2, have an eastward phase velocity and tilt eastward with height. The lower stratosphere Kelvin wave has periods of 10-30 days and a vertical wavelength of 10km, in agreement with many observational results. The upper stratospheric Kelvin wave is associated with periods of 5-7 days and a vertical wavelength of 20km, as observed a few years ago by Hirota. The mesospheric Kelvin wave has periods of 3-4 days and a vertical wavelength of about 40km. This corresponds closely to the wave discovered very recently by Salby and colleagues. All these Kelvin waves transport eastward momentum upward.

In addition, SKYHI gravity waves of zonal wavenumbers 1-15 and periods $\sim$0.5 - 2 days are prevalent in the equatorial mesosphere. Their eastward and westward moving components transport eastward and westward momentum upward, respectively, and contribute to the mesospheric zonal momentum balance as much as or even more than do Kelvin waves.

2.2.4 Generation and Dispersion of Equatorial Disturbances

A series of calculations has been undertaken to understand the mechanisms producing the middle atmosphere tropical disturbance observed by satellite and in SKYHI (2.2.3). In particular, transient responses to localized, impulsive tropical latent heat release scenarios are being addressed by an initial value approach which includes the effects of wave absorption and refraction.

The results show the presence of a "spectrum" of equatorially trapped vertically propagating Kelvin and gravity waves centered about a vertical wavelength twice the depth of the imposed heating. Selective absorption of the slower, shorter vertical wavelength components of the wave spectrum appears to be responsible for the predominance of higher frequency disturbances at upper levels in SKYHI simulations (2.2.3) and in observations by Hirota and Salby.

The second initial disturbance response corresponds to a specrum of normal modes with an equivalent barotropic character. These waves are vertically trapped, but they disperse energy toward higher latitudes.

2.2.5 Medium Resolution (N18) Annual Cycle Experiment

The first phase of analysis of an annual cycle version of the SKYHI GCM has been completed, including a comparison of the model simulation against observations (vv). Simulation successes include: the cold equatorial tropopause; the midlatitude warm belts of the winter lower stratosphere; clear separation between the subtropical and polar night jet streams; reversed meridional temperature gradients in the winter mesosphere (and closed off polar night jet); stratospheric summer easterlies of the proper magnitude and depth; a strong sudden warming in the model lower mesosphere; and a pronounced equatorial semi-annual oscillation.

Simulation failures in the middle atmosphere include: an excessively cold polar night vortex with correspondingly too strong zonal winds; a modest but significant underestimate of the magnitude of the vertical component of the Eliassen-Palm flux escaping the troposphere; an easterly jet stream in the summertime mesosphere which does not close off; and no evidence of a quasi-biennial oscillation in the tropical lower stratosphere.

The sudden warming event exhibits many features of observed warmings which do not penetrate downward into the middle stratosphere. In the lower mesosphere, the polar cap warms by over 43° in 15 days. The higher temperatures increase the polar cap diabatic cooling rates to more than 15°C day^{-1}. Accompanying the warming is a deceleration of the mesospheric jet by more than 80 m sec^{-1}. This sudden warming was initiated by a large increase in the vertical component of Elliassen-Palm flux emanating from the troposphere. That flux leads to flux divergences exceeding -40 m sec^{-1} day^{-1} just above the stratopause. Such a level of model forcing is sufficient to induce the large deceleration (and its associated warming). The process appears to have been facilitated by an onset of easterly winds in the Northern Hemisphere subtropics of the upper stratosphere.

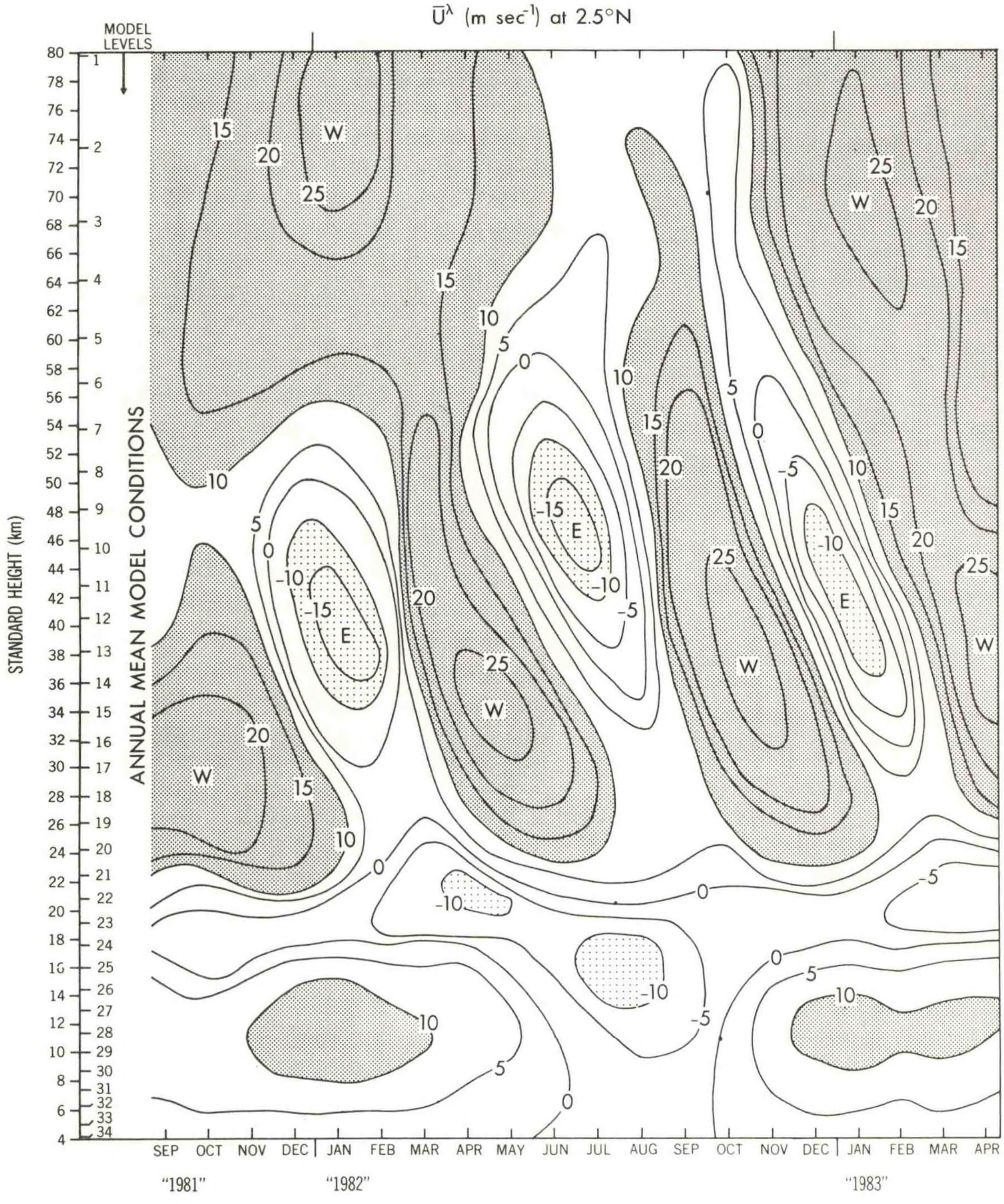
Simulation of the equatorial semi-annual oscillation has been successful in a number of respects. The amplitude maximum of about 20 m sec^{-1} between 40 and 50km and the phase of the oscillation agrees rather well with observations (see Fig. 2.1). The westerly phase is driven by absorption of dissipating Kelvin waves, just as in the previous simulation (436). For the easterly phase, however, the model mechanism is more complex. On the summer hemisphere side of the equator, the easterly acceleration is provided by meridional advection of easterly angular momentum in the cross equatorial flow from the summer to the winter hemisphere. On the winter hemisphere side, however, the dominant model mechanism for the easterly acceleration is provided by absorption of planetary waves propagating in from higher latitudes. Thus, according to this simulation, the easterly phase of the semi-annual oscillation depends upon the cooperative contributions of the advection and wave-propagation mechanisms.

2.2.6 Evaluation of Satellite Sampling of the Middle Atmosphere

A new research effort has begun to provide some estimates on the types of errors to be expected in satellite sampling of the middle atmosphere. The approach chosen is to employ the SKYHI GCM (2.2.5) annual cycle experiment as a sample data set in which all variables are known "perfectly." This model data set is then sampled in a way similar to the way in which polar orbiting satellites sample the actual atmosphere.

Although the research is in a comparatively early stage, some useful results have been obtained. Sampling of temperature spatial averages (the basic variable) can be rather accurate. However, quantities which require derivatives of the temperature field become significantly worse as the order of differentiation is increased. Thus, errors in quantities such as wind are noticeable, but acceptable, while quantities such a vorticity become seriously distorted. In virtually all instances, the sampling errors are considerably larger in lower latitudes.

Fig. 2.1-- Time-height cross section of monthly averaged zonal wind at 2.5°N from the GFDL "SKYHI" seasonal model (2.25). Abscissa is standard altitude for the model isobaric levels. Grid point positions are as indicated. This integration was begun on astronomical date September "1981" from the annual mean model (2.2.2).



PLANS FY84

The initial analysis of equatorial Kelvin wave structure will be completed. Analysis of various aspects of the SKYHI seasonal integrations will continue. A higher-resolution (N30) SKYHI model is to be tested extensively in preparation for a new generation of middle atmosphere numerical experiments. The transmission and momentum deposition of equatorially generated waves will be investigated.

2.3 PHYSICAL PROCESSES IN THE MIDDLE ATMOSPHERE

S. B. Fels S. C. Liu*
J. D. Mahlman J. A. McAfee*
M. D. Schwarzkopf *Aeronomy Laboratory/NOAA

2.3.1 Radiative Transfer Model Development

The radiative transfer model designed for use in the SKYHI GCM (2.2) was extensively recoded for optimization on the CYBER-205 computer. In addition, a number of physical processes have been added: improved CO_2 transmission functions; the $(H_2O)_n$ continuum; and the effects of breakdown of local thermodynamical equilibrium. This latter effect only becomes important above 75km. At 80km, this effect acts to reduce the 15μm CO_2 cooling rates by about 2° day^{-1}.

A new version of the GFDL (441) 15μm transmission function tape was produced on a uniform grid stretching from 1100mb to 10^{-3}mb using a fine mesh and an improved interpolation scheme. This revised tape is already being used at several outside research centers.

2.3.2 Radiative Damping in the Mesosphere

A comprehensive calculation of scale-dependant radiative damping of waves in the mesosphere was undertaken, extending the work previously reported (496) to shorter wavelengths and greater altitudes. The effects of the breakdown of local thermodynamic equilibrium were explicitly included. The results are complicated in detail, but yield damping times of about 1.5 days for disturbances with vertical wavelength of 6km in the mesosphere. Simple scaling laws were also derived allowing easy extension of the results to other CO_2 mixing ratios. A doubling of the present CO_2 loading in the mesosphere will typically lead to an increase in damping rates of 40%.

2.3.3 Seasonal March of Radiative-Photochemical Temperatures

The GFDL SKYHI radiative transfer model has been successfully combined with the ozone chemistry model developed collaboratively with Aeronomy Laboratory/NOAA scientists (2.3.4). To determine the joint radiative-photochemical equilibrium of the middle atmosphere, the combined model has been run for two years at each of 20 latitudes. The solar insolation and surface temperature are specified as a function of season.

The results show generally good agreement with the comparable radiation-only results obtained earlier using specified ozone distribution. This suggests that joint radiative-chemical-dynamical calculations may now be planned with some confidence. The radiative-photochemical temperatures at the summer polar stratopause imply that the dynamical cooling in this region must be substantially smaller in magnitude than that of the required dynamical heating at the winter polar stratopause.

2.3.4 Ozone Photochemistry

The collaborative effort with NOAA Aeronomy Laboratory scientists has continued with an emphasis toward developing an ozone photochemistry model which is compatible with the 3-D SKYHI GCM (2.2.5). The CYBER-205 chemical code has now been developed so that either diurnal or diurnally averaged chemistry can be calculated. The diurnal chemistry is used to provide a continuous parameterization of the correction terms required for inclusion in the diurnally averaged chemistry. This allows a far more economical model for GCM work, but which remains self-consistent with the strongly diurnal character of stratospheric photochemistry.

PLANS FY84

The new improvements to the radiative transfer model will be added to the SKYHI GCM. Research will continue on the interaction of radiation and ozone photochemistry. The chemical codes will be developed further toward the goal of developing a SKYHI model which self-consistently includes the most important radiative-chemical-dynamical interactions.

3. EXPERIMENTAL PREDICTION

GOALS

* To identify important external forcing mechanisms for the forecast range of several weeks to several months, including initial conditions in the atmosphere, oceans, soil and snow-ice.

* To investigate the influence of additional internal processes such as cloud-radiation interaction and cumulus convection, upon atmospheric variability on the seasonal time scale.

* To develop more accurate and efficient atmospheric and oceanic GCM's suitable for monthly and seasonal forecasts, respectively.

* To study the mechanisms of various atmospheric phenomena such as tropospheric blocking, orographic cyclogenesis, tropical waves, equatorial ocean-atmosphere interaction processes, and teleconnection.

3.1 LONG-RANGE FORECAST

K. Miyakoda   R. Pierrehumbert
J. Sirutis   W. Stern
J. Ploshay

ACTIVITIES FY83

3.1.1 Monthly Forecasts

The "1980-version GCM" (i.e., N48L9-E) has been frozen and is being applied to four cases of monthly prediction for January 1977-79. Each case includes an ensemble of three individual forecasts, starting with three different initial conditions. Besides these basic experiments, two additional forecasts are being made for each case. One is a forecast with real sea surface temperatures (instead of climatological normals) as the surface boundary conditions, and the other is a forecast with an advanced physics (i.e., N48L9-F). The number of cases of successful monthly predictions has been increased. It is suggested that, so far as the monthly forecast is concerned, internal dynamics are extremely important. In this respect, the refined physics as well as the good quality of initial conditions play an essential role (see figure 3.1).

PLANS FY83

A study involving 4 cases will be completed. The historically anomalous 1982-83 winter case will be tested. A Spectral GCM (R42L18-F) will be prepared, and applied to the cases of 1980-82.

3.2 MODEL IMPROVEMENT

C. Gordon   K. Miyakoda   R. Pierrehumbert
J. Sirutis   W. Stern   R. Strickler
B. Wyman   G. Vandenburgh   B. Carissimo

ACTIVITIES FY83

3.2.1 Various Versions of Subgrid-Scale (SGS) Processes

Continuing from the previous report, three atmospheric GCM's with different treatments of SGS parameterization (A, E, and F) have been integrated over a period of 30 days for six cases. The experiments have revealed that the effects of SGS parameterization on the monthly time scale are substantial, with the F-model consistently showing the highest forecast skill. In particular, during the GATE period of August-September, 1974, the tropical rainfall, as predicted by the F-model, agrees very well with observation in terms of spatial distribution as well as time isopleth.

3.2.2 Cloud-Radiation Interaction

Work has continued on the generation of analyses of model-dependent monthly mean cloud amount. By examining the results, biases in the GCM

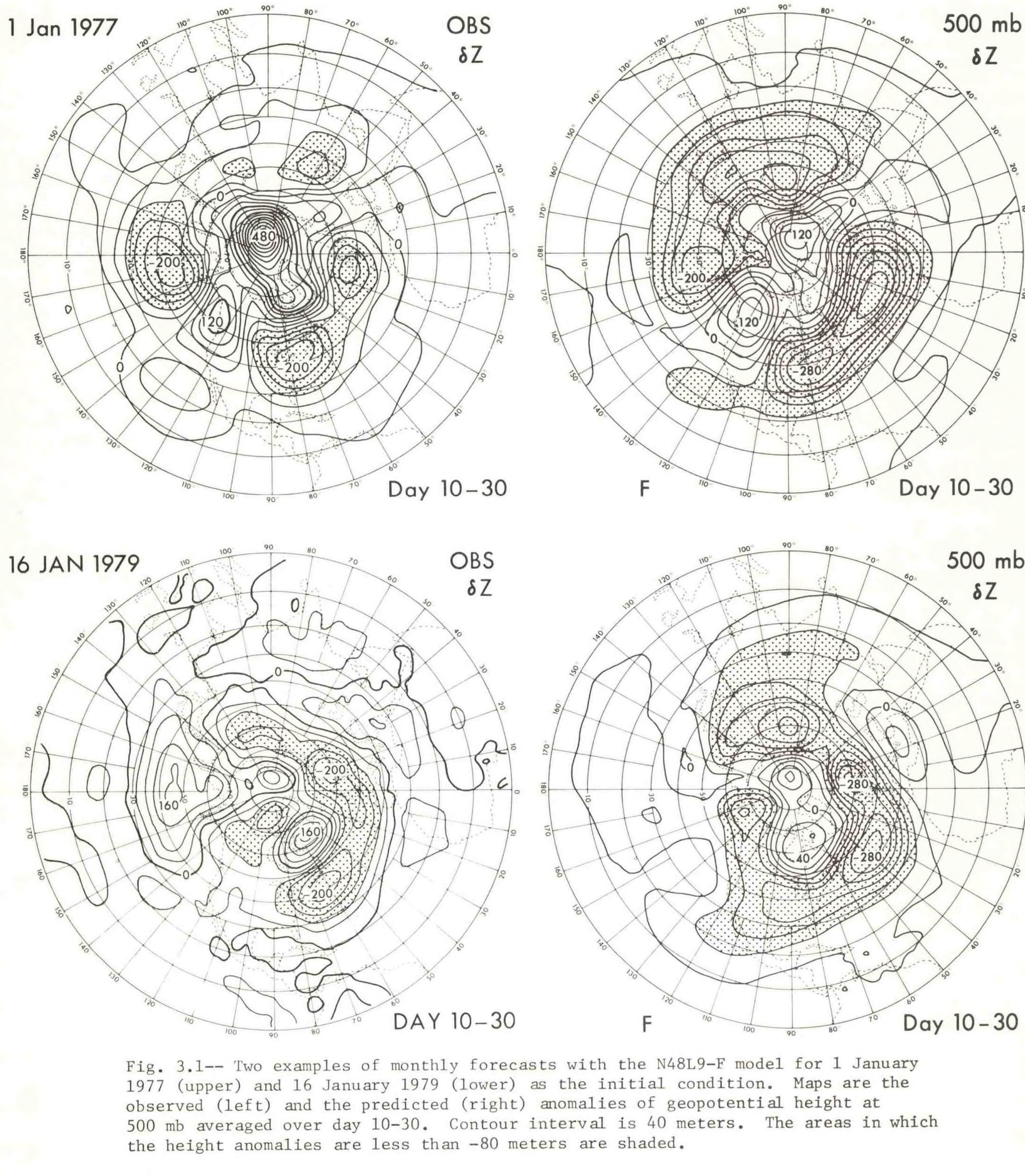


Fig. 3.1-- Two examples of monthly forecasts with the N48L9-F model for 1 January 1977 (upper) and 16 January 1979 (lower) as the initial condition. Maps are the observed (left) and the predicted (right) anomalies of geopotential height at 500 mb averaged over day 10-30. Contour interval is 40 meters. The areas in which the height anomalies are less than -80 meters are shaded.

specification of surface albedo over subtropical deserts and snow covered land have been clearly revealed. Also, a cloud prediction scheme has been refined such that the latitude-dependent critical range of relative humidity will lead to radiatively consistent clouds (z,cc).

3.2.3 Orographic Effects

A number of aspects of the effects of mountains on the atmosphere need to be clarified in order to improve the representation of orography in numerical models. Considerable progress was made toward this goal. A linear analysis of mountain induced deceleration has revealed why smoothing leads to an underestimation of the orographic effect (yy). In addition, a nonlinear theory predicting the depth and upstream extent of layers of blocked air occurring upstream of steep mountains was developed (bbb). Comparisons of the theory with data from the ALPEX field experiment are encouraging. Finally, an analysis system for ALPEX data was completed, and is being used to test the above theories and to investigate the mechanism of orographic cyclogenesis.

3.2.4 Spectral Model

The conversion of the spectral model to the CYBER 205 has been completed, and the efficiency is being improved. The tentative target for CPU efficiency is 10 min per daily forecast with the R30L9-E model, whereas the current speed is 16 min. As for the next generation model, the R42L18-F model is being developed, with plans to include diurnal variability and an envelope mountain.

3.2.5 HIBU Model

A low-resolution global version of the HIBU advanced gridpoint model has been completed. E2 physics has been incorporated in the model. A new polar filtering scheme was implemented; this eliminated the polar instability which hampered earlier attempts to use this model for long-term integration. A 30-day integration starting from January 1, 1977 initial condition was successfully carried out.

PLANS FY84

The comparative study of A, E and F physics, which started in 1973, will be finalized. The construction of the R42L18-F model will be completed. Research will be carried out on the inclusion of an interactive cloud scheme in a GCM. The mechanism of lee cyclogenesis will be investigated.

3.3 DYNAMICS OF PLANETARY WAVES AND BLOCKING

J. Kinter R. Pierrehumbert
K. Miyakoda

ACTIVITIES FY83

3.3.1 Planetary Waves

Wallace and Gutzler (Mon. Wea. Rev.,1981) identified five large-scale circulation patterns in the northern hemisphere. One of the most prominent of these is the Pacific-North-American (PNA) pattern. The strength of each pattern in each month is characterized by an index which ranges continuously from negative to positive values.

An analysis of 15 years of data has revealed that the zonal winds averaged over certain longitude sectors have distinct meridional profiles associated with positive or negative index patterns (figure 3.2). Moreover, when these zonal winds are used in a linearized barotropic model, the observed circulation patterns can be reproduced to a considerable extent. The method is particularly successful for the PNA pattern.

3.3.2 Simulation of Blocking

In the GCM simulation of the blocking event of January 1977, some models were found to be very successful in predicting the evolution of a blocking pattern on the monthly time scale, whereas other models have entirely failed. The crucial elements for a skillful forecast appear to be the subgrid-scale processes, spatial resolution, and treatment of mountain barriers. These key features affect the meridional profile of zonal wind, the character of tropical heating, and the transient eddy field upstream of the blocking ridge; the effect on blocking is probably mediated by these phenomena.

3.3.3 Local Equilibrium Theory of Blocking

A theory of blocking as a locally amplified response to time-average eddy momentum flux was proposed (oo). It was shown analytically that a large amplitude ridge can occur in response to plausible forcing patterns. This prediction was verified in a series of simulations with a barotropic model, which indicated that a large amplitude blocking ridge could indeed be maintained upstream of a localized region of forcing.

PLANS FY84

Investigate the generation of transients in local baroclinic zones, the distribution of the consequent eddy fluxes, and the effect of these fluxes on blocking.

3.4 FOUR-DIMENSIONAL ANALYSIS

N. Lau K. Miyakoda
K. Puri J. Ploshay
W. Stern R. White

ACTIVITIES FY83

3.4.1 FGGE Operation

The operational production of FGGE Level III-b data has been completed. The products were mailed to and archived at two World Data Centers, i.e., Asheville, USA and Obninsk, USSR.

A book of daily weather maps Part I has been published, and another containing monthly mean statistics is being prepared. Further information is reported in (c) and (11).

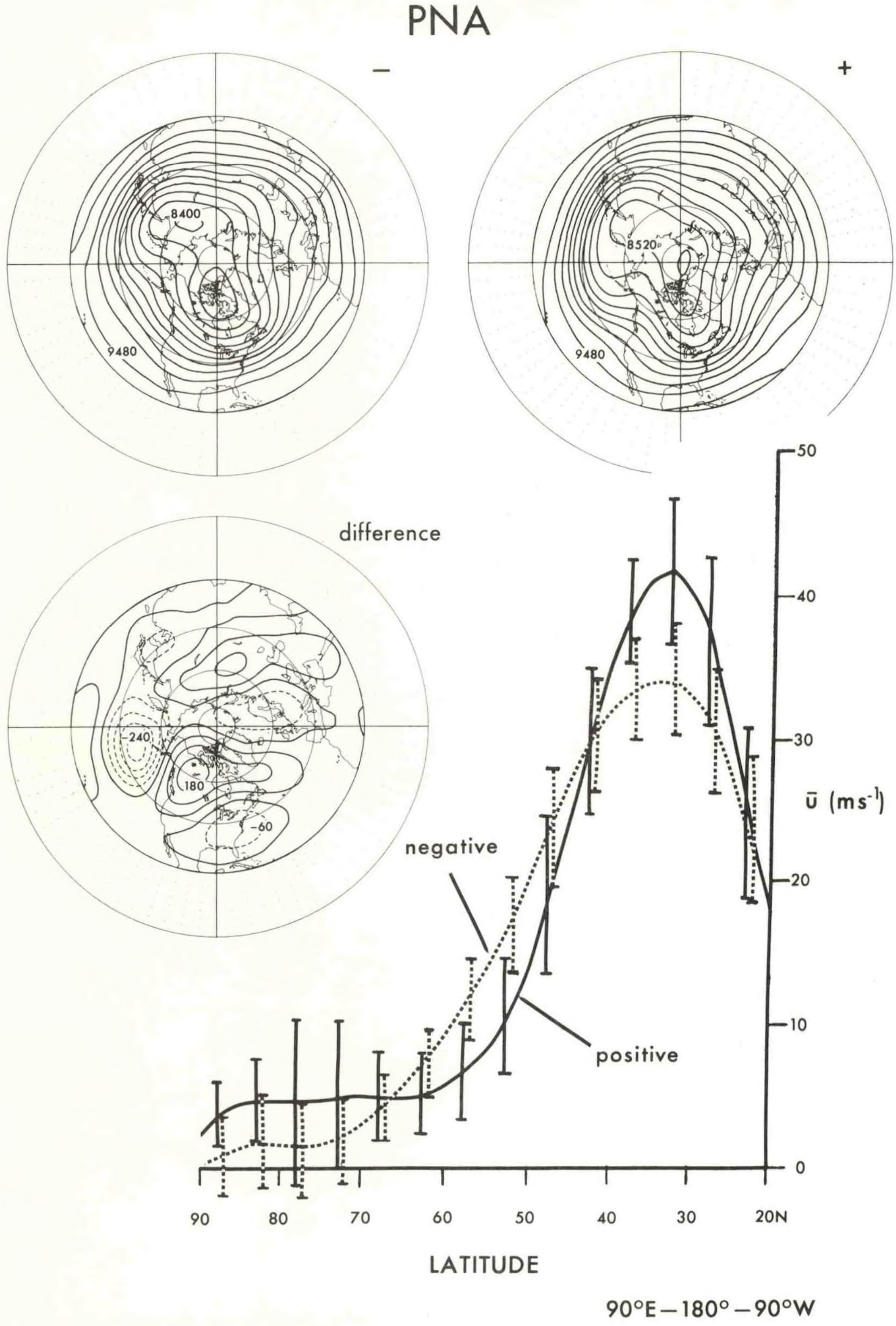


Fig. 3.2-- Wallace and Gutzler's (1981) geopotential height composites for the Pacific-North-American (PNA) pattern positive index (upper right) and negative index (upper left) at 300 mb based on 15 years of NMC winter monthly mean data. The map of geopotential height difference between the positive and negative index composites is given at the lower left. The 300 mb zonal winds (averaged over 90 E-180 -90 W) corresponding to positive and negative index are plotted at the lower right along with bars indicating plus or minus one standard deviation from the composite means.

3.4.2 Conversion and Improvement of Four-Dimensional Analysis

The four-dimensional analysis system as used to process FGGE data has been converted to the CYBER 205. The continuous data assimilation scheme is being improved based on an idea of K. Puri. The inclusion of a linear normal mode adjustment and the application of the non-linear normal mode initialization to the surface pressure and wind data every time-step seem to show some promise.

3.4.3 Walker Circulation at the Indonesian Archipelago

Using the FGGE data, the vertical velocity in the Indonesian Archipelago is being determined accurately. This updraft is very intense, and is likely to be linked with many significant phenomena.

3.5 UPPER OCEAN FORECASTS

K. Miyakoda J. Sirutis
C. Gordon A. Rosati

ACTIVITIES FY83

3.5.1 Sea Surface Temperature Forecasts

Ocean forecast experiments with a one-dimensional model have been completed. The results indicate that the treatment of evaporation and radiation must be done carefully in order to simulate the evolution of sea temperature accurately. So far the three-dimensional GCM for the ocean has not demonstrated its superiority over the one-dimensional model. Development of equatorial high resolution ocean model is underway.

PLANS FY84

An atmosphere-ocean coupled model will be constructed in order to simulate the air-sea interaction process in the equatorial region.

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 it regional components and interpret these in terms of a coherent hydronynamical 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

R. Gardiner Garden
R. Pacanowski
S. Philander
A. Seigel
T. Yamagata

ACTIVITIES FY83

4.1.1 El Niño Southern Oscillation Phenomena

The 1982/83 El Niño was exceptionally severe and evolved in an unusual manner. Anomalous conditions, which appeared in the western tropical Pacific in May 1982 and then expanded eastward, persisted into July 1983. A typical event starts off the coast of Peru, expands westward and terminates in February or March a year after its initiation. A review of these events was published in Nature (541,aaa,ccc).

A study with two coupled shallow water models that simulate the ocean and atmosphere respectively demonstrates that unstable interactions between the ocean and atmosphere can cause modest initial perturbation to amplify (ww). The perturbation, if it is a warm SST anomaly, heats the atmosphere and causes low level winds to converge on the region. The oceanic response to these winds amplifies the original perturbation which therefore has a bigger effect on the atmosphere. This is offered as an explanation for the amplification of anomalous conditions simultaneously in the ocean and atmosphere during El Niño. The seasonal movements of the large-scale atmospheric convergence zones modulate the instability because a warm SST anomaly heats the atmosphere only if there is rising air over the anomaly.

4.1.2 Dynamics of Tropical Oceans

A high resolution three dimensional model for the simulation of the seasonal cycle in the tropical Atlantic Ocean is remarkably realistic. The large seasonal changes in the slope of the equatorial thermocline, the reversal of the North Equatorial Countercurrent, the separation of the Brazilian Coastal Current from the coast during certain months, all are reproduced. Analysis routines to study the dynamics of these phenomena are now being developed.

Waves with a period of twenty days approximately dominate current meter records from the eastern tropical Pacific Ocean. Those records, obtained from PMEL Seattle, are being analyzed to determine the properties of the waves. Previous stability analyses of equatorial currents have predicted periods of thirty days rather than the observed twenty days. Further analyses with a channel model reveal that this discrepancy is a result of underestimation of the intensity of the currents.

PLANS FY84

The study of unstable interactions between the ocean and atmosphere will be continued and CISK processes will be included.

A high resolution model of the tropical Pacific Ocean will be developed and will be used to study the seasonal and interannual variability, including simulation of El Niño phenomena.

4.2 MARINE GEOCHEMISTRY

F. Bryan
S. Gorlick
B. Gwinn
S. Hellerman
M. Jackson
M. Kawase
R. Key
E. Romer
R. Rotter
J. Sarmiento
R. Toggweiler

ACTIVITIES FY83

The basic long range goal of the marine geochemistry group is the development of models of chemical recycling within the oceans. This involves the development of appropriate ocean circulation models using chemical tracers for validation. There were four major areas of activity during the last year.

The first major area of activity was the continuation of our ocean model development. During this last year F. Bryan performed a series of experiments with an idealized sector model of the oceans. He explored the effect of variations in vertical mixing and seasonal forcing on meridional overturning, heat transport, and tracer penetration. The results indicate a stronger sensitivity than we had expected. These results will be written up in the near future. Further experiments are being carried out and we are beginning to develop a new model of the Atlantic Ocean which will take advantage of what we have learned. During FY83 a previous study of how to parameterize isopycnal mixing by coordinate rotation was published (555) and the result of a North Atlantic simulation of the tritium distribution were accepted for publication (nnn).

The second major area of activity was a new one that began in FY83, the development of a model of nutrient cycling in the oceans. This is being done by Toggweiler and Sarmiento. A detailed review of recent literature on sediment trap and suspended particle studies led to a development of a series of equations for predicting nutrient recycling based on biological activity. Preliminary studies of these equations with box and 1-D models are very promising. The box model studies reveal a mechanism for oceanic control of atmospheric CO_2 that may explain the glacial decrease of 30 to 50% in atmospheric CO_2. Two papers are in preparation explaining the equations and the glacial $_pCO_2$ theory.

A third major area of activity was our work with tracer data. A descriptive study of the tritium distribution in the North Atlantic was published (510). A paper which estimates thermocline ventilation time scales from a tritium box model is in press (ooo). The estimates show that seasonal convection and isopycnal mixing are completely dominant over Ekman pumping in ventilating the thermocline. A monthly input function for Sr-90 into the oceans was developed by Gwinn and Sarmiento and a description will soon be completed. This input function has been used to study the seasonality in surface ocean measurements at Weatherships in the North Atlantic for the period 1962 to 1973.

Hellerman and Jackson continue their vital support function, compiling and mapping Transient Tracers in the Oceans data, Cs-137 and Sr-90 measurements in the Atlantic, Ra-228 measurements throughout the world, and tritium observations in the Pacific.

The fourth major area of activity is our participation in the Transient Tracers in the Oceans measurement efforts. Sarmiento planned and coordinated the execution of the 3 month Tropical Atlantic study. He and Kawase are now using the data from this and previous geochemical projects to study the biological cycling of nutrients and develop techniques for obtaining mixing and velocity fields. Key, Gorlick, Rotter, and Sarmiento continued their radium-228 measurement efforts in their laboratory. A technical report by Key was published and three papers describing the first North Atlantic and Amazon River measurements are in preparation. The Amazon River shows a dramatic desorption of radium in the estuary which was far larger than we had expected.

PLANS FY83

The coarse-resolution sector model experiments will be continued. The effect of vertical resolution and isopycnal mixing on model dynamics will be studied. Römer will work on the development of a new North Atlantic model for tracer studies. An eddy resolving version of this model will be developed in coordination with the Ocean Model Development Group.

The nutrient cycling parameterizations will be tested in the sector model and then in the North Atlantic model as it comes on line. We will be studying how these models can be used to predict atmospheric CO_2 levels.

We plan on completing our analysis of Cs-137/Sr-90 Weathership and other observations. The major focus of our data studies during the next year will be an analysis of the Transient Tracers in the Ocean's observations in the North Atlantic.

The radium-228 measurements take a full year to complete. We are just now beginning to get substantial numbers of measurements. Several descriptive papers are planned and we will also begin now to study how these data can be used for model validation.

4.3 WORLD OCEAN STUDIES

K. Bryan F. Komro
M. Cox N. Bogue

ACTIVITIES FY83

The installation of the CYBER 205 offered the opportunity to make a detailed parameter study of a three-dimensional ocean model in a simple geometry. The study (uu) was undertaken in cooperation with Woods Hole Oceanographic Institution. The results were analyzed in such a way as to make detailed comparison with theories for and observations of the potential vorticity distribution in the main thermocline. The analytical studies provide solutions for specific regions, while the numerical model with high vertical resolution provides a self consistent solution for the entire basin. Convection is shown to be a crucial factor in the vorticity balance, and surface wind distribution rather than seasonal effects prove to be the essential element in simulating subtropical mode water, known as the 18° water in the North Atlantic. The changing shape of the thermocline in response to strong and weak winds indicates the differences in ocean circulation to be expected in cold and warm climatic periods.

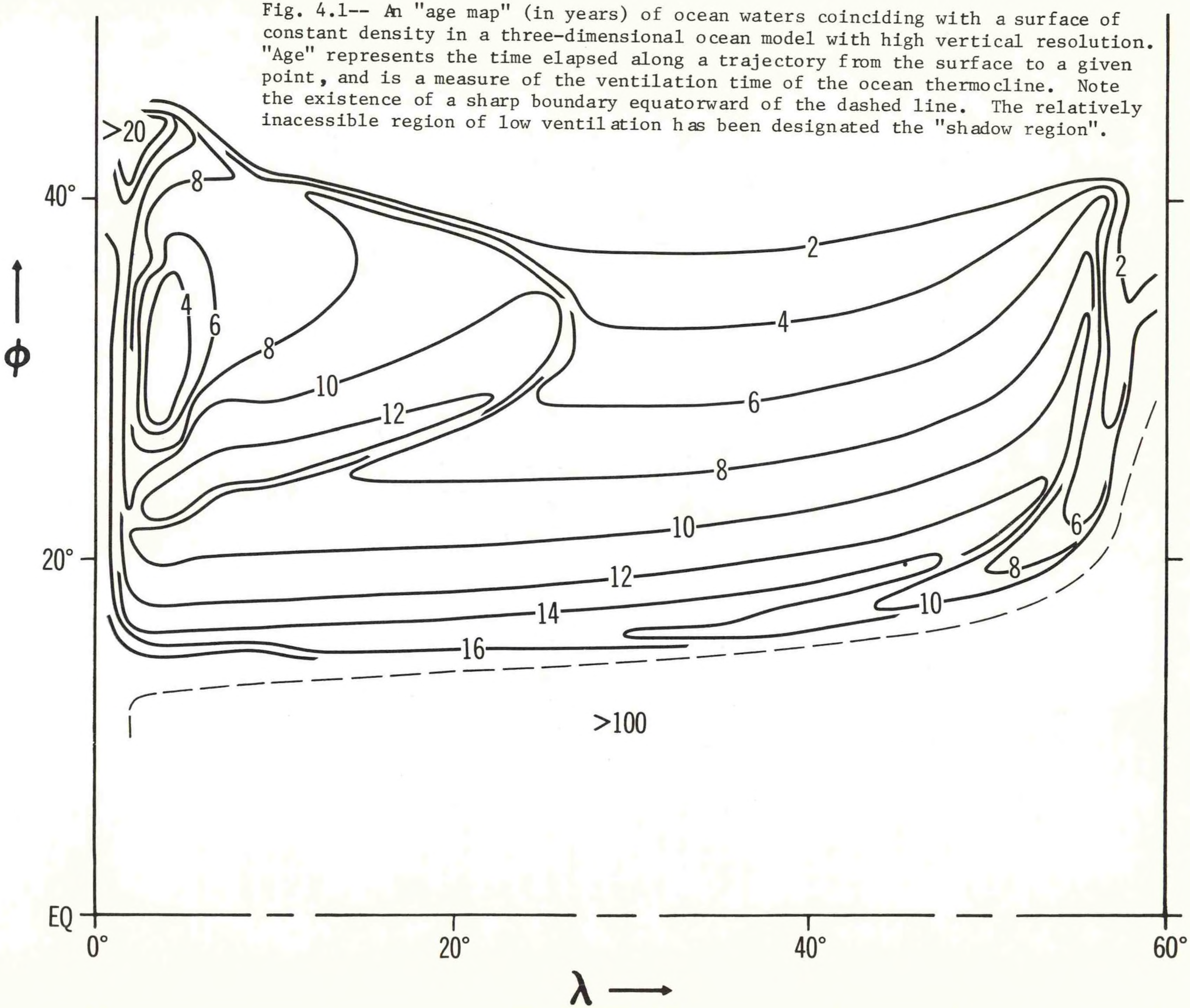


Fig. 4.1-- An "age map" (in years) of ocean waters coinciding with a surface of constant density in a three-dimensional ocean model with high vertical resolution. "Age" represents the time elapsed along a trajectory from the surface to a given point, and is a measure of the ventilation time of the ocean thermocline. Note the existence of a sharp boundary equatorward of the dashed line. The relatively inacessible region of low ventilation has been designated the "shadow region".

Eddy resolving experiments were carried out using the 1°x1° resolution model as a starting point. A series of tests have been carried out to isolate the factors involved in the separation of the western boundary current.

The time scale of penetration of thermal anomalies into a World Ocean model was analyzed in a separate study (fff).

PLANS FY84

Eddy resolving models will be extended to a more realistic geometry, and the results analyzed to assess the role of eddies in the transport of water mass properties. Eddy tracer experiments will be carried out with the marine geochemistry group. A World Ocean model coupled to an atmospheric model will be analyzed in cooperation with the Climate Dynamics Group with particular emphasis on the difference between the Northern and Southern Hemisphere.

4.4 POLAR OCEAN STUDIES

ACTIVITIES FY83

A study of the yearly cycle of interaction between the Arctic Ice Pack and the underlying ocean has been completed (qq). The model parameters are fitted to the data of the AIDJEX field experiment. More detailed analysis of the coupled ice pack/ocean model for the Arctic has been carried out. The study carried out in collaboration with the CRREL (U.S. Army Corps of Engineers, Hanover, N.H.) showed that the trajectories of buoys riding on the ice pack could be predicted with some skill by the combined model including the ocean than was possible using the ice model alone. A study of the Ross Ice Shelf and the ocean below the shelf has been completed (x,ss). This study included a calculation of tides below the shelf, which provides a map of the tidal energy available for mixing. The calculations indicate that part of the area under the ice corresponds to a well mixed estuary, and the rest is well stratified. On this basis, a theory has been formulated for the distribution of melting and freezing along the lower base of the ice shelf. Melting would only occur in the well mixed regions. The theory is consistent with what little data is available, and new measurements are now being carried out along the outer edge of the ice shelf in a field experiment.

PLANS FY84

The work with the coupled ice pack/ocean model with CRREL will continue using a higher resolution model. The model will be tested using the trajectories of ice drift which now extend over several years. The model will be used to identify these areas of maximum ice growth, and examine the effect on the heat and salinity budget of the Arctic Ocean.

4.5 OCEAN MODEL DEVELOPMENT

ACTIVITIES FY83

A shear dependent mixing was introduced into our climate model, and sensitivity tests carried out. A world ocean model has been set up on the CYBER 205. An analysis of the numerical methods used to speed up the convergence to steady state solutions of the ocean model has been completed (zz).

PLANS FY84

Much of the effort in the coming year will center on eddy resolving models and the most efficient way to analyze the vast arrays of numbers that such an experiment generates. Attention will also be devoted to isopycnal coordinate models.

5. PLANETARY CIRCULATIONS

GOALS

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

5.1 PLANETARY ATMOSPHERES

G. Williams

ACTIVITIES FY83

Analysis and documentation was commenced on 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). Model versions are characterized by the presence or absence of moisture, longitudinal variations and surface drag. The implications of these solutions for the planets has been discussed in publication 497.

A study of the solitary vortices that occur at intermediate-geostropic (IG) scales of motion suggested that Jupiter's Great Red Spot (GRS) and Large Ovals may be related to such phenomena. The genesis and longevity of GRS-like and Oval-like vortices was simulated using the shallow water equations for Jovian parameters in the IG range. The vortices may be initiated by weakly and moderately unstable zonal currents. IG motions occur at scales intermediate to those of quasi-geostrophic and planetary-geostrophic motions. Horizontal divergence plays a crucial role in IG dynamics and produces asymmetries in vortex behavior; in particular, anticyclonic vortices are more stable than cyclonic ones. This may explain why most of Jupiter's super-eddies prefer anticyclonic spin (ppp).

PLANS FY84

The detailed analysis and documentation of the dynamics of the multiple, parametrically varying GCM experiments will be completed.

Model development will continue for Jupiter and Venus. The nature of IG vortices in 3-dimensional models will be examined to develop more realistic models of the Great Red Spot.

5.2 VENUS ATMOSPHERIC TIDES

D. Crisp D. Andrews*
S. Fels J. Schofield*
* Dept. of Atmospheric Physics, Oxford University

ACTIVITIES FY83

The Pioneer Venus Orbital Infrared Radiometer was constructed by scientists at Oxford University, and made observations of the thermal structure of the Venus mesosphere for over 70 consecutive days in 1979. This data provides persuasive evidence for the existence of diurnal and semi-diurnal temperature perturbations. These structures show distinct phase propagation with height, and are almost certainly tides. Through an examination of their behavior, one may hope to gain insight into the structure of the Venus mesosphere. This is true largely because of the sensitivity of the tides to the distribution of mean winds and thermal forcing.

To model these waves requires a good understanding of the thermal forcing, and a suitable theoretical method for calculating the response. The development of the former has been in progress for several years at GFDL, (see Sec. 5.3).

The Venus Tidal problem differs from the classical one in that the mean zonal winds are almost everywhere larger than the motion due to planetary rotation, and are apparently not well approximated by solid body rotation. Because of this, conventional tidal theory does not apply, and new methods are required.

In the course of a six month visit to Oxford, a new analytical approximation was developed which renders the Venusian tidal problem relatively tractable. The theory makes use of a two-scale method, which although approximate, has the advantages of computational simplicity and conceptual transparency when compared with other techniques. Preliminary results show encouraging agreement with observations of the horizontal structure of the semi-diurnal tide.

Due to the short vertical wavelength of the tides, the aliasing errors introduced by the finite resolution of the OIR sounder can be very large. It is therefore necessary to verify that the model tides give the observed radiances when inserted in a suitable radiative model. This project is currently underway as a collaborative effort of GFDL and the Pioneer Venus OIR group at Oxford. Early results give grounds for optimism: the observed phase structure of the semi-diurnal tide seems to be well predicted by the model, and the amplitude is also approximately correct.

PLANS FY84

The collaboration with the Oxford group will continue, and an attempt will be made to determine properties of the mean state by comparison of predicted and observed tidal fields.

5.3 RADIATIVE PROCESSES IN THE VENUS MESOSPHERE

D. Crisp S. Fels

New methods for computing radiative fluxes and heating rates in atmospheres where gaseous absorption and multiple scattering are of nearly equal importance have been developed. These new methods have been used to determine the role of radiative processes in the Venus mesosphere (60-100 km). The global-mean radiative equilibrium thermal structure of this region was established and its sensitivity to uncertainties in the optical properties at these levels was determined. The meridional dependence of the radiative equilibrium thermal structure was also computed. These experiments show that radiative processes act to destroy the observed reversed meridional temperature gradients and produce polar mesospheric temperatures up to 40°K cooler than those in the tropics. To maintain the observed thermal structure in the presence of this radiative forcing, net dynamical heating rates of 15°K/Earth-day are needed at low latitudes. The structure of these required net heating and cooling rates suggests the presence of a meridional circulation cell with rising motion at low latitudes, poleward flow at levels near the top of the mesosphere, and descending motion in polar regions. Mechanisms for maintaining a meridional cell of this form are now being investigated.

6. OBSERVATIONAL STUDIES

Goals

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

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

6. OBSERVATIONAL STUDIES

6.1 ATMOSPHERIC ANALYSIS

N. C. Lau
A. H. Oort
M. Rosenstein

S. Fagen - Junior Fellow
M. Forman - Junior Fellow
S. Prasad - Student
J. P. Peixotó - Visitor

6.1.1 Statistical Description of the Atmospheric Circulation

Many of the research results obtained in earlier years have appeared in print during this fiscal year. Most comprehensive is the NOAA Professional Paper No. 14 (u) on "Global Atmospheric Circulation Statistics, 1958-1973" describing the structure of the global atmosphere in great detail. The physical implications of these analyses were published in two extensive, complementary papers on the global angular momentum and energy balance requirements (533) and on the atmospheric branch of the hydrological cycle (544) in cooperation with Prof. José Peixóto of the University of Lisbon. Special emphasis was given to the year-to-year variability in a position paper for a WMO/ICSU Study Conference in Leningrad (551). A joint paper with Dr. Y-H Pan of the Academia Sinica in Bejing, China, (w) clarified some of the global aspects of the El Niño-Southern Oscillation phenomena based on our 15-year data set of atmospheric and sea surface parameters. A remarkable and highly significant correlation was found between the vertical-mean atmospheric temperature averaged over the entire Northern Hemisphere and the sea surface temperature in the eastern equatorial Pacific Ocean. The warming of the atmosphere especially in the Tropics was ascribed to increased convection in the tropical belt during El Niño conditions. Similar effects have been observed during the most recent, record-breaking 1982-1983 El Niño. Part of this research is also being prepared for publication in "Acta Oceanologica Sinica" in China.

Preliminary work on interhemispheric comparisons in our data sets show the important role of the Antarctic continent in the Southern Hemisphere. Evidence is found that the troposphere in the Southern Hemisphere is on the average 1°C colder than in the Northern Hemisphere, and that the pole-equator temperature gradient is much stronger in the Southern Hemisphere, especially in the summer season. These findings have important repercussions leading to increased baroclinicity in the Southern Hemisphere and greater intensity of the transient eddy circulations and of the year-to-year variability in the various statistics in that hemisphere.

The forcing of the time mean flow by transient eddies was further investigated (514,tt). The eddy effects were found to be dominated by disturbances with time scales longer than 10 days. Both heat and vorticity fluxes tend to destroy zonal asymmetries in the time-mean circulation.

A study of midlatitude disturbances accompanying cold air outbreaks over East Asia was completed (see Fig. 6.1). Through an analysis of synoptic charts during the winter MONEX the structure and energetics of various wave phenomena prevalent over East Asia were documented. Disturbances with time scales of several days evolved through a life cycle characterized by baroclinic growth coinciding with the polar outbreaks, followed by a decay phase dominated by barotropic processes.

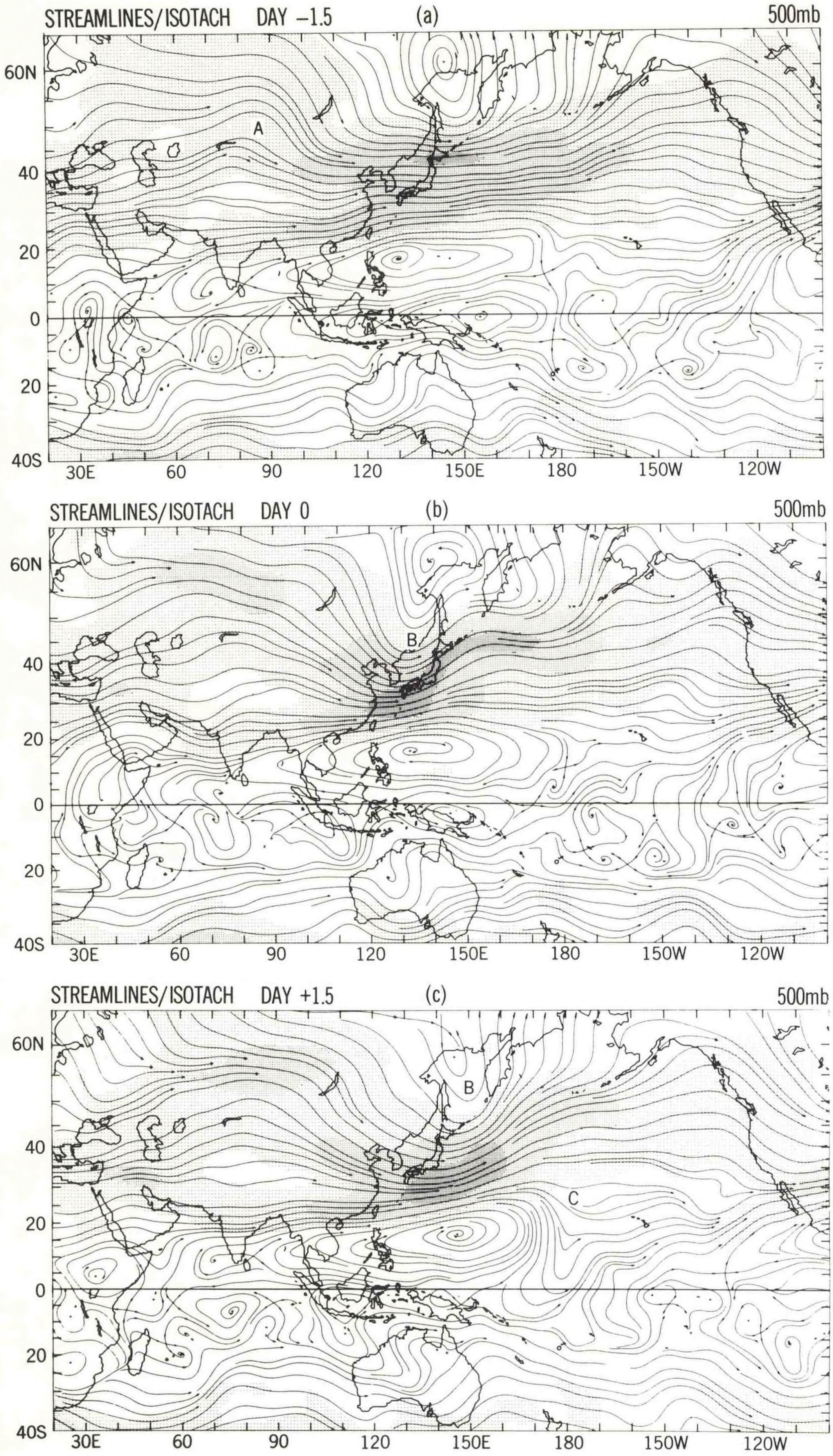


Fig. 6.1-- Severe cold outbreaks over East Asia. Observed composite streamline charts at 500 mb on (a) 1.5 days before a cold outbreak, (b) the day of the cold outbreak, and (c) 1.5 days after the outbreak. The local wind speeds are indicated by degree of shading: 0-20 knots (no shading), 20-40 knots (light), 40-60 knots (medium), over 60 knots (heavy).

Monthly and seasonal circulation statistics were documented for the entire FGGE year (Dec 1978-Nov 1979) based on the level-3B analyses produced by GFDL. Similar statistics were also computed using the analyses produced by ECMWF for the Special Observing Periods. Despite considerable enhancement of the data during the FGGE year, there still exist considerable differences between the two sets of analyses over data-sparse areas.

6.1.2 Diagnosis of General Circulation Model (GCM) Results

The seasonal variation of the three-dimensional structure of the stationary waves generated by various GCM's was verified against observations (j). The seasonal dependence of the orographic and diabatic forcing in the GCM's as well as the propagation characteristics of low-frequency fluctuations were documented and compared with observations.

The exchange of angular momentum between the atmosphere and earth was studied by evaluating the mountain and friction torques (gg) on a global scale both from observations and from general circulation model runs. The overall correspondence between model and observed results turned out to be quite good in spite of the large uncertainties in the model formulation of vertical momentum exchange.

PLANS FY84

The basic 15-year (1958-1973) and FGGE (1979) data sets will be used in a continuing research effort to study the role of the atmosphere and oceans. This will be done through, e.g., evaluating certain regional balances of angular momentum, energy and water vapor. Main emphasis will be on indirectly inferred oceanic heat and fresh water transports in cooperation with the oceanic data studies.

Data processing for a new 5 to 6-year period as a bridge between the 1958-1973 and 1979 (FGGE) periods will begin. Additional basic rawinsonde station data, besides the operational NMC data, will have to be acquired especially in the Southern Hemisphere.

The 6-times a day FGGE analyses generated earlier at GFDL in the Experimental Prediction Group will be studied for selected months in order to investigate the diurnal cycle in the atmosphere.

A comprehensive atlas containing circulation statistics for the FGGE year, as well as highlights of the differences between the level-3B analyses produced by GFDL and ECMWF will be prepared.

The diagnosis of the interaction between the transient eddies and the time-mean flow will continue, using novel techniques such as local extension of the Eliassen-Palm flux concept, and alternative formulations of the atmospheric energy cycle.

Following the successful 15-year GCM integration presently in progress, in which observed SST variations over the equatorial Pacific are introduced as the lower boundary condition. The new level of variability in the model and the circulation anomalies associated with the El Niño episodes will be studied.

6.2 OCEANIC ANALYSES

S. Levitus A. Oort

6.2.1 Global Analysis of Oceanic Data

The "Climatological Atlas of the World Ocean" was printed as NOAA Professional Paper 13 as a culmination of an almost 10-year long effort to document the 3-dimensional structure of the world ocean. Extensive use is already being made by many investigators inside and outside the U.S. of the statistics published in the paper and of the analyzed fields provided on tape by GFDL and in the future by NODC.

A paper describing the annual cycles of temperature and heat storage in the various oceans is in the final stages of preparation. This information will be a basic input for further studies of seasonal variations in the oceanic heat transport.

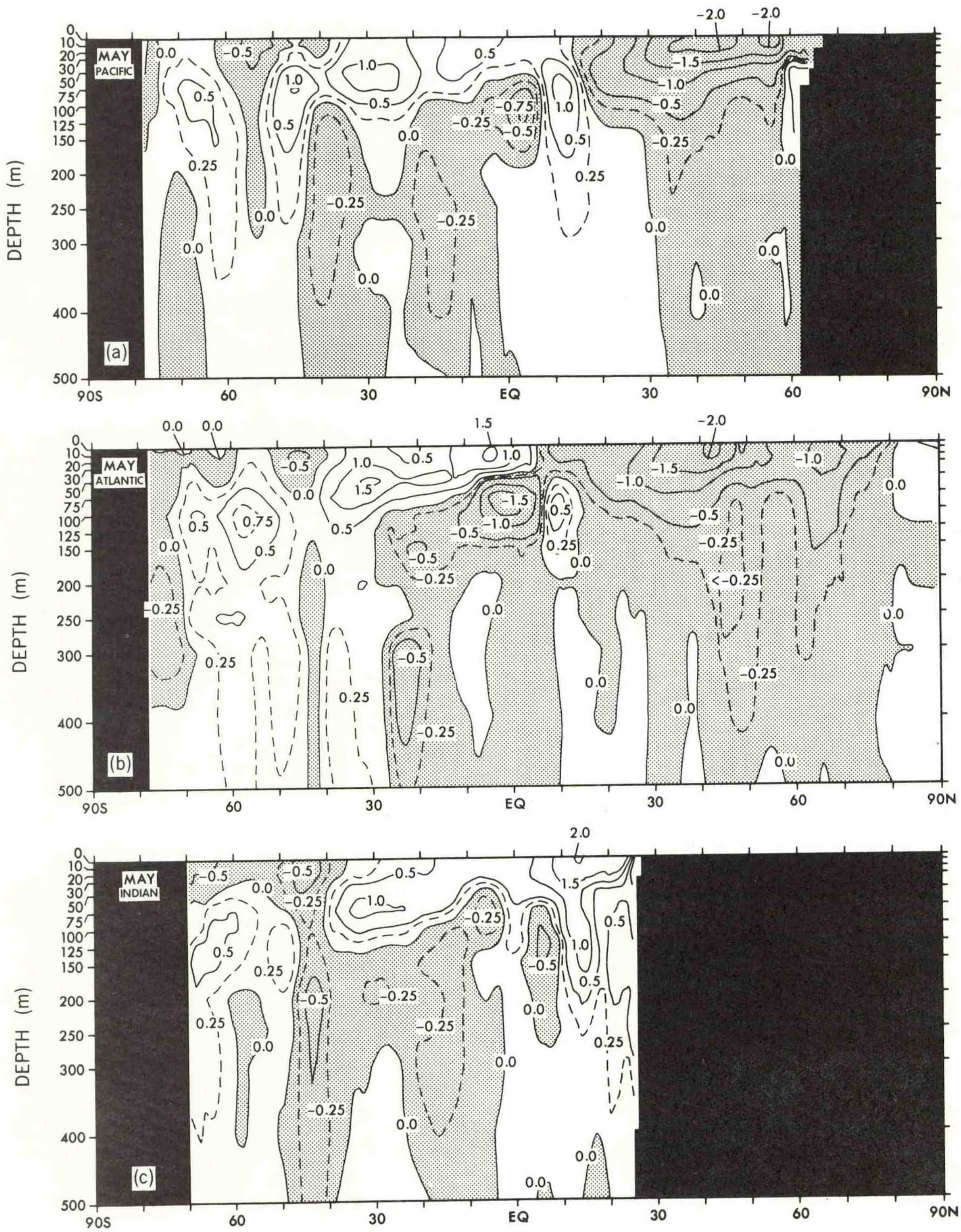
A study of the salinity balance and its seasonal variation based on the oceanographic data atlas is in progress.

PLANS FY84

In conjunction with the atmospheric branch of the Observational Studies Project the study of the heat and fresh water balances over individual oceans will continue.

The year-to-year variability in subsurface heat storage will be investigated over data-rich areas in the North Atlantic Ocean. Presumably, additional historical data sets will have to be acquired to study this problem so crucial to issues of climate change.

Fig. 6.2-- Observed basin-wide zonal averages of May minus annual mean temperatures (degrees Centigrade) for the Pacific, Atlantic and Indian Oceans. The cell-like distributions in the tropics are due to displacements of the thermocline.



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. HURRICANE DYNAMICS

7.1 GENESIS AND DECAY OF TROPICAL STORMS

M. Bender R. Tuleya
Y. Kurihara

ACTIVITIES FY83

The decay process of tropical cyclones after the landfall was investigated. Several ideal simulations of hurricane landfall were performed for a zonal flow of 10 m s^{-1} with a movable triply-nested model with open lateral boundary. General characteristics similar to observed landfalling tropical cyclones were obtained in the primary simulation experiment including an abrupt change in the low level winds at the coastline and a decay of hurricanes as it moves inland. Figure 7.1 shows horizontal distribution of maximum low level wind during the tropical storm passage for landfall experiment as well as for the ocean only experiment. A major cause for decay of a storm is the reduction of water vapor supply to a storm system after the landfall. It was found that the low land surface temperature of 298K made a large contribution to the decay through the suppression of evaporation in spite of the presence of available water, the alteration in the boundary layer wind and the decrease in conditional instability. The analysis results of additional experiments indicate: the surface wind speed responds rather quickly to variable roughness of the land surface; a small, less intense storm fills less rapidly, in good agreement with observations. This study is sumarized in (ff). Lately, the model has been upgraded with the inclusion of the effect of topography.

An investigation of the mechanism of comma vortex formation is almost complete. Comparative analysis of the experiments with both an f-plane model and a spherical model revealed that: (1) the high wind side of the disturbance is the favorable region for the formation of the tail of the comma shape pattern; (2) the β-effect retards the development of a comma vortex in the case of easterly environmental winds and enhances it in the case of westerlies; (3) although a band-like feature may be induced in a purely barotropic model by the non-linear effect alone in the non-circular flow case and by the β-effect in a circular flow case, air-sea interaction is a necessary ingredient for the formative process of the distinct comma vortex. A paper reporting the simulation and analysis results was submitted for publication (111).

The study on the transformation of a tropical easterly wave to a distinct vortex was performed through the time integration of a simple numerical model. The initial condition represents a slowly decaying, adiabatic linear normal mode resembling an easterly wave. The addition of a CISK-type heating effect causes the growth of the wave. Inclusion of the nonlinearity effect alone has little impact on the wave evolution. However, if the nonlinearity effect is combined with the heating effect, it can cause the contraction of the disturbance and enhance the development. The initial free wave undergoes significant structural changes during its transformation into a developing system. The paper on the above subject is in preparation.

The follow-up study of the hurricane eye simulation experiment carried out in the preceding year (490) was made with the emphasis on the energy budget

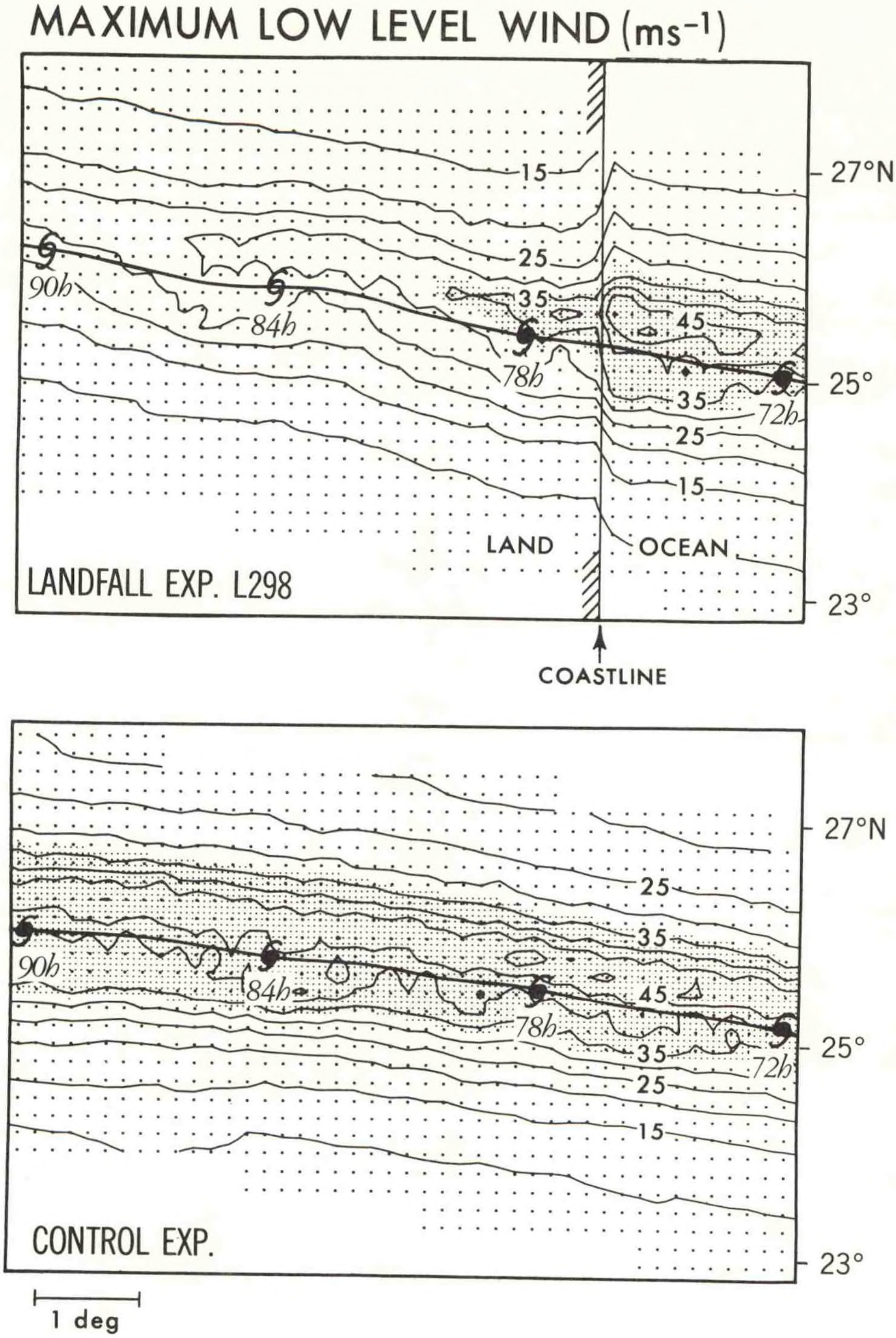


Fig. 7.1-- Top: Horizontal distribution of maximum low level wind during the tropical storm passage for the primary basic landfall experiment (land surface temperature = 298K, SST = 302K). A storm track is shown with 6 hourly positions indicated. Shading indicates hurricane force winds (above 33 m/s). Land is located to the west of the indicated coastline and the dots indicate the fine mesh resolution of approximately 17 km at 25 N. Bottom : Same as Top, except for the ocean only experiment (SST = 302K).

analysis. It was found that the eddy kinetic energy within the eye is supplied by import from the eye wall regions as well as by the conversion from total potential energy. The obtained results were summarized in (549).

PLANS FY84

The hurricane landfall simulation study will continue with a new model to investigate the effect of topography on the landfall of hurricanes.

The paper on the transformation of easterly waves will be prepared and submitted for publication.

A study on the influence of quasi-stationary field on the storm genesis in the tropics may start.

7.2 EXPERIMENTAL HURRICANE PREDICTION

M. Bender R. Tuleya
Y. Kurihara

ACTIVITIES FY83

Testing has been continued on a numerical scheme to treat the open lateral boundary of a limited area primitive equation model. The scheme examined is basically similar to the one reported in (540).

The attempt has been made to devise an efficient scheme of model initialization.

PLANS FY84

Activities in the preceding year will continue. In addition, the selection of cases for experimental prediction may be made.

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 FRONTAL DYNAMICS

8.1.1 The Dynamics of Mesoscale Convective Systems (MCS)*

I. Orlanski R. Shaginaw
B. Ross K. Moore
L. Polinsky

ACTIVITIES FY83

A detailed analysis has been made of a three-dimensional numerical simulation of a frontal squall line (488,hh). The simulated squall line which develops along the front exhibits a dual updraft structure with low-level convergence near the nose of the front and mid-level convergence located a hundred kilometers to the rear at a height of 3 km. This configuration is very similar to one found by Ogura and Liou (1980) in their analysis of an Oklahoma squall line not associated with a cold front.

Analysis of the equations of motion within the convective zone of the mature squall line shows the diabatic heating to be closely balanced by adiabatic cooling due to vertical temperature advection. As a result, the only net warming within this region occurs as adiabatic heating in the clear air outside of the cloud zone.

A linear, two-layer dry model containing stable lower and unstable upper layers is shown to reproduce the dual updraft structure for certain low-level wind intensities without requiring microphysics. Also, for all wind conditions, this simple model produces convergence at the interface between the two layers. This suggests that the occurrence of a convergence maximum at the level of free convection should be a common feature of convectively unstable cloud systems.

A stability analysis of the narrow cold-frontal rainband has revealed a mechanism by which horizontal shear can organize the convection in the rainband into cells. Although the rainband is barotropically stable, the coupling between the convective activity and the shear results in an unstable mode with properties similar to the observed regularly spaced precipitation cores in the narrow cold-frontal rainband.

PLANS FY84

Simulation of the Pacific comma cloud and the mid-west summer mesoscale convective complex will be attempted.

Research will be completed on the development of cellular structure in frontal rainbands.

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* The term "Mesoscale Convective Systems" as used here refers to squall lines, comma clouds, supercell thunderstorm, mesoscale convective complexes, and other organized convective systems.

8.1.2 The Ocean Response to Mesoscale Atmospheric Forcing

I. Orlanski
L. Polinsky

ACTIVITIES FY83

Many processes have been proposed as possible forcing mechanisms for mesoscale oceanic variability. The present study (r) shows that atmospheric forcing can be an important source of mesoscale variability in the ocean. It was shown that the oceanic response is linearly proportional to the product of the time scale of the storm and its intensity. It also clarifies the point that, for storms with scales considerably smaller than the barotropic Rossby radius of deformation, the oceanic stratification and the horizontal extent of the storm are the only factors determining the penetration depth of the response. This result implies that the scale of the penetration depth, rather than the Rossby radius of deformation, characterizes the response.

8.1.3 Interaction of Fronts with Orography

W-D Chen
I. Orlanski

ACTIVITIES FY83

Research has been carried out to investigate the interaction of an atmospheric cold front with mountainous terrain. The cyclogenesis which develops on the downstream side of a ridge-type mountain barrier during frontal passage was intensively observed in the ALPEX field experiment which recently took place in the European Alps. Laboratory experiments have been performed to simulate this lee cyclogenesis using a two-layer fluid in a cylindrical rotating tank with a long ridge barrier on its lower surface. A heavier fluid was injected at the bottom center of the tank, filled with a lighter fluid, to produce an outward-moving, zonally symmetric front which encountered the ridge barrier. The interaction of this front and the bottom topography has been analyzed and compared with theory for various different experimental conditions.

PLANS FY84

This research will be completed during FY84.

8.2 MESO-ALPHA PREDICTABILITY

8.2.1 Initialization Impact for Nested Limited-Area Forecasts

I. Orlanski   K. Miyakoda*
D. Miller

ACTIVITIES FY83

Despite the improvement seen in recent years in the numerical prediction

* In cooperation with the Experimental Prediction Group

of most meteorological variables with the advent of more powerful computers and the introduction of nested limited-area models, no similar improvement has been seen in the prediction of quantitative precipitation. A research effort is underway to utilize a nested system of models to explore the impact of synoptic-scale initialization analyses upon the forecasting of both planetary-scale waves and quantitative precipitation.

An initial experiment was run, simulating the 48-hour period from 1200 GMT April 9 to 1200 GMT April 11 1979, during which a severe tornadic outbreak occurred in the vicinity of the Texas-Oklahoma border, but for which previous limited-area modeling attempts to simulate the large mesoscale features and precipitation fields had met with only limited success. Two cases were run in which both the global and limited-area models of the system were initialized either with standard, NMC-analyzed observations or with a specially analyzed dataset prepared at GFDL from an enhanced set of observations taken during the First Global GARP Experiment (FGGE).

The results show some improvement in the placement and orientation of the precipitation fields for the run initialized from the enhanced and presumably superior FGGE dataset. However, the coarse resolution of the global model induces uncertainties in the higher-resolution, interior model through the lateral boundary conditions, thereby producing imprecise predictions of mesoscale circulations that are primarily responsible for determining precipitation patterns.

PLANS FY84

Further investigation will be made of the impact of initial and boundary data on the simulation of mesoscale convective systems by meso-scale models.

8.2.2 Simulations with "Profiler" Initial Data

I. Orlanski
B. Ross

ACTIVITIES FY83

Numerical experiments have been carried out which indicate the sensitivity of a numerical simulation of an observed cold front to the use of spatially smoothed thermodynamic initial conditions. Moist and dry versions of the 48h control solution discussed in 8.1.1 (488,hh), were reinitialized after 24h with initial conditions which use exact velocity and velocity tendencies from the control but employ thermodynamic fields which are smoothed either horizontally (the original 60-km grid resolution was filtered to a resolution of 540 km) or vertically (the original 1-km vertical resolution was filtered to a 3-km grid spacing in the troposphere). A comparison of the resulting 24h dry simulations with the corresponding control indicates that the horizontally smoothed solution requires nearly 2 hours to approach the control solution while the vertically smoothed case is less disturbed initially and adjusts more rapidly. When moisture is present in the solution, the smoothing procedure disrupts the developing moist convection in the frontal zone, producing large temperature and velocity differences in this region over the entire 24h integration. In particular, the horizontal smoothing of the water vapor maximum occurring along the front drastically weakens the intensity of the frontal precipitation.

8.2.3 Boundary Data Experiments in Nested Limited-Area Models

I. Orlanski
D. Miller

ACTIVITIES FY83

Three basic problems may cause contamination of the solution obtained by nesting a fine into a coarse resolution model: (1) Long-lived mesoscale disturbances that are not resolved in the relatively-coarse outer model are lost to the limited-area solution. However, a well-conceived limited-area model should be able, after an adjustment time, to produce such features from the larger-scale baroclinic fields; (2) Any numerical scheme for prescribing lateral boundary conditions will be important and will therefore be a source of errors in the limited-area solutions. Various mathematical treatments may be used to reduce these errors, but moving the boundaries far away from the region of interest may provide the simplest short-term remedy; (3) Another source of mesoscale errors in the limited-area model is that the prescribed solution along the boundaries from the large-scale model contains the uncertainties of the large-scale solution. The nested model may then simulate mesoscale disturbances associated with the misplaced large scale patterns quite well but will still yield substantial local errors.

The experiment that has been performed here consists of switching the time-dependent boundary conditions from two spectral forecasts with NMC and FGGE initial conditions (as in 8.2.1) in the limited-area model. The analysis of the differences between the "switched" solution and the control will determine the effect of initial and boundary data in the limited-area solution. Preliminary results show that, in a nested-model system designed as described, lateral boundary conditions from the global forecast play a dominant role in determining the position and strength of the synoptic as well as mesoscale features in the limited-area solution after only a few hours of simulation time. Accurate prediction of the planetary-scale waves by the global model throughout the simulation period is thus of critical importance if any real benefit is to be gained from the enhanced resolution and more sophisticated physics of the limited-area model in the way of achieving a more accurate prediction of mesoscale features and precipitation patterns.

PLANS FY84

Analysis of the impact of boundary data in the nested solution will be continued.

8.3 MESO-BETA PREDICTABILITY

8.3.1 Sensitivity of Precipitation Forecast to Initial and Boundary Data

B. Ross

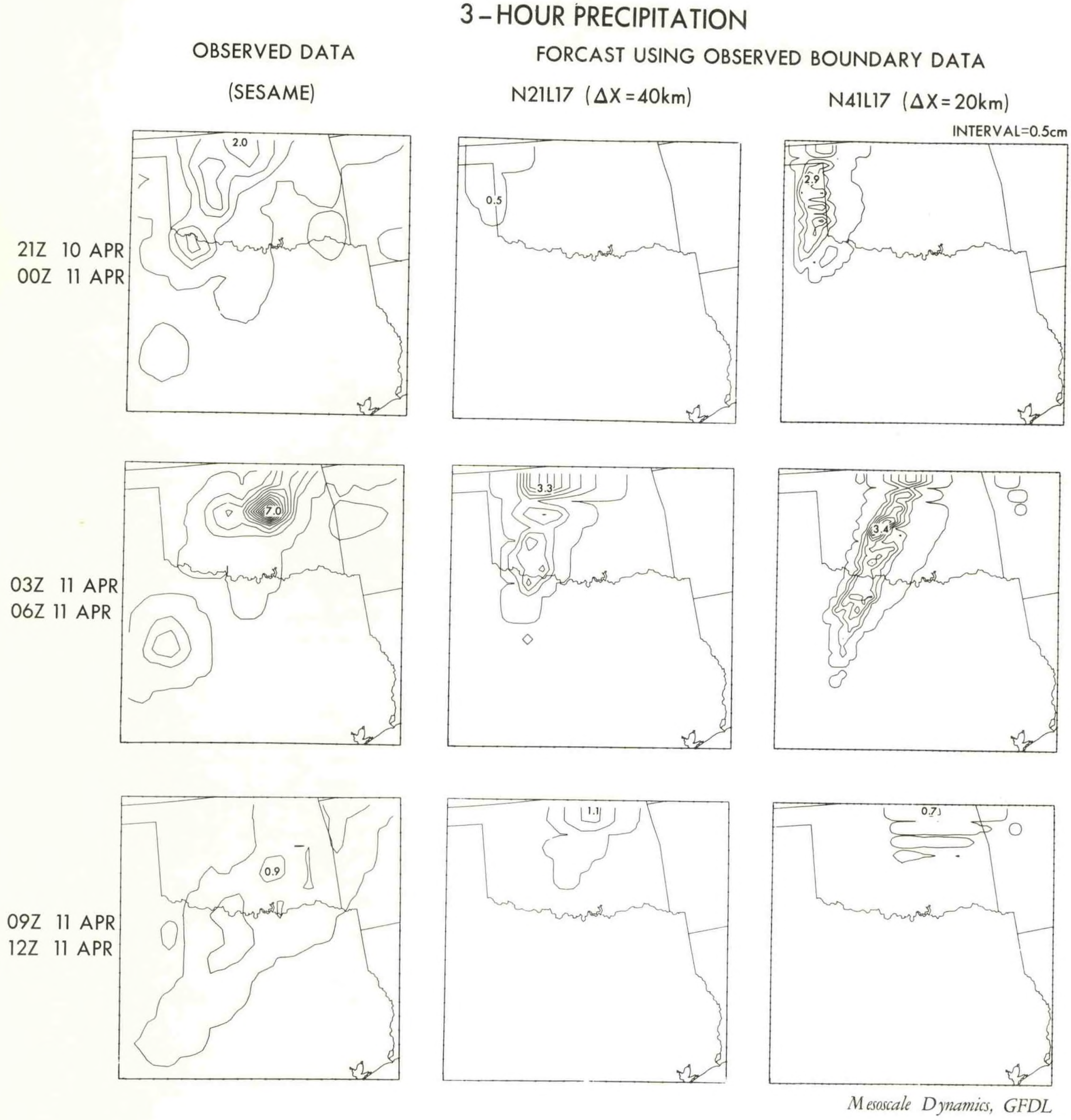

Fig. 8.1-- Comparison of 3-hour precipitation amounts over Oklahoma and Texas for different times during SESAME Day I, 12Z 10 April - 12Z 11 April 1979, as taken from observations (left column) and mesoscale model simulations with 40-km (center) and 20-km (right) grid resolution. Contour intervals are 0.5 cm with the maximum precipitation amount indicated in each frame.

ACTIVITIES FY83

An investigation has been made of the sensitivity of meso-β scale precipitation patterns to the specification of initial and boundary data in a nested grid model in which moist convection is represented explicitly. A beta-scale (BES) model, positioned over Oklahoma and north Texas, was used to predict the timing and location of precipitation during the SESAME I period of 12Z 10 April to 12Z 11 April 1979. Solutions which were obtained using initial and boundary conditions from a meso-α scale (MAC) model, were shown to produce increased mesoscale convective structure but did not alter the geographical location of the precipitation as predicted by the large-scale solution.

When higher resolution SESAME data for moisture and low-level temperature lapse rate was used in the meso-β solution, precipitation patterns were modified considerably but do not verify the observed precipitation for the period. However, when all SESAME data, including momentum and complete temperature fields, were used in the model initial and boundary conditions, the predicted precipitation showed good agreement with observations with regard to both location and time of occurrence, particularly when a 20-km grid-size was used (Fig. 8.1). The improved rainfall in the latter cases seems to be due primarily to proper representation of the formation and movement of the cold front which was observed to develop in this case but which was less intense at this time in the previous nested solutions and in numerical simulations reported by other investigators.

PLANS FY84

Further investigations will be made of the value of an explicit formulation of moist convection as a means of representing convective processes in a meso- scale model. Inclusion of a rainwater phase as well as other modifications such as consideration of precipitation efficiency will be incorporated in order to improve the performance of this parameterization technique.

An attempt will be made, in collaboration with the Convection Group, to nest a meso- scale cloud model within the meso-β scale solution.

8.4 MODEL DEVELOPMENT

B. Ross L. Polinsky
D. Miller I. Orlanski
R. Shaginaw

ACTIVITIES FY83

Both the MAC/BES and HIBU mesoscale models, together with the supporting analysis and initialization programs, have been converted to the CYBER 205. Extensive effort has been devoted to improving the I/O efficiency of the MAC/BES model in order to decrease its wall-clock execution time.

Modifications have been made to the three-dimensional mesoscale MAC/BES model to include the effect of rainwater in the explicit treatment of moist convection. The presence of a rainwater phase within the model simulation becomes more important in meso-β scale solutions because of the increased need at high resolutions to properly represent water loading within the precipitation cores of the cloud and evaporative cooling of rainwater beneath the cloud. Preliminary results show that the increased water loading due to rainwater decreases the intense precipitation rate which the higher resolution model produces. Studies in collaboration with the Convection Group have suggested ways in which the rainwater treatment can be improved.

Three-dimensional experiments have been performed to compare convective solutions which employ quasi-hydrostatic and hydrostatic approximations. Preliminary results show little difference between convective simulations using the different approximations when a grid size of 15 km or larger is used.

PLANS FY84

Further improvements will be made in the explicit representation of convection, in collaboration with the Convection Group.

Further tests will be performed using simulations of moist convection in which quasi-hydrostatic techniques are incorporated.

Efforts will be made to optimize the MAC/BES mesoscale model so as to improve central processor efficiency and reduce memory utilization.

Code modifications required to incorporate a body-force parameterization of topography in the MAC/BES model will be converted to the CYBER 205.

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

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

9.1 CONVECTION

R. Hemler
F. Lipps

ACTIVITIES FY83

At the beginning of this year the primary effort was devoted to converting numerical models and analysis routines from the TI-ASC to the CDC-CYBER 205 and making them run efficiently on the new computer. In addition, the deep moist convection model, initially adapted to simulate tropical maritime convection characteristic of the GATE area, was modified to simulate continental convection characteristic of the Central U.S. The basic structure of this numerical model is described in (516) and (303) with subsequent modifications in the Kessler-type bulk cloud physics and the subgrid-scale turbulence parameterization. For the continental convection the grid intervals are 1000 m in each horizontal direction and 500 m in the vertical. In all calculations the depth of the model is 17 km. For three-dimensional computations the horizontal domain is 48 km by 32 km while for two-dimensional computations the channel length is 64 km. The initial disturbance consists of a saturated bubble in the center of the horizontal domain and extending in the vertical from 1750 m to 4750 m. The maximum disturbance potential temperature is at 3250 m and is either 0.5 K or 1.0 K. For the present calculations periodic side boundary conditions are used.

Here the results are summarized for three-dimensional calculations with a unidirectional wind shear present. The maximum vertical velocity was slightly over 20 m/sec and the maximum rainfall at the ground was 1.5 cm which fell in one-half hour. The whole life history of the storm was approximately one hour. Due to the periodic side boundary conditions, no quasi-steady system could develop. When compared with the previously simulated GATE convection, the layer of downdraft outflow was deeper and cooler and the cloud efficiency E, defined as the ratio of the total rainfall reaching the ground to the total water vapor condensed, was less. The maximum surface cooling for the tropical maritime convection was about 2°C whereas for the present case the cooling is about 6°C. The cloud efficiency $E \simeq 0.4$ for the tropical case while present results give $E \simeq 0.26$.

Another set of three-dimensional calculations was carried out with the horizontal grid interval of 10 km in both directions and the horizontal domain of 480 km by 320 km. The purpose of these computations was to compare the results obtained with the present Kessler-type bulk cloud physics with the results obtained using the mesoscale parameterization (325) in which all cloud water in excess of 1.5 g/kg immediately falls out as rain. It was found that the scheme in (325) predicted point values of rain three times as large and area mean values twice as large as predicted using the Kessler-type scheme. Another effect of the mesoscale scheme is that about ten per cent of the total water vapor condensed remained in the atmosphere as high level clouds. For the Kessler-type scheme only two per cent remained as clouds. Collaboration is underway with the Mesoscale Dynamics Group to include a rain-water phase in the mesoscale model.

Preliminary experiments have been carried out to examine the mixing of a passive tracer due to deep moist convection. The initial distribution of tracer is a uniform concentration from the surface to 1750 m and no tracer above that level. Using the disturbance discussed above for continental convection, the tracer is mixed during the lifetime of the convection (about one hour). Calculations have been performed for two- and three-dimensional convection and with and without a unidirectional wind shear. In all cases a bimodal distribution of the horizontal mean tracer is found at the end of the calculations. The primary maximum of tracer concentration remains in the boundary layer, but a secondary maximum also exists at about 10 km, the level for the moist convective outflow. The minimum at mid-levels is well defined, being a factor of ten smaller than the upper level maximum with no wind shear present. This ratio is reduced to a factor of two for the three-dimensional case with wind shear. When shear is present, the subgrid scale turbulence plays a relatively more important role.

A new version of the moist convection model has incorporated open lateral boundary conditions in place of the previous periodic side conditions. For normal velocities a radiation condition* is used. For non-normal velocities and scalar variables, however, the more common inflow-outflow boundary conditions are applied; at inflow boundaries specification is used and at outflow boundaries extrapolation from the interior is used. For planned future calculations, the open boundary conditions will allow for more realistic simulations with vertical wind shear present.

Finally, the analyses of the tropical maritime simulations have been completed. A comparison of the simulated vertical velocities in regions of strongest updrafts and downdrafts (cores) has been made with observed GATE data. Reasonable agreement with observations is found, but somewhat better agreement is seen for updraft cores than downdraft cores.

PLANS FY84

A cooperative effort will be carried out with the Mesoscale Dynamics Group to simulate an observed case of deep moist convection on April 10, 1979. 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 vertical momentum transfer and kinetic energy transformation associated with the interaction of vertical wind shear and deep moist convection will be examined. Results obtained using the open lateral boundary conditions will be compared with data obtained using periodic side boundary conditions.

The passive tracer study will continue. Downward advection of tracer from the upper atmosphere due to convection will be examined in addition to the boundary layer source discussed above. The effect of water solubility will be included.

A primary objective of this research is to determine how moist convection acts to transfer water vapor, heat and momentum in the vertical as well as to

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* Orlanski, I., 1976: A simple boundary condition for unbounded hyperbolic flows. J. Comp. Phys., 21, 251-269.

account for precipitation and evaporation at the surface. A long-term goal is to use the knowledge gained from convection modeling to improve cumulus-scale parameterizations in mesoscale and larger-scale numerical models.

9.2 ATMOSPHERIC AND OCEANIC BOUNDARY LAYERS

J. Domaradzki B. Rajkovic
G. Mellor

ACTIVITIES FY83

A new closure hypothesis for the two-point triple correlation functions in homogeneous turbulence was investigated for the special case of isotropic turbulence (jjj). The results of theoretical calculations performed in an extensive Reynolds number range $50 < R < 10^4$ are in a good agreement with a variety of experimental data chosen for comparison. The new closure was used to demonstrate the influence of large scales of turbulence from beyond the experimental range on the decay of turbulence (kkk). The closure was used to develop a numerical model which will be used for description of decaying, weakly anisotropic, axisymmetric homogeneous turbulence.

Work on the extension of the turbulence closure model to include condensation physics and application to two-dimensional frontal dynamics problems has been restarted after a three year suspension of effort.

PLANS FY84

Work on the extension of the turbulence closure model will be continued.

9.3 COASTAL AND ESTUARINE OCEANOGRAPHY

G. Mellor L. Oey
D. Henn

ACTIVITIES FY83

Work was completed on the three-dimensional, real-time simulation of the Hudson/Raritan estuary. Comparisons of the numerical results with NOS observations and our own field observations (in cooperation with R. Hires of the Stevens Institute of Technology) have shown good agreement. Salt flux analyses at a number of key cross-sections in the estuary were completed and it is shown that the time-correlation term $\langle u_1 S_1 \rangle$, where the subscript 1 denotes the time deviation of the cross-sectionally averaged quantity and the angle brackets denote time averaging, contributes most to the upstream salt balance. Physically, this means that minimum salinity does not occur at the end of ebb, as one might intuitively assume. Rather, the phase angle between u_1 and S_1 is somewhat less than $\pi/2$ because some water is trapped in coastline bends and irregularities and is released at a different stage of the tide. The effects of local and coastal-shelf winds on the subtidal currents and elevations in the harbor have been analyzed. The unsteady winds were found to have magnitudes of about 0.5 dynes/cm^2 and periods of five, eight and twenty days. The winds correlate well with computed velocities and salinities, especially in the Raritan Bay where the depth is generally less than 4 meters. The winds were also found to contribute significantly to the upstream salt balance.

A high fresh-water discharge simulation of the estuary has also been completed and compard with the low discharge case (10 times less fresh water discharge rate). It is found that while high discharge increases buoyancy and hence stratification, it also increases the baroclinic velocity shear amplitude, giving values of the vertical mixing diffusivity coefficient not much different from the low-discharge simulation.

Previous theoretical analyses on steady salinity distribution and circulation in partially mixed and well-mixed estuaries have been further generalized. It is shown that Hansen and Rattray's theory for predicting the importance of upstream salt transport due to the vertical gravitational circulation in estuaries is valid for arbitrary longitudinal variations in width, depth, fresh water discharge, wind stress and various dispersion and mixing coefficients. This finding is checked against available observations in the Mersey estuary, in the channel of Rio Guayas and in the Hudson River. It is also checked against the previously described, real-time, three-dimensional numerical model's results in the New York harbor. This theoretical study has been submitted and accepted for publication in the Journal of Physical Oceanography (hhh).

A two-dimensional, depth-integrated nested model of the Delaware River, bay and the adjoining continental shelf has been constructed to study the tidal hydraulics in the region. The numerical results compared well with observations. A model of the surrounding marshes in the bay has been incorporated into the numerical program to take account of the rather complex variations in the observed phase lines with varying degree of success. This study constitutes D. Henn's master of science thesis in the Mechanical and Aerospace Department.

PLANS FY84

A three-dimensional model of the Delaware estuary will be completed. Studies will be focussed on the interaction of the water circulation between the continental shelf and the bay. The three-dimensional model should give better representation of the bottom friction and the resulting tidal phase prediction will be compared with the simpler, two-dimensional results.

APPENDIX A

GFDL Staff Members

and

Affliated Personnel

during

Fiscal Year 1983

Isidoro Orlanski, Acting Director	FTP
Rosemary Kelly-Champ, Secretary	FTP
Alan R. Thomas, Associate Director	FTP
Joyce C. Jarvis, Secretary	PTP
Joseph Smagorinsky, Director	FTP*
Howard M. Frazier, Assistant Director	FTP*

CENTRALIZED SUPPORT SERVICES

Administrative and Technical Support

Fraulino, Philip	Librarian	PTP
Shaffer, Daryl	Administrative Officer	FTP
Byrne, James	Jr. Technician	FTP
Capasso, Elaine	Administrative Clerk	FTP
Tunison, Philip	Sr. Technician	FTP
Ellis, William	Sr. Technician	FTP
Raphael, Catherine	Jr. Technician	PTP
Zadworney, Michael	Jr. Technician	FTP
Uveges, Frank	Actg. Admin. Officer	FTP
Chandler, Annette	Secretary	WAE
Conner, John	Sr. Technician	FTP
Kennedy, Joyce	Editorial Assistant	FTP
Pege, Joan	Management Support Clerk	FTP
Williams, Betty	Editorial Assistant	FTP

Computer Support

Welsh, James	Sr. Computer Sys. Analyst	FTP
Baker, Philip	Computer Sys. Analyst	FTP
Lewis, Lawrence	Computer Sys. Analyst	FTP
Shaginaw, Richard	Research Associate	FTP
Yeager, William	Computer Sys. Programmer	FTP
Conover, Leonard	Sr. Computer Technician	FTP
Bennett, Lois	Peripheral Equip. Opr.	FTP
Brandbergh, Gerald	Computer Technician	FTP
Brown, Gerald	Peripheral Equip. Opr.	FTT*
Cordwell, Clara	Computer Technician	FTP
Lydon, Cheryl	Peripheral Equip. Opr.	FTT*
Miller, Almore	Computer Technician	FTP
Heinbuch, Ernest	Sr. Computer Technician	FTP
Deuringer, Howard	Computer Technician	FTP
Hand, Joseph	Computer Technician	FTP
Kreuger, Mark	Computer Technician	FTP
Littell, Nancy	Peripheral Equip. Opr.	FTT*
Shearn, William	Sr. Computer Technician	FTP
Dattoli, Francis	Peripheral Equip. Opr.	FTP*

* Affiliation Terminated Prior to September 30, 1983

Henne, Ronald	Computer Technician	FTP
Henry, James	Peripheral Equip. Opr.	FTT*
Hopps, Frank	Computer Technician	FTP
King, John	Computer Technician	FTP
Mitman, Mark	Peripheral Equip. Opr.	FTP
Smith, Robert	Computer Technician	FTP
Taylor, Thomas	Computer Technician	FTP
Weltman, Richard	Peripheral Equip. Opr.	FTT*

* Affiliation Terminated Prior to September 30, 1983

CLIMATE DYNAMICS

Manabe, Syukuro	Sr. Research Scientist	FTP
Bowman, Kenneth	Student	PU
Fels, Stephen	Research Scientist	FTP
Crisp, David	Student	PU
Miyahara, Saburo	Visiting Scientist	PU
Schwarzkopf, M. Daniel	Research Associate	FTP
Hughes, John	Junior Fellow	PTT
Sneider, R.K.	Student	PU
Hahn, Douglas	Sr. Research Associate	FTP
Broccoli, Anthony	Research Associate	FTP
Daniel, Donahue	Research Associate	FTP
Hayashi, Yoshikazu	Research Scientist	FTP
Golder, Donald	Research Associate	FTP
Held, Isaac	Research Scientist	FTP
Nigam, Sumant	Student	PU*
Osinga, J.	Student	PU
Panetta, Richard	Visiting Scientist	PU
Sardeshmukh, Prashant	Student	PU*
Holloway, J. Leith	Sr. Research Associate	FTP
Phillipps, Peter	Research Associate	FTP
Spelman, Michael	Sr. Research Associate	FTP
Penik, Stephen	Junior Fellow	PTT
Stouffer, Ronald	Research Associate	FTP
Prettyman, William	Junior Fellow	PTT
Wetherald, Richard	Sr. Research Associate	FTP

MIDDLE ATMOSPHERE DYNAMICS AND CHEMISTRY

Mahlman, J.D.	Sr. Research Scientist	FTP
Bacmeister, J.T.	Student	PU
Graves, Denise S.	Student	PU
Levy, H. II	Research Scientist	FTP
Liu, S.C.	Visiting Scientist	+
Moxim, W. J.	Sr. Research Associate	FTP
Plumb, R.A.	Visiting Scientist	PU
Salby, Murry L.	Visiting Scientist	PU
Umscheid, Ludwig J.	Sr. Research Associate	FTP
Kranz, Christopher	Junior Fellow	PTT

\+ Aeronomy Laboratory/NOAA

* Affiliation Terminated Prior to September 30, 1983

EXPERIMENTAL PREDICTION

Miyakoda, Kikuro	Sr. Research Scientist	FTP
Gordon, Charles	Research Scientist	FTP
Vandenberghe, George	Research Assistant	FTP
Ploshay, Jeffrey	Research Associate	FTP
Rosati, Anthony	Research Associate	FTP
Sirutis, Joseph	Research Associate	FTP
Fork, David	Junior Fellow	PTT
Kinter, James	Student	PU
Navarra, Antonio	Student	PU
Pierrehumbert, Raymond	Assoc. Research Scientist	FTP
Carissimo, D.C.	Student	PU
Dritschel, David	Student	PU
Stern, William	Research Associate	FTP
Dilliplane, Steven	Junior Fellow	PTT*
Fine, Benjamin	Junior Fellow	PTT
Strickler, Robert	Sr. Research Associate	FTP
White, Robert	Research Associate	FTP
Wyman, Bruce	Research Associate	FTP
Puri, Kamal	Visiting Scientist	PU
Seller, Joseph	Visiting Scientist	+

OCEANIC CIRCULATION

Bryan, Kirk	Sr. Research Scientist	FTP
Bogue, Neil	NOAA Corps Officer	FTP
Cox, Michael	Sr. Research Associate	FTP
Hibler, William	Visiting Scientist	++
Komro, Fred	Research Associate	FTP
Reed, Kimberly	Junior Fellow	PTT
Jackson, Martha	Sr. Technician	FTP
Lemke, Peter	Visiting Scientist	PU*
MacAyeal, Douglas	Student	PU*
Philander, Samuel G.	Sr. Research Scientist	FTP
Carton, James	Student	PU*
Gardiner-Garden, R.S.	Student	PU
Greatbatch, Richard	Visiting Scientist	PU
Pacanowski, Ronald	Sr. Research Associate	FTP
Seigel, Anne	Research Associate	FTP
Yamagata, T.	Visiting Scientist	PU*

+ National Meteorological Center/NOAA

++ Cold Region Research and Engineering Laboratory/U.S. Army

* Affiliation Terminated Prior to September 30, 1983

PLANETARY CIRCULATIONS

Williams, Gareth	Sr. Research Scientist	FTP
Wilson, Robert	Research Assistant	FTT

OBSERVATIONAL STUDIES

Oort, Abraham	Sr. Research Scientist	FTP
Fagen, Scott	Junior Fellow	PTT
Forman, Mark	Junior Fellow	PTT
Huot, Jean-Paul	Student	PU*
Lau, Ngar-Cheung	Research Staff	PU
Levitus, Sydney	Sr. Research Associate	FTP
Peixoto, Jose	Visiting Scientist	+
Rosenstein, Melvin	Sr. Technician	FTP

HURRICANE DYNAMICS

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

MESOSCALE DYNAMICS

Orlanski, Isidoro	Sr. Research Scientist	FTP
Chen, Wen-Dar	Student	PU
Goldman, Samuel	Laboratory Tech.	PU*
Miller, Dennis	Research Associate	FTP
Moore, G.W. Kent	Student	PU
Polinsky, Larry	Research Associate	FTP
Ross, Bruce	Sr. Research Associate	FTP
Baum, John	Junior Fellow	PTT
Steele, Michael	Student	PU

CONVECTION AND TURBULENCE

Lipps, Frank	Research Scientist	FTP
Hemler, Richard	Research Associate	FTP
Mellor, George	Professor	PU
Domaradzki, J.A.	Visiting Scientist	PU*
Oey, Lie-Yauw	Research Staff	PU
Rajkovic, Borivoje	Student	PU

+ Geophysical Institute, University of Lisbon, Lisbon, Portugal

* Affiliation Terminated Prior to September 30, 1983

GFD PROGRAM

Sarmiento, Jorge	Professor	PU
Bryan, Frank	Student	PU
Callan, Johann	Secretary	PU
Gwinn, Elizabeth	Computer Programmer PT	PU*
Hellerman, Solomon	Computer Programmer PT	PU
Kawase, Mitsubiro	Student	PU
Key, Robert	Research Associate	PU
Neelin, J. David	Student	PU
Olsen, Esther	Secretary	PU
Papademetriou, Demetra	Student	PU
Prasad, Shailesh	Student	PU
Toggweiler, John	Visiting Scientist	PU

CONTROL DATA CORPORATION

J. Hannon, Sales Representative

Glassbrook, Richard A.	Project Leader	CDC
Feder, Michael	Analyst	CDC*
Graham, Donald	Senior Analyst	CDC*
Jacobson, Elaine	Senior Analyst	CDC
Lehane, Denis	Senior Analyst	CDC*
Mansfield, Harold	Senior Analyst	CDC
Reiff, Atara	Associate Analyst	CDC*
Siebers, Bernard	Senior Analyst	CDC
Skelly, Gretchen	Analyst	CDC*
Stringer, John	Analyst in Charge	CDC
Clark, David	Systems Analyst	CDC
Davis, Robert	Systems Analyst	CDC
Decker, Gregory	Consultant	CDC
Markowitz, Alan	Systems Analyst	CDC
Reiss, Israel	Systems Analyst	CDC
Helster, Paul	Senior Eng. in Chg.	CDC
Armbrister, Richard	Senior Customer Eng.	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
Weiss, Edward	Senior Customer Eng.	CDC

* Affiliation Terminated Prior to September 30, 1983

TEXAS INSTRUMENTS

Webb, William	Site Manager	TI*
Caldwell, Lee	Maintenance Engineer	TI*
Devlin, Thelma	Secretary	TI*
Fedor, John	Maintenance Engineer	TI*
Iasello, Anthony	Maintenance Engineer	TI*
Schaffer, Ralph	Maintenance Engineer	TI*
Smith, Mark	Maintenance Engineer	TI*

* Affiliation Terminated Prior to September 30, 1983

PERSONNEL SUMMARY

September 30, 1983

FTP - Full Time Permanent (GFDL)	83
PTP - Part Time Permanent (GFDL)	3
WAE - When Actually Employed (GFDL)	1
Junior Fellows (GFDL)	10
Visiting Scientists (PU)	10
Visiting Scientists (GFDL)	4
Students (PU)	21
Professors (PU)	2
Secretaries (PU)	2
Control Data Corporation Computer	
System Program Conversion Support	17
Staff	153

APPENDIX B

GFDL

Bibliography

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Director
Geophysical Fluid Dynamics Laboratory
Princeton University - Post Office Box 308
Princeton, New Jersey 08542

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BAER, Ferdinand	(131)
BAKER, Phillip L.	(110)
BANNON, Peter	(289)
BENDER, Morris	(355),(380),(434),(490),(540),(549),(ff)
BLUMBERG, Alan F.	(229),(279),(280),(281),(291),(292),(326),(338),(362),(371),(393)
BOLAND, F.E.	(a)
BOURKE, W.	(547),(c)
BOWMAN, Harold D. II	(204)
BOWMAN, K.P	(522)
BRIGGS, M.	(307)
BROECKER, W.S.	(523)
BROCCOLI, A.J.	(vv)
BRYAN, Kirk	(16),(20),(22),(36),(41),(47),(70),(71),(78),(80),(83),(85),(114),(139),(141),(207),(208),(228),(234),(253),(265),(334),(335),(350),(359),(360),(372),(375),(390),(484),(485),(491),(520),(554),(uu),(zz),(fff)
CARTON, J.A.	(f),(g)
CAVERLY, Richard	(547)
CERASOLI, Carmen	(241),(409),(454)
CHAN, Paul H.	(309)

APPENDIX C

Computational Support

APPENDIX C

Computational Support

FY82 saw the final stage of transition from the TI ASC to the CYBER 205 as the computational system for the Laboratory. The ASC was powered off in the middle of October 1982, completing eight years of steady service to the Laboratory.

The CYBER 205 finally passed acceptance testing on September 25, 1982. It also passed in December 1982 an increase in average daily availability from 20 hours to 21 hours.

The reliability of the CYBER 205 hardware has been generally good except for magnetic tapes and the link between the front-end 170 and the 205. The reliability of the CYBER 205 software, on the other hand, has been very disappointing. This past year has been largely occupied with identifying problems with the 205 software for CDC to repair. The implementation of user features has progressed at a slower than expected pace because of the many system problems that have been encountered as various purported capabilities are exercised.

FY84 will witness the delivery of a second 205 and, hopefully, more complete and reliable software from CDC.

TABLE C-1. Achieved CPU Hours for GFDL Systems

Month	TI/ASC	CYBER 170	CYBER 205
Sep 82*	466	204	**
Oct 82	294	266	**
Nov 82	***	192	**
Dec 82	***	272	524
Jan 83	***	169	520
Feb 83	***	182	458
Mar 83	***	283	570
Apr 83	***	238	535
May 83	***	262	548
Jun 83	***	306	495
Jul 83	***	254	496
Aug 83	***	**	**
Sep 83	***	**	**

* Not reported in the FY 82 Annual Report

** Not available

*** The ASC was turned off in October 1982

TABLE C-2. Average Monthly ASC CPU Hours by Fiscal Year

Fiscal Year	CPU Hours per Month
1982	498
1981	551
1980	508
1979	513
1978	497
1977	523
1976	499

APPENDIX D

Seminars Given at GFDL

During Fiscal Year 1983

Seminars not in included in FY 82 Report

September 1, 1982	"Numerical Experiment with a Seven-level Primitive Equation Spectral Model" by Dr. Zheng Qinglin, Central Meteorological Bureau, Beijing, Peoples Republic of China
September 3, 1982	"Langrangian Mean Motions Forced by Planetary Waves" by Dr. Michiya Uryu, Department of Physics, Kyushu University, Kyushu, Japan
September 21, 1982	"Topics on Ice-Phase Microphysics-Dynamics Interaction" by Prof. Norihiko Fukuta, Department of Meteorology, University of Utah, Salt Lake City, Utah

FY 83

October 21, 1982	"Can We Assess the Impacts of Climatic Changes" by Dr. Jesse Ausubel, Climate Board, National Academy of Sciences, Washington, DC
October 25, 1982	"On the Variability of the Circulation in the Subtropical North Atlantic" by Dr. Friedrich Schott, Division of Meteorology and Physical Oceanography, University of Miami, Miami, Florida
October 26, 1982	"A Survey of Early Results of ALPEX" by Dr. R. T. Pierrehumbert, Geophysical Fluid Dynamics Laboratory
November 3, 1982	Sampling Theory for Asynoptic Satellite Observations" by Dr. M. L. Salby, National Center for Atmospheric Research, Boulder, CO
November 4, 1982	"Newest Results of Climate Measurements from Satellites Including Cloud Climatologies" by Dr. Thomas H. Vonder Haar Department of Atmolspheric Sciences, Colorado State University, Fort Collins, CO
November 5, 1982	"Drought Forecasting: Consequences and Responsibilities" by Dr. Michael J. Glantz, Environmental and Societal Impacts Group, National Center for Atmospheric Research, Boulder, CO
November 9, 1982	"Structure and Energetics of Mid-Latitude Disturbances Associated with Cold Air Outbreaks over Eastern Asia" by Dr. N.-C. Lau, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ

November 12, 1982	"Numerical Simulation of the Dynamics of the Saharan Mixing Layer" by Dr. Toby N. Carlson, College of Earth and Mineral Sciences, Department of Meteorology, The Pennsylvania State University, University Park, PA
November 16, 1982	"The Potential Enstrophy Budget of Tropospheric Stationary Waves" by Dr. Isaac M. Held, Geophysical Fluid Dynamics Laboratory
November 19, 1982	"Observations of Wave-Mean Flow Interaction in the Southern Hemisphere Stratosphere" by Dr. Carlos R. Mechoso, Department of Atmospheric Sciences, University of California, Los Angeles, CA
November 23, 1982	"Influence of the CLIMAP Ice Sheet on the Climate of a General Circulation Model" by Anthony J. Broccoli, Geophysical Fluid Dynamics Laboratory
November 23, 1982	"Climate Simulations with a Simple Atmosphere-Ocean Energy Balance Model" by Prof. Erik Eliasen, University of Copenhagen, Institute for Theoretical Meteorology, Copenhagen, Denmark
November 29, 1982	"Dynamics of the Equatorial Middle Atmosphere" by Dr. Timothy J. Dunkerton, Physical Dynamics, Inc., Bellevue, WA
November 30, 1982	"Effects of Wave-Wave Interaction on Transient Planetary Waves" by Dr. Yoshikazu Hayashi and Mr. Donald G. Golder, Geophysical Fluid Dynamics Laboratory
December 7, 1982	"Two-point Turbulence Closure Model" by Dr. J. A. Domaradski, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
December 7, 1982	"Frequency Dependence and Lag Correlation of Teleconnection Pattern" by Dr. Maurice Blackmon, National Center for Atmospheric Research, Boulder, CO
December 8, 1982	"The Simultaneous Use of Tracers for Ocean Circulation Studies" by Prof. Bert Bolin, Department of Meteorology, University of Stockholm, Stockholm, Sweden
December 10, 1982	"Orographically Disturbed Wind and Pressure: Theory and Convection" by Dr. Ronald B. Smith, Department of Geology and Geophysics, Yale University, New Haven, CT
December 14, 1982	Variation of Cloud Cover in Response to Changes of Various Model Climates" by Mr. R. T. Wetherald, Geophysical Fluid Dynamics Laboratory
December 14, 1982	"Experimental Study on Stratospheric Gravity Waves" by Prof. O. Talagrand, Laboratoire de Meteorologie Dynamique, Paris, France

December 17, 1982	"Seasonal Snow Cover and the Atmospheric Circulation in the Northern Hemisphere" by Dr. John Walsh, Department of Atmospheric Sciences, University of Illinois at Urbana-Champaign, Urbana, IL
January 5, 1983	"Observed Relationships Between Extra-Tropical Circulations and Tropical Convectin at Low Frequencies" by Dr. Ennis L. Hartmann, University of Washington, Department of Atmospheric Sciences, Seattle, WA
January 14, 1983	"Estimates of Arctic Ocean Circulation from Sea-Ice Motion" by Dr. Alan S. Thorndike, Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, WA
January 27, 1983	"Statistical Dynamical Modeling of Large-Scale Atmospheric Flows" by Mr. Siegfried Schubert, Meteorology Department, University of Wisconsin, Madison, WI
February 4, 1983	"The Analysis of Upper-Level and Surface Fronts from the BAO Tower and Platteville-Denver Profiler System" by Dr. M. A. Shapiro, Cooperative Institute for Research and Environmental Sciences (CIRES), Boulder, CO
February 8, 1983	"Observations and a Simple Model of Multiple Vortices in Tornadoes" by Mr. David Dritschel, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
February 15, 1983	"The Formation of Comma Vortices in a Tropical Numerical Simulation Model" by Mr. Robert E. Tuleya and Dr. Yoshio Kurihara, Geophysical Fluid Dynamics Laboratory
February 22, 1983	"Stratospheric and Mesospheric Kelvin Waves Simulated by the "SKY HI" Model, by Dr. Yoshikazu Hayashi, Mr. Donald Golder, and Dr. Jerry Mahlman, Geophysical Fluid Dynamics Laboratory
March 1, 1983	"Evidence for Equatorial Models in Nimbus-7 LIMS" by Dr. Murry Salby, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
March 1, 1983	"Small-Scale Structure of the Taylor-Green Vortex" by Prof. Steven A. Orszag, Department of Applied Mathematics, Massachusetts Institute of Technology, Cambridge, Mass.
March 3, 1983	"NOAA Satellite Detection of the El Chichon Eruptions and Stratospheric Cloud" by Mr. Michael Matson, NOAA/National Earth Satellite Service
" " "	"Optical Thickness Measurements of El Chichon Aerosol from NOAA-7 AVHRR Data" by Mr. Larry L. Stowe, NOAA/NESS

March 3, 1983	"The Effect of El Chichon on Sea Surface Temperatures and Their Measurements by NOAA-AVHRR by Mr. Alan E. Strong, NOAA/NESS
March 4, 1983	"V-States: Steady Solutions of the Euler Equations and Their Stability and Nonlinear Evolution" by Prof. Norman L. Zabusky, Dept. of Mathematics and Statistics, University of Pittsburgh, Pittsburgh, PA
March 8, 1983	"Simple Ice Sheet Models" by Mr. K. Bowman, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
March 11, 1983	"Mixed Layer Models of the North Sea" by Dr. H. Friedrich Institute fur Meereskunde, Hamburg University, Hamburg, Republic of West Germany
March 15, 1983	"Eliassen-Palm Diagnostics of Wave, Mean-Flow Interaction in the "SKYHI" Model" by Drs. D. Andrews, J. Mahlman, and Mr. R. Sinclair, Geophysical Fluid Dynamics Laboratory, Princeton, NJ
March 15, 1983	"New Insights on the Thermocline" by Dr. Joseph Pedlosky, Woods Hole Oceanographic Institution, Woods Hole, MA
March 24, 1983	"A Diagnostic, Ice Covered Ocean Model" by Dr. W. Hibler, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH
March 25, 1983	"SST Anomalies and U.S. Summer Climate" by Prof. P. Handler University of Illinois at Urbana-Champaign, College of Engineering, Coordinated Science Laboratory, Urbana, IL
March 29, 1983	"The Relationship Between Convective Adjustment, Hadley Circulation and Normal Modes of the ANMRC Spectral Model by Dr. Kamal Puri, Geophysical Fluid Dynamics Program, Princeton University
March 29, 1983	"Internal Baroclinic Instability" by Dr. Ian James, University of Reading, United Kingdom
April 5, 1983	"Stationary Waves in Linear and Nonlinear Models" by Mr. James L. Kinter, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
April 7, 1983	"Practical Use of Hamilton's Principle in Oceanography and Meteorology" by Prof. Richard Salmon, Scripps Institution of Oceanography, University of California, San Diego, CA
April 19, 1983	"Statistical Prediction of Sea Ice" by Dr. Peter Lemke, Geophysical Fluid Dynamics Program, Princeton University

April 21, 1983	"Structure and Life Cycle of Mesoscale Convective Systems in the Tropics and Mid-Latitudes" by Dr. Edward J. Zipser, Convective Storms Division, National Center for Atmospheric Research, Boulder, CO
29 April 1981	"Are Glaciation Cycles Predictable?" by Prof. Michael Ghil, Courant Institute of Mathematical Sciences, New York University, New York, NY
3 May 1983	"Numerical Simulation of the Landfall of Tropical Cyclones" by Messrs. M. Bender and R. Tuleya, and Dr. Y. Kurihara, Geophysical Fluid Dynamics Laboratory
5 May 1983	"Chemical Dynamics in the Amazon Estuary" by Prof. R.F. Stallard Princeton University, Princeton, NJ
10 May 1983	"Tides in the Venusian Atmosphere" by Dr. Stephen B. Fels, Geophysical Fluid Dynamics Laboratory
17 May 1983	"Dynamics of Narrow Cold Frontal Rainbands" by Mr. K. Moore, Geophysical Fluid Dynamics Program, Princeton University
19 May 1983	"Weather on Venus: Continuing Observations by Pioneer Venus Spacecraft" by Dr. William B. Rossow, NASA Goddard Institute for Space Studies, New York, NY
20 May 1983	"Modeling of Warm Core Rings: Their Structure, Motion and Radiation Fields" by Dr. Glenn R. Flierl, Massachusetts Institute of Technology, Cambridge, Mass.
24 May 1983	"Effect of Baroclinic Eddies on the Zonal Mean Flows" by Dr. Yoshikazu Hayashi, Geophysical Fluid Dynamics Laboratory
26 May 1983	"The Onset of the Asian Summer Monsoon and Tibetan Heat Sources" by Prof. Mishio Yanai, University of California, Los Angeles, Dept. of Atmospheric Sciences, Los Angeles, CA
31 May 1983	"Continuous Assimilation System Used for Processing FGGE Data" Messrs. W.F. Stern and J. Ploshay, and Dr. K. Miyakoda, Geophysical Fluid Dynamics Laboratory
7 June 1983	"Soaring the Mountain Wave" by Dr. Murry Salby, Geophysical Fluid Dynamics Program, Princeton University, Princeton, NJ
7 June 1983	"Isentropic Trajectories and Regional Scale Transport Modeling of SEAREX Data by Dr. John Merrill, University of Rhode Island
9 June 1983	"Stratospheric Circulation Research at Goddard" by Dr. Marvin A. Geller, NASA/Goddard Space Flight Center, Greenbelt, MD

17 June 1983	"Climate Model Response to the El Chichon Volcanic Eruption" by Dr. Alan Robock, University of Maryland, College Park, MD
24 June 1983	"Weakly Nonlinear Theory of Vacillation" by Dr. A. Barcilon, Florida State University, Tallahassee, FL
28 June 1983	"Recent Research Activities at the European Centre" by Dr. D.M. Burridge, Head, Research Department, European Centre for Medium Range Weather Forecasts, Reading, Berkshire, United Kingdom
29 June 1983	"Coastal Wave Measurements off Japan" by Prof. M. Kubota, Tokai University, Japan
21 July 1983	"Numerical Experiments in Mesoscale Prediction in the Australian Region" by Dr. Lance Leslie, Australian Numerical Meteorological Research Centre/CSIRO, Melbourne, Australia
9 August 1983	"A Simple Diagnositic Model for the 30-50 day Oscillation in the Tropics" by Drs. T. Yamagata, Geophysical Fluid Dynamics Program, Princeton University, and Y. Hayashi, Geophysical Fluid Dynamics Laboratory

APPENDIX E

Talks, Seminars, and Papers Presented Outside GFDL

During Fiscal Year 1983

TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL DURING FISCAL YEAR 1983

Not included in FY 82 Report

September 13, 1982	Dr. Murry L. Salby "Sampling Theory for Asynoptic Satellite Observations" at the International Symposium on Remote Sensing and Data Interpolation, Toulouse, France
September 16, 1982	Dr. Murry L. Salby "Synoptic Field Retrieval from Asynoptic Satellite Observations" at the International Symposium on Remote Sensing and Data Interpolation, Toulouse, France
September 17, 1982	Dr. Murry L. Salby "Sampling Considerations for Asynoptic Satellite Measurements" at the Institut Spatiale d'Aeronomie, Brussels
September 20, 1982	Dr. Murry L. Salby "Sampling Considerations for Asynoptic Satellite Measurements" at the British Meteorological Office, Berkshire, Reading, UK
September 21, 1982	Dr. Syukuro Manabe "Influence of Ocean's Heat Transport on the Sensitivity of Climate" at the Department of Energy CO_2 Research Conference Berkley Springs, WV
September 27, 1982	Dr. Hiram Levy II "Research Needs in Tropospheric Ozone" at the 1st Meeting of Global Tropospheric Chemistry Panel, West Greemwich, RI
September 27, 1982	Dr. Kikuro Miyakoda "Large-Scale Weather Systems - Modeling" at Weather Observation and Prediction Research Review Meeting, Boulder, CO

FY 83

October 12, 1982	Dr. Isidoro Orlanski "The Effect of Initial and Boundary Data in Mesoscale Forecasts" at the National Meteorological Center, Camp Springs, MD
October 14, 1982	Dr. Yoshio Kurihara "On the Genesis of Typhoons" at the Japan Meteorological Agency, Tokyo, Japan
October 15, 1982	Dr. Yoshio Kurihara "Typhoons - Prediction and Numerical Experiments" at the Electronic Computation Center, Japan Meteorological Agency, Tokyo, Japan

October 15, 1982	Dr. Stephen B. Fels "Tidal Forcing and the Circulation of the Venus Mesosphere" at the University of Reading, Reading, UK
October 18, 1982	Mr. James L. Kinter, III "A Numerical Study of Planetary Scale Waves and the Blocking Phenomenon Using Barotropic Models" at the 7th Climate Diagnostics Workshop, National Center for Atmospheric Research, Boulder, CO
October 18, 1982	Dr. Yoshio Kurihara "On a Mechanism of the Genesis of Tropical Storms" at the Regional Scientific Conference on Tropical Meteorology, Tsukuba, Ibaraki, Japan
October 18, 1982	Dr. Kikuro Miyakoda "Anomaly Model Using a Baratropic Vorticity Equation" at the Climate Diagnostic Workshop, Boulder, CO
October 20, 1982	Dr. Kirk Bryan "The Ocean as a Climatic Buffer" at the Department of Earth Sciences, Massachusetts Institute of Technology, Cambridge, MA
October 21, 1982	Dr. Stephen B. Fels "Radiative Damping in the Terrestrial Middle Atmosphere" at Oxford University, Department of Atmospheric Physics, Oxford, UK
October 21, 1983	Mr. Douglas MacAyeal "Ocean Currents Below the Ross Ice Shelf" at the Institute of Polar Studies, Ohio State University, Columbus, OH
October 27, 1982	Dr. J. D. Mahlman "Atmospheric Physics and Chemistry: Some Major Environmental Issues" at the Science Awareness Seminar, "Scientist Meets Science Teacher", Princeton University, Princeton, NJ
October 28, 1982	Prof. George L. Mellor "Mixed Layer Modeling" at a workshop on Weather Modification, Cesarea, Israel
October 29, 1982	Mr. Douglas R. MacAyeal "Tidal Rectification Below the Ross Ice Shelf" at the Institute for Quarternary Studies and Department of Physics and Astronomy, University of Maine, Orono, ME
November 4, 1982	Dr. Hiram Levy II "Tropospheric O_3: Who Needs Photochemistry?" at Harvard University, Center for Planetary Sciences, Cambridge, MA
November 9, 1982	Dr. J. D. Mahlman "A Conceptual View of Stratospheric Transports" at the U.S.-Japan Seminar on Middle Atmospheric Dynamics, Honolulu, HI

November 10, 1982	Mr. Douglas R. MacAyeal "Tidal Rectification and Tidal Front Formation Below the Ross Ice Shelf" at the Lamont-Doherty Geological Observatory, Columbia University, Palisades, NY
November 11, 1982	Dr. J. D. Mahlman "Some Conceptual Difficulties with the Transformed Eulerian Equations at the U.S.-Japan Seminar on Middle Atmospheric Dynamics, Honolulu, HI
November 12, 1982	Dr. J. D. Mahlman "The Circulation of the Winter Polar Stratosphere: Problems of Modeling" at the U.S.-Japan Seminar on Middle Atmospheric Dynamics, Honolulu, HI
November 17, 1982	Dr. J. D. Mahlman "Global Atmospheric Modeling from the Ground to the Mesopause" at the Institute for Atmospheric Physics, Academia Sinica, Beijing, Peoples Republic of China
November 17, 1982	Dr. Stephen B. Fels "Radiative Damping in the Terrestrial Middle Atmosphere" at the European Centre for Medium Range Weather Forecasting, Reading, UK
November 18, 1982	Dr. Stephen B. Fels "Radiative Damping in the Terrestrial Middle Atmosphere" at the Imperial College, London, UK
November 18, 1982	Dr. J. D. Mahlman "Dynamics of Atmospheric Tracer Transports" at the Institute for Atmospheric Physics Academia Sinica, Beijing, Peoples Republic of China
November 23, 1982	Dr. Kirk Bryan "The Ocean as a Thermal Buffer in Climate" at the Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA
November 29, 1982	Mr. Douglas R. MacAyeal "Tidal Rectification and Tidal Front Formation Below the Ross Ice Shelf" at the Department of the Geophysical Sciences, University of Chicago, Chicago, IL
November 30, 1982	Dr. Isaac M. Held Interhemispheric Interaction and the Southern Hemisphere's Response to Insolation Anomalies" at the Milankovitch and Climate Symposium, Lamont-Doherty Geological Observatory, Palisades, NY

November 30, 1982	Dr. Hiram Levy II "The Role of Precipitation Scavenging and Dry Deposition in a General Circulation/Transport Model of Tropospheric Chemistry" at the Fourth International Conference on Precipitation, Scavenging, Dry Deposition and Resuspension, Los Angeles, CA
December 1, 1982	Mr. Kenneth P. Bowman "Snowfall Parameterizations in Energy Balance Models and Ice Sheet Size" at the Milankovitch and Climate Symposium, Lamont-Doherty Geological Observatory, Palisades, NY
December 2, 1982	Mr. Anthony J. Broccoli "Influence of the CLIMAP Ice Sheet on the Climate of a General Circulation Model: Implications for the Milankovitch Theory" at the Milankovitch and Climate Symposium, Lamont-Doherty Geological Observatory, Palisades, NY
December 2, 1982	Dr. Syukuro Manabe "Influence of the CLIMAP Ice Sheet on the Climate of a General Circulation Model" at the Milankovitch and Climate Symposium, Lamont-Doherty Geological Observatory, Palisades, NY
December 3, 1982	Dr. Stephen B. Fels "Tidal Forcing and the Circulation of the Venus Mesosphere" at Cambridge University, Department of Applied Mathematics and Physics, Cambridge, UK
December 6, 1982	Mr. Douglas R. MacAyeal "Ocean Circulation Below the Ross Ice Shelf, Antarctica" at the Department of Geological Sciences, Brown University, Providence, RI
December 9, 1982	Mr. James G. Welsh "Supercomputers: Parallel and Vector Processors" at the Association for Computing Machinery, Princeton University, Princeton, NJ
December 13, 1982	Dr. Kikuro Miyakoda "Forecast Impact of Subgrid-Scale Parameterization in Global Models" at the Workshop on Impact of Cumulus Parameterization on Large-Scale Numerical Weather Prediction, Tallahassee, FL
December 14, 1983	Prof. George L. Mellor "Diagnostic and Prognostic Ocean Modeling" at the Joint US/ Australian Workshop on the Wind Driven, Transient Circulation on Continental Shelves, Monterey, CA
January 7, 1983	Mr. Douglas R. MacAyeal "Modeling the Flow of the Ross Ice Shelf" at the Standard Oil of Ohio, Arctic Research Group, Cleveland, OH

January 10, 1983	Dr. Kikuro Miyakoda "A Review of Dynamic Modeling Approaches to Short-Term Climate Prediction" at the Second Conference on Climate Variations, New Orleans, LA
January 11, 1983	Mr. Douglas R. MacAyeal "Ocean Circulation Below the Ross Ice Shelf: A Consequence of Tidal Rectification, Tidally-Induced Vertical Mixing and Basal Melting" at the Applied Physics Lab and the Joint Institute of Studies of the Atmosphere and Ocean, University of Washington, Seattle, WA
January 12, 1983	Mr. Douglas R. MacAyeal "Modeling the Deformation of the Ross Ice Shelf" at the University of Washington, Geophysics Program, Seattle, WA
January 12, 1983	Dr. S.G.H. Philander "Southern Oscillation/El Nino Phenomena" at Columbia University, Palisades, NY
January 14, 1983	Mr. Douglas R. MacAyeal "Ocean Circulation Below the Ross Ice Shelf: A Consequence Of Tidal Rectification, Tidally-Induced Vertical Mixing and Basal Melting" at CIRES/NCAR, University of Colorado, Boulder, CO
January 17, 1983	Mr. Douglas R. MacAyeal "Ocean Circulation Below the Ross Ice Shelf, Antarctica" at the Department of Meteorology, University of Wisconsin, Madison, WI
January 19, 1983	Dr. Stephen B. Fels "Effect of CO_2 Increase in the Middle Atmosphere" at the Royal Meteorological Society, London, UK
January 20, 1983	Dr. Stephen B. Fels "Tides in the Atmosphere of Venus" at Oxford University, Department of Atmospheric Physics, Oxford, UK
January 20, 1983	Mr. Douglas R. MacAyeal "Ocean Circulation Below the Ross Ice Shelf: A Consequence of Tidal Rectification, Tidally-Induced Vertical Mixing and Basal Melting" at Yale University, Department of Geology and Geophysics, New Haven, CT
January 27, 1983	Dr. Kikuro Miyakoda "Monthly Dynamical Prediction at GFDL" at the Climate Research Committee Meeting, Washington, DC
February 4, 1983	Dr. Syukuro Manabe "Numerical Modeling Studies of CO_2 Induced Climate Change" at Goddard Space Flight Center, Greenbelt, MD

. ebruary 8, 1983	Dr. S.G.H. Philander "El Nino/Southern Oscillation" at the Laboratory Oceanographic Physique, Paris, France
February 9, 1983	Dr. J. D. Mahlman "Some Research Recommendations for U.S. Participation in the Middle Atmospheric Program (MAP)" at the Meeting of the Interagency Working Group on the Middle Atmosphere Program (MAP), Washington, DC
February 14, 1983	Dr. Hiram Levy II "Tropospheric Modeling-Chemical Processes" by at NOAA Air Quality Bin Review Meeting, Rockville, MD
February 14, 1983	Dr. Kikuro Miyakoda "GFDL 4-Dimensional Analysis System" at the Design of Credible Simulation Studies Workshop, Washington, DC
February 15, 1983	Dr. Kamal Puri "Impact of FGGE Observing Systems on Numerical Weather Prediction in the Southern Hemisphere" at the Workshop on the Design of Credible Simulation Experiment, Washington, DC
February 25, 1983	Mr. Anthony J. Broccoli "The Influence of Continental Ice Sheets on the Climate of an Ice Age" at Rutgers University, Dept. of Meteorology and Physical Oceanography, Brunswick, NJ
March 3, 1983	Dr. Bruce B. Ross "Sensitivity of a Moist Front Simulation to Decreased Temperature/Water Vapor Resolution" at the Profiler Workshop Wave Propagation Laboratory, Boulder, CO
March 8, 1983	Dr. J. D. Mahlman "Tropospheric Modeling of Chemical Processes" at the Atmospheric Quality Research Review, NOAA Headquarters, Rockville, MD
March 14, 1983	Dr. Yoshio Kurihara "A Genesis Mechanism of Tropical Storms" at Florida State University, Tallahassee, FL
March 15, 1983	Dr. S.G.H. Philander "El Nino/Southern Oscillation Phenomena" at Harvard University, Boston, MA
March 16, 1983	Dr. Yoshio Kurihara "On the Formation of Tropical Storms" at NOAA Ad hoc Hurricane Committee Meeting, Hurricane Research Laboratory/NOAA, Coral Gables, FL

March 22, 1983	Prof. George L. Mellor "A Turbulence Closure Model with Application to Geophysical Fluid Problems" at Naval Post Graduate School seminar, Monterey, CA
March 22, 1983	Dr. Yoshikazu Hayashi "Nonlinear Energy Transfer of Transient Planetary Waves Simulated by GFDL Spectral Models" at the Fourth Conference on Atmospheric and Oceanic Waves and Stability sponsored by the American Meteorological Society, Boston, MA
March 22, 1983	Dr. Murry L. Salby (1) "Evidence for Equatorial Kelvin Modes in Nimbus-7 LIMS"; (2) "Transient Wave Response to Impulsive Latent Heat Release in the Tropical Convergence Zone"; (3) "Survey of Planetary-Scale Traveling Wave: The Current State of Observations and Theory" at the Fourth Conference on the Meteorology of the Upper Atmosphere sponsored by the American Meteorological Society, Boston, MA
March 22, 1983	Mr. Ludwig J. Umscheid "Modeling Seasonal Behavior of the Middle Atmosphere: Progress and Problems" at the Fourth Conference on the Meteorology of the Upper Atmosphere sponsored by the American Meteorological Society, Boston, MA
March 22, 1983	Dr. J. D. Mahlman "Eliassen-Palm Diagnostics of Wave, Mean-flow Interaction in the GFDL "SKIHI" General Circulation Model" at the Fourth Conference on the Meteorology of the Upper Atmosphere sponsored by the American Meteorological Society, Boston, MA
March 22, 1983	Dr. Raymond T. Pierrehumbert "A Simple Model of the Local Baroclinic Instability" at the Fourth Conference on Atmospheric and Oceanic Waves and Stability sponsored by the American Meteorological Society, Boston, MA
March 22, 1983	Mr. Marcel D. Schwarzkopf "Radiative Calculation of the Annual Cycle of Middle Atmosphere Temperatures and Winds" at the Fourth Conference on Meteorology of the Upper Atmosphere sponsored by the American Meteorological Society, Boston, MA
March 22, 1983	Dr. Isaac M. Held "On the Interaction of the Hadley Cell with Rossby Waves Forced in Mid-Latitudes" at the Fourth Conference on Atmospheric and Oceanic Waves and Stability sponsored by the American Meteorological Society, Boston, MA

March 22, 1983	Dr. Kirk Bryan "GFDL Research Connected with Satellite Oceanography" at the NOAA Satellite Oceanography Meeting, Washington, DC
March 24, 1983	Mr. Sumant Nigam "Linear & Quasi-linear Stationary Waves: Influence of a Critical Latitude" at the Fourth Conference on Atmospheric & Oceanic Wavaes & Stability sponsored by the American Meteorological Socety, Boston, MA
March 24, 1983	Mr. James L. Kinter, III "Topographically Forced Stationary Anomalies in Linear and Nonlinear Barotropic Models" at the seminar on Atmospheric Research and Climate, Canadian Climate Center, Downsview, Canada
April 11, 1983	Dr. Kirk Bryan "Evaluation of Altimeter Measurements from Models of the Ocean Circulation" at the Satellite Altimetry and Ocean Circulation Workshop, San Miniato, Italy
April 14, 1983	Dr. Toshio Yamagata "Numerical Simulation of Viscous Flows Past Right Circular Cylinders in a Rotating Frame" at Wyoming University, Laramie, WY
April 15, 1983	Dr. Toshio Yamagata "The Evolution of Intermediate-Geostrophic Eddies in Planetary Fluids" at the National Center for Atmospheric Research, Boulder, CO
April 18, 1983	Dr. Toshio Yamagata "The Evolution of Intermediate-Geostrophic Eddies in Planetary Fluids" at Scripps Institution of Oceanography, La Jolla, CA
April 19, 1983	Dr. J. D. Mahlman "Research Recommendations of the N.A.S. Panel on the Middle Atmosphere" at the Spring Meeting of the National Academy of Sciences Committee on Solar-Terrestrial Research, Washington, DC
April 22, 1983	Dr. J. D. Mahlman "Transport and Interhemispheric Circulation" at meeting on the Long-Term Atmospheric and Climatic Consequences of Nuclear War, Cambridge, MA
May 2, 1983	Dr. Ray T. Pierrehumbert (1) "Orographic Distortion of Fronts and its Role in Cyclogenesis"; (2) "Theory of Upstream Influence of Steep Mountains" at the Workshop on Cyclogenesis and the Alpine Experiment, Erice, Italy

May 2, 1983	Dr. Bruce B. Ross "Dynamics of Atmospheric Fronts: A Review" at US Department of Energy, Los Alamos National Laboratory, Los Alamos, NM
May 31, 1983	Mr. Michael D. Cox "A Numerical Model of the Subtropical Thermocline" at the American Geophysical Union Spring Meeting, Baltimore, MD
May 31, 1983	Mr. G.W. Kent Moore "On the Dynamics of the Narrow Cold-Frontal Rainband" at conference at Oklahoma University, Norman, OK
May 31 - June 4, 1983	Dr. Isidoro Orlanski Three lectures on "Theoretical Framework for Mesoscale Dynamics", and one lecture on "Numerical Modeling of the Mesoscale" at the Swedish Meteorological Institute, Norkopping, Sweden
June 1, 1983	Dr. S.G.H. Philander "Unstable Air-Sea Interactions" at the American Geophysical Union Spring Meeting, Baltimore, MD
June 1, 1983	Dr. Bruce B. Ross "Sensitivity of Meso-Beta Scale Precipitation Forecasts to Specification of Initial and Boundary Data" at the First Conference on Mesoscale Meteorology, Norman, OK
June 1, 1983	Mr. Dennis L. Miller "The Impact of Initialization Analyses in the Forecasting of Mesoscale Precipitation Patterns" at the First Conference on Mesoscale Meteorology, Norman, OK
June 6, 1983	Mr. Robert E. Tuleya "A Numerical Study of Simulated Hurricane Landfall" at the Sixth Conference on Numerical Weather Prediction, Omaha, NB
June 6, 1983	Mr. William Stern "An Assessment of GFDL's Continuous Data Assimilation System Used for Processing FGGE Data" at the Sixth Conference on Numerical Weather Prediction, Omaha, NB
June 7, 1983	Prof. George L. Mellor "Two Point Turbulence Closure and its Relevance to One Point Turbulence Closure" at Navel Post Graduate School seminar, Monterey, CA
June 7, 1983	Prof. Jorge L. Sarmiento "Thermocline Ventilation Processes Inferred from Oceanic Tracer Distributions" at NATO-ARI meeting, Yale University, New Haven, CT

June 7, 1983	Mr. Michael D. Cox "A Numerical Model of the Ventilated Thermocline" at Woods Hole Oceanographic Institution, Woods Hole, MA
June 7, 1983	Dr. Kikuro Miyakoda "Anomaly Model Using a Barotropic Vorticity Equation" at the Sixth Conference on Numerical Weather Prediction, Omaha, NB
June 8, 1983	Mr. Michael D. Cox "A Numerical Model of the Ventilated Thermocline" at the University of Rhode Island, Kingston, RI
June 19, 1983	Dr. S.G.H. Philander (1) "El Nino Southern Oscillation Phenomena" at the Institute of Atmospheric Physics, Beijing; (2) Coastal Oceanography" at the First Institute of Oceanography, Qingdao, Peoples Republic of China
June 21, 1983	Dr. S.G.H. Philander "El Nino/Southern Oscillation Phenomenon" at the University of Tokyo, Tokyo, Japan
June 23, 1983	Dr. Abraham H. Oort "Climate Variability During a Recent Decade" at the Department of Meteorology, Coloroda State University, Fort Collins, CO
June 27, 1983	Dr. Syukuro Manabe "The Influence of Continental Ice Sheets on the Climate of an Ice Age" at the symposium on Ice and Climate Modeling, Northwestern University, Evanston, IL
June 30, 1983	Mr. Ronald C. Pacanowski "A Numerical Model of the Annual Cycle in the Equatorial Atlantic Ocean" at a SEAQUAL Meeting in Boston, MA
July 5, 1983	Mr. R. T. Wethherald "A Review of CO_2 Induced Hydrologic Change" at the Meeting of Experts on Anthropogenic Climatic Change, Leningrad, USSR
July 8, 1983	Prof. Jorge L. Sarmiento "A Preliminary Model of the Role of Upper Ocean Chemical Dynamics in Determining Oceanic O_2 and Atmospheric CO_2 Levels" (Sarmiento and Toggweiler) at NATO ARI meeting - Chemical Dynamics of the Upper Oceans, Paris, France
July 19, 1983	Prof. George H. Mellor "A Geostrophic Calculation Scheme with no Reference Level Requirements" at Naval Post Graduate School seminar, Monterey, CA

July 25, 1973	Dr. Raymond T. Pierrehumbert "Passage of Fronts Across the Alps" at Yale University, New Haven, CT
July 26, 1983	Dr. S.G.H. Philander "El Nino/Southern Oscillation Phenomenon" at the National Aeronautics and Space Admin., Washington, DC
July 26, 1983	Dr. J. D. Mahlman "Global Dispersion and Removal of a Ground-Source Trace Contaminant" at the National Academy of Sciences Workshop on "Atmospheric Response to a Nuclear Exchange", Palo Alto, CA Exchange", Palo Alto, CA
July 26, 1983	Dr. S.G.H. Philander "El Nino Southern Oscillation Phenomena: Unstable Air-Sea Interactions Modulated by Seasonal Cycle" at the Goddard Space Flight Center, Greenbelt MD
July 29, 1983	Dr. Toshio Yamagata "The Evolution of Intermediate-Geostrophic Eddies in Planetary Fluids" at Florida State University, Department of Meteorology, Tallahassee, FL
August 1, 1983	Dr. Abraham H. Oort "Interhemispheric Comparisons Based on a 10-Year Global Data Set" at the First International Conference on Southern Hemisphere Meteorology, Sao Jose' dos Campos, Brazil
August 3, 1983	Dr. Kamal Puri "Assimilation Analysis and Data Impact in the Southern Hemisphere During SOP-2 Period FGGE" at the First International Conference on Southern Hemisphere Meteorology, Sao Jose' dos Campos, Brazil
August 8, 1983	Dr. Kirk Bryan "Climate Models for Stream 3" at the National Academy of Sciences Workshop on Global Observations and Understanding of the Oceans, Woods Hole, MA
August 9, 1983	Dr. Lie-Yauw Oey "Second Order Turbulence Closure and Estuarine Numerical Modeling" at the ASCE Conference, Massachusetts Institute of Technology, Cambridge, MA
August 10, 1983	Prof. Jorge L. Sarmiento "Tracers and Modeling" at the Workshop on Global Observations and Understanding of the General Circulation of the Oceans, Woods Hole Oceanographic Institution, Woods Hole, MA

August 11, 1983	Prof. George L. Mellor "Turbulence Closure and Estuarine Numerical Modeling at the ASCE Conference, Massachusetts Institute of Technology, Cambridge, MA
August 16, 1983	Dr. Isidoro Orlanski "Model Initialization" at the WMO Workshop on Very Short-Range Forecasting Systems Research Aspects, National Center for Atmospheric Research, Boulder, CO
August 19, 1983	Dr. R. Alan Plumb "Super-rotation in Planetary Atmospheres" at the IUGG/IAMAP General Assembly, Hamburg, Federal Republic of Germany
August 19, 1983	Dr. Murry L. Salby "Traveling Waves in the Stratasphere: Implications for Theory and Observations" at the IUGG/IAMAP General Assembly, Hamburg, Federal Republic of Germany
August 24-25, 1983	Dr. Isidoro Orlanski "The Influence of Nesting in Limiting Mesoscale Predictability" at the IUGG/IAMAP XVIII General Assembly, Hamburg, Federal Republic of Germany
August 24-25, 1983	Dr. Raymond T. Pierrehumbert (1) "Formation of Shear Layers Upstream of the Alps: Observations and a Theory"; (2) "Local Multiple Equilibria of the Barotropic Vorticity Equation" at the IAMAP/WMO Symposium on Maintenance of the Quasi-Stationary Components of the Flow in Atmospheric Models, Paris, France
August 26, 1983	Mr. Sumant Nigam "The Influence of a Critical Latitude on Topographically Forced Stationary Waves in a Barotropic Model" at the IUGG/IAMAP XVIII General Assembly, Hamburg, Federal Republic of Germany
August 26, 1983	Mr. James L. Kinter III "Numerical Simulation of Anomalous Stationary Waves in a Barotropic Atmosphere" at the IAMAP/WMO Symposium, Paris, France
August 29, 1983	Dr. Hiram H. Levy II "The Global Impact of Combustion NOx: A Preliminary General Circulation/Transport Study" at the CACGP Symposium on Tropospheric Chemistry, Oxford, UK
August 30, 1983	Dr. Ray T. Pierrehumbert "Towards a Physical Basis for Envelope Orography" at the IAMAP/WMO Symposium on Maintenance of the Quasi-stationary Components of the Flow in Atmospheric Models, Paris, France

August 30, 1983	Dr. R. Alan Plumb "The Interaction of Transient Eddies with the Time-Mean Flow" at the IAMAP/WMO Symposium on Maintenance of the Quasi-Stationary Components of the Flow in Atmospheric Models, Paris, France
August 30, 1983	Dr. Isaac M. Held "Review of Work with Barotropic Models of Quasi-Stationary Flows" at the IAMAP/WMO Symposium on Maintenance of the Quasi-Stationary Components of the Flow Atmospheric Models, Paris, France
August 30, 1983	Mr. Sumant Nigam "Linear and Quasi-linear Stationary Waves: Influence of a Critical Latitude" at the IAMAP/WMO Symposium on Maintenance of the Quasi-Stationary Components of the Flow in Atmospheric Models, Paris, France
August 31, 1983	Dr. Ngar-cheung Lau "The Structures of Stationary and Quasi-Stationary Flows in General Circulation Models and their Seasonal Dependence" at the First International Conference on Southern Hemisphere Meteorology, Sao Jose' dos Campos, Brazil
September 7, 1983	Prof. George L. Mellor "A Numerical Ocean Model" at the Fleet Numerical Ocean Center Monterey, CA

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