GEOPHYSICAL FLUID DYNAMICS LABORATORY

ENVIRONMENTAL RESEARCH LABORATORIES

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

ACTIVITIES - FY78
PLANS - FY79

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PREFACE

This document is intended to serve as a brief resume of the recent work of the Geophysical Fluid Dynamics Laboratory (GFDL) and to present a glimpse of the near-time future direction viewed through the research plans of the Laboratory.

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

The organization of the document encompasses a number of basic categories. The overview includes a measure of the scope of the Laboratory's efforts, some specialized highlights of the past year, and a perspective of future goals. In the body of the text are included specific recent achievements and future goals for the following major research categories: Climate Dynamics, Middle Atmosphere Dynamics and Chemistry, Experimental Prediction; Oceanic Circulation; Planetary Circulations; Observational Studies; Hurricane Dynamics; Mesoscale Dynamics; Convection and Turbulence. It should be emphasized that these categories are somewhat arbitrary and are far from being mutually exclusive. Interaction occurs among the various groups and is strongly encouraged.

The appendices contain the following: a list of GFDL staff members and affiliates during Fiscal Year 1978; a cumulative bibliography of research papers published by staff members and affiliates during their tenure with GFDL (these are referred to in the main body according to the appropriate reference number or letter); a description of the Laboratory's computational support and its plans for FY79; a listing of seminars presented at GFDL during Fiscal Year 1978; a listing of seminars and talks presented during Fiscal Year 1978 by GFDL staff members and affiliates at other locations.

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

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AN OVERVIEW

SCOPE OF THE LABORATORY'S WORK

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

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

- the predictability of weather, large and small scale;
- the particular nature of the Earth's atmospheric general circulation within the context of the family of planetary atmospheric types;
- the structure, variability, predictability, stability and sensitivity of climate, global and regional;
- the structure, variability and dynamics of the ocean over its many space and time scales;
- the interaction of the atmosphere and oceans with each other, and how they store and transport properties and trace substance and react to them.

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

SOME HIGHLIGHTS OF FISCAL YEAR 1978

The climatic effect of increasing CO_2-content in the atmosphere has been investigated using a simple general circulation model with limited computational domain, idealized geography, no seasonal variation and simplified cloud-radiation interaction. The general warming of the model atmosphere is accompanied by a change in regional climates, e.g., large gains in runoff rate in high latitudes, reduced wetness in a zonal belt of middle latitudes, and increased wetness along the east coast of subtropical portions of the model continent. These results underscore the urgency for investigating this problem with more realistic models.

A spectral climate model developed at GFDL simulates many of the large-scale features of climate. These simulations are competitive with those of GFDL finite-difference models of comparable resolution. Owing to the computational economy of the "semi-implicit" time integration incorporated in the model, it has now become possible to perform multiple-year integrations of a low resolution spectral model with moderate expenditures of computer time.

To study the generation of transient planetary waves in the tropics, controlled experiments have been conducted by eliminating, one by one, the effects of topography, mid-latitude disturbances and condensational heating from a general circulation model of the atmosphere. It is found that even if topography and mid-latitude disturbances are eliminated, both Kelvin and mixed Rossby-gravity waves appear in the model stratosphere due to the effect of latent heat release in the model troposphere. In contrast to Kelvin waves, however, mixed Rossby-gravity waves are significantly enhanced by mid-latitude disturbances.

The GFDL troposphere-stratosphere-mesosphere GCM was used in an experiment assuming a 50% reduction in the ozone amount. A significant result is that the dynamical response acts to increase the magnitude of the reversed meridional temperature contrast in the lower stratosphere by about 4-5°K. This result is opposite to that predicted from radiative-convective equilibrium models.

Various aspects of the anomalous North American weather events in January 1977 were studied. Using a model with differing sea temperature, land surface albedo, sea-ice heat conduction and cloud-radiation feedback, one-month forecasts were made, starting from January 1. So far, however, observed anomalies have not been successfully simulated by any of the model variants. It is suspected that the results are highly sensitive to the initial condition over the Pacific Ocean. Using an amalgamation of ship and satellite data, global charts of monthly mean sea surface temperature were constructed for the years of 1976 and 1977. From 700 mb atmospheric data, it appears likely that the cold Pacific water temperature was forced by the atmospheric conditions.

The construction of a spectral 18-level model which will be used for the FGGE implementation has been completed. The four-dimensional analysis includes diurnal variability and the inserted observed data is weighted according to the reliability of the observation.

An Antarctic circulation study now completed sheds light on many questions about peculiarities of the dynamics of the high latitude Southern Hemisphere atmosphere. The re-intensification of cyclones that travel south after being generated in mid-latitudes and the appearance of a local jet over Antarctica are a few of the points clarified.

A simplified, three-dimensional model correctly simulates the seasonal changes in currents indicated by surface drift measurements along the western boundary of the North Atlantic.

Studies of the GATE oceanographic data set indicate that there is a close relationship between seasonal changes in the Equatorial Atlantic and El Ñino phenomena in the Pacific. The difference in time scales is explained by the fact that the Atlantic is much smaller than the Pacific.

Tracer experiments with a new diagnostic ocean circulation model for the North Atlantic are able to simulate the main features of the entry of bomb-produced C^{14} and H^3 into the upper oceans, providing valuable insight into the buffering effect of the oceans for atmospheric CO_2.

Simulation of the Great Red Spot of Jupiter indicates that the feature can be described by quasi-geostrophic processes and is associated with the localized instability of an ultra-long baroclinic wave. Also, a new model for the Venus atmosphere revealed that the classical Hadley regime can indeed exist on a weakly rotating planet.

Construction of a three-dimensional movable nested mesh model ultimately to be used in hurricane studies is almost complete and the accompanying static and dynamic initialization schemes have been developed. In this model noise, which is inevitably excited by the mesh movement, is suppressed in a few minutes.

Eighteen hours integration of a fine mesh (60 km) mesoscale model fed by boundary variables obtained from a coarse (240 km) resolution model was completed. The results show minimal distortion at the boundary or elsewhere and are a step forward in an effort to develop a fine mesh predictive mesoscale model.

A numerical simulation of a three-dimensional dry thermal rising in a neutral environment has been completed using a simple subgrid-scale turbulence parameterization. The numerical results are in good agreement with the laboratory data of Scorer and Woodward for a self-similar thermal.

SOME IMMEDIATE OBJECTIVES

The sensitivity of regional, as well as global climate to the increase in CO_2 content in the atmosphere will be assessed using a coupled atmosphere-mixed layer ocean model with a global computational domain, realistic geography and seasonal variation of insolation. *** Long-term integrations of spectral climate models of about 10-years duration will be conducted to compare the interannual variability of the model climate and that of the actual climate. *** The basic causes for the variation of paleoclimate will be studied by subjecting a climate model to changes in the orbital parameters of the earth, in the distribution of continents, and in atmospheric composition. *** By use of a spectral general circulation model, a series of control experiments will be performed to study the effects of topography and condensational heat on the generation of large-scale atmospheric disturbances in the mid-latitude.

The N_2O 3-D tracer experiments will be completed and analyzed. These results will be input for an "odd nitrogen" experiment, a necessary precursor to a self-consistent ozone calculation. *** The middle atmosphere GCM work will emphasize improvement of model physics, effects of resolution, seasonal behavior, and sensitivity analysis.

A limited area model will be applied to several cases of "Genoa" cyclogenesis. The model will also be applied to the GATE area by nesting the limited area model within the global spectral model. *** Limited domain forecasts with the 34 km nested grid model will be produced for several cases over the United States.*** Prior to the beginning of FGGE IIIb data processing, revision of the assimilation and optimum interpolation system in the four-dimensional analysis will be made including: forward-backward assimilation, weighted insertion, vertical optimum interpolation, geostrophic insertion, water vapor insertion, correction of error covariance of satellite soundings, and more optimal blending of various types of insertion data. *** Forecasts of 1976-1977 sea surface temperature of the middle latitude North Pacific will be carried out with a mixed layer model, applied to different atmospheric forcings. This model provides for up/down-welling and lateral advection.

More tests will be carried out with the World Ocean model with prescribed boundary conditions, testing its properties for short-term climate variability studies and long-term climate equilibrium research. The resolution will be refined to provide a better simulation of equatorial upwelling. The effect of continental drift on ocean circulation will be examined with the prospect of final calculations with a coupled ocean-atmosphere model. *** In response to the NOAA and NORPAX field programs, a model study of the tropical Pacific will be initiated. A careful comparison of numerical experiments with similar models of the Atlantic and of an idealized rectangular basin will be made to isolate factors which lead to differences in seasonal and long-term variations in sea surface temperature currents. *** Tracer experiments will be continued introducing winter-time convection and a specification of tritium inflow from the Greenland Sea.

Analysis of the parametric variation of the quasi-geostrophic terrestrial regime will be completed. *** For Jupiter, further isolation of the circumstances under which the Great Red Spot occurs will be attempted from analysis of the simulated form. *** Further analysis of the first Venus experiment is planned. A second Venus experiment will examine the effect of introducing diurnal upper-atmosphere temperature variations into the relaxed state of the first experiment.

A comprehensive, pictorial description of the observed mean climate in the global atmosphere and its variability during the 1958-1973 period will be prepared for publication. Besides this more or less descriptive work, the main emphasis will be on a further understanding of the interannual variability at the various space-and-time scales. *** A comprehensive 3-dimensional description of the observed mean "climate" in the global oceans and its normal annual cycle will be prepared for publication. The main thrust of further oceanographic research will be toward the understanding of the spatial and seasonal variability, the determination of oceanic heat transports, and possibly some aspects of the year-to-year variability.

Simulation studies on the genesis of tropical depressions will continue. In addition to thermodynamical factors, dynamical effects such as the vertical and the horizontal wind shear will be taken into consideration. *** The construction of a nested grid model will be completed with the inclusion of the effects of surface friction and moisture. The model will then be utilized to investigate the effect of computational resolution on the movement of a vortex.

A major effort will be to complete the 36-hour simulation of a realistic frontal system by including moisture effects, boundary layer physics and Reynolds stresses in a 3-D model. *** Work on the generation, interaction and decay of cyclones at high latitudes will be completed after a comparison with observations. *** Work on the structure of the diurnal tide in the lower 10 km will be continued. *** The condition under which a saturation spectra for internal waves is achieved, and its relevance to the actual oceanic spectra, will be studied. *** The availability of potential energy in a stably-stratified fluid and its dynamics will be studied experimentally.

Numerical simulations for the dry thermal in a neutral environment will be made. *** Calculations for the warm rain cloud will be continued and the ability of the K-theory model to simulate deep moist convection with a vertical wind shear present will be tested. *** Three-dimensional calculations are planned for shallow, intermediate and deep moist convection.

A coastal ocean dynamics model is currently being applied to the Middle Atlantic Bight. An attempt to gather synoptic observations will get underway and a program using these observations to verify the model will proceed. Other plans include the study of coastal upwelling and shelf/slope interactions by means of a simplified version of the coastal model.

1. CLIMATE DYNAMICS

Objectives

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

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

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

* To evaluate the impact of human activities on climate.

1.1 OCEAN-ATMOSPHERE INTERACTION

This is a collaborative project between the Oceanic Circulation group and the Climate Dynamics group of the Geophysical Fluid Dynamics Laboratory.

ACTIVITIES FY78

A manuscript which describes the results from the long-term integration of the joint ocean-atmosphere model with seasonal variation of insolation has been completed during this fiscal year (m). It is shown that the joint model successfully simulates many characteristics of the seasonal variation of climate, including in particular, that of the thermal structure of the joint system. (See Section 1.1 of the report of the last fiscal year for further details of the simulation.) Comparison between results from the seasonal model and those from a model with annual mean insolation reveals that the seasonal variation of insolation prevents the excessive growth of sea ice and continental snow cover.

Encouraged by the success in simulating the seasonal variation of climate, which is mentioned above, it is planned to begin a series of numerical experiments described below.

PLANS FY79

Cretaceous climate. Geological evidence suggests that the climate of the Mesozoic era was much warmer than the modern climate. Many theories have been presented to explain this difference. For example, it has been suggested that the Mesozoic distribution of continents, which is markedly different from the present distribution, is responsible for the warm climate. In order to evaluate this hypothesis, it is planned to conduct a long-term integration of the joint ocean-atmosphere model which incorporates the land-sea distribution of the Cretaceous period. By comparing this Cretaceous climate simulation with the simulated modern climate, it is hoped to gain some insight into the relationship between climate and the geographical distribution of continents.

Variability of tropical climate. It has been suggested that the long-term variation of tropical climate results in part from the interaction between the ocean and the atmosphere. Therefore, it is of interest to determine whether the joint model described above can generate such a variation. For this purpose, a long-term integration of the joint model will be started during this fiscal year.

1.2 CO_2 SENSITIVITY STUDY

1.2.1 Simple Geography

ACTIVITIES FY78

Using the results from a simple general circulation model, the climatic effect of increasing the CO_2-content in the atmosphere has been investigated. The model (Sector model) has a pie-shaped computational domain which is bounded by two meridians and the Equator and occupies one third of a hemisphere. Half of this domain is occupied by continent and the other half is a wet swamp-like ocean with no heat capacity. One of the new features of this model is the simple radiation-cloud feedback described in Section 1.4. For the computation of solar radiation, annual mean insolation is assumed at the top of the atmosphere.

Preliminary results from this study were summarized in the report of the last fiscal year. As pointed out in that report, the response of the model climate to the doubling of CO_2-content is far from uniform geographically. For example, one can identify a high latitude region over the continent where the runoff rate increases markedly, a zonal belt of reduced wetness in middle latitudes, and a zone of enhanced wetness along the east coast of subtropical portions of the continent in the doubled CO_2 simulation.

It is found that the general warming and the increased moisture content of air in this simulation contribute to the large reduction in the meridional temperature gradient as a result of the following causes:

i) large increase in poleward transport of latent heat;
ii) poleward retreat of highly reflective snow cover.

The reduction in the meridional temperature gradient causes the reduction of eddy kinetic energy in the middle and lower model troposphere and accounts for the lack of increase in precipitation rate and the reduction of soil moisture over a zonal belt in middle latitudes. The penetration of moist air into higher latitudes of the CO_2-rich, warm climate is responsible for the large increase in the rates of precipitation and runoff in higher latitudes of the model. A manuscript describing the results from this study has been completed.

1.2.2 Realistic Geography

ACTIVITIES FY78

The model described above includes many simplifications, e.g., removal of seasonal variation and idealization of geography. Therefore, it is desirable to perform a CO_2-sensitivity study using a model without these simplifications.

During the last fiscal year, the major emphasis of this project was placed on the construction of the joint ocean-atmosphere model coupling a spectral atmosphere model (see Section 1.6) with a simple mixed-layer constant heat capacity ocean model. The model has a global computational domain with realistic geography. Seasonally varying insolation is imposed at the top of the model atmosphere. An economical method of time integration, which accelerates the convergence of the model state towards an equilibrium climate, has been developed and tested. Although the joint model developed here lacks heat transport by ocean currents, it is encouraging that the simulated climate contains many geographical features of the actual climate. It is hoped that this model will provide a preliminary insight into climate sensitivity before we proceed to a study with a comprehensive model of the joint ocean-atmosphere system.

PLANS FY79

Using the joint model described above, it is planned to determine the geographical distribution of the climatic response to an increase in CO_2-content in the atmosphere. In addition, the influence of the seasonal variation of insolation upon the sensitivity of the model climate will be investigated.

1.3 PALEOCLIMATIC STUDY

ACTIVITIES FY78

Among the possible causes of long-term changes in the Earth's climate, variation in atmospheric composition and variation in the Earth's orbital parameters are two of the strongest candidates.

The large value of the temperature difference between the present and certain earlier eras suggests that, if changes in composition were responsible, they must have been substantial. Therefore, an examination of the climatic effects of large compositional changes has been undertaken.

A study of the climatic effects of very high (3%) atmospheric CO_2 levels was begun by investigating the response of a radiative-convective equilibrium model to a hundredfold (100 X) increase. At these high concentrations, very weak lines normally ignored become important, especially the 10μm complex. Preliminary runs show a surface temperature increase of $\sim$ 14° due to the enhanced greenhouse effect. It is interesting to note that this increase is consistent with the rule of thumb that the temperature increase is linear in the log of the change in CO_2 mixing ratio.

PLANS FY79

The very strong temperature dependence of the 10μm intensities suggests that there may be important latitudinal radiative effects due to massive CO_2 increases, in addition to those due to interactions with dynamics and snow cover. These will be investigated by use of simple zonal heat balance models, and, if possible, by inserting the 100x radiative module into a simple general circulation model of the sector type.

We shall also be analyzing the responses of a hierarchy of simple climate models to variations in the earth's orbital parameters. If these responses can be related to the earth's "ice ages" (the Milankovitch theory), then the paleoclimatic record has within it a wealth of information on climatic sensitivity to precisely known changes in external parameters. Some calculations with a simple, diffusive energy balance model suggest that the Milankovitch theory has some validity. The parameter and model-dependence of these results, within the framework of simple energy balance models, will be analyzed. If these results prove promising, experiments with dynamic atmospheric models will be contemplated.

1.4 CLIMATIC EFFECT OF CLOUD

1.4.1 Cloud Simulation

ACTIVITIES FY78

An attempt has been made to simulate the large-scale distribution of clouds by use of a spectral climate model in which cloud cover is a prognostic variable. Since this is a preliminary study, the prognostic scheme for clouds is made as simple as possible. In this scheme, cloud cover is predicted whenever relative humidity is larger than a certain critical value, and clear sky is indicated when relative humidity is less than this critical value. Figure 1.4.1 illustrates the comparison of the geographical distribution of cloud cover generated by the model with that of the actual atmosphere. According to this figure, the model fails to reproduce low stratus clouds which cover the trade wind regions of both the western Atlantic and the western Pacific. However, it is encouraging that, despite the extreme simplifications contained in the prognostic system of cloud cover, the model successfully simulates some of the large-scale features of the observed cloud distribution.

PLANS FY79

It is planned to continue the analysis of the results from the global cloud simulation experiment in detail, to identify unrealistic features in the simulated distributions of cloud and radiation fluxes, and to attempt to determine the basic causes for these difficulties.

1.4.2 Determination of Global Cloud Distribution

ACTIVITIES FY78

It has been recogized that the available data on the distribution of clouds over the globe is incomplete. A diagnostic calculation of the global three-dimensional cloud distribution was carried out by using July climatology for total cloud amount, outgoing longwave radiation at the top of the atmosphere and temperature and humidity distributions. The evaluation of cloud amount was made for three categories of cloud level in the atmosphere (high, middle and low) under three main assumptions: surfaces of middle and low clouds radiate as black bodies; high cloud clouds are partially (10%) transparent; and distributions of clouds at each level is random. It is found that the derived vertical cloud distribution has a close association with the gross circulation patterns of the atmosphere and the ocean, e.g., clouds at all three levels are mostly observed in the ITCZ and in zones of baroclinic instability for both hemispheres as well as over the Asian monsoon area;

low level clouds dominate over subtropical zones and, in particular, over upwelling regions in the oceans.

PLANS FY79

It is planned to determine the influence of the geographical cloud distribution on regional climate by comparing the results from the following two numerical experiments:

i) time integrations of the global semi-spectral model with three-dimensional cloud distribution determined by the above method;

ii) time integration of the global model with zonally uniform clouds which are consistent with outgoing radiation.

1.4.3 Cloud-Radiation Interaction

ACTIVITIES FY78

The report of the last fiscal year (Section 1.2.1) discusses how the cloud radiation feedback mechanism affects the response of a model climate to an external forcing, i.e., a change in the solar constant. This study has been continued throughout this fiscal year. A manuscript describing the results from this study is being written.

PLANS FY79

The study described above investigates how the interaction between cloud and radiation affects the sensitivity of area-mean or zonal-mean climate. During the next fiscal year, it is planned to evaluate how the cloud-radiation interaction controls the response of the geographical distribution of climate to a change in atmospheric CO_2-concentration in air.

1.5 ATMOSPHERIC DISTURBANCES

Atmospheric disturbances play an important role in maintaining the general circulation of the atmosphere. The use of a general circulation model can be a powerful tool for studying the dynamics of large-scale atmospheric waves. The first step of this study is to make detailed analyses of atmospheric waves as simulated by the model and to compare them with those observed and those given by theories. The second step is to conduct controlled numerical experiments in which some of the physical processes are eliminated, one by one, from the original model in order to examine their role in the generation and maintenance of wave disturbances in the atmosphere.

1.5.1 Wave Analysis

ACTIVITIES FY78

Spectral formulas have been derived to compute the space-time spectra of rotary vector series. The space-time rotary spectra resolve transient waves into clockwise and counter-clockwise rotating components as well as eastward- and westward-moving components. This method is used for a statistical identification of mixed Rossby-gravity waves simulated by an 11-layer general circulation model (v).

Spectral formulas have been derived for partitioning the time-power spectrum of transient disturbances composed of multiple wave numbers into standing and travelling parts. This method is used for analyzing transient planetary waves simulated by an 11-layer general circulation model.

PLANS FY79

A space-time spectral analysis will be made of the seasonal variation of tropical transient planetary waves simulated by an 11-layer general circulation model. The monthly spectra will be estimated by the use of a maximum entropy method which gives finer frequency resolutions, even for a short record.

1.5.2 Wave Dynamics

ACTIVITIES FY78

Control experiments using a 13-layer general circulation grid model have been conducted to study the generation of transient planetary waves in the tropics by eliminating, one by one, the effects of topography, mid-latitude disturbances and condensational heating. These experiments have been completed and a manuscript has been accepted for publication (jj). It was found that even if topography and mid-latitude disturbances are eliminated, both Kelvin and mixed Rossby-gravity waves appear in the stratosphere as a result of the effect of latent heat release in the troposphere. In contrast to Kelvin waves, however, mixed Rossby-gravity waves are significantly enhanced by westward-moving mid-latitude disturbances which are found to propagate toward the Equator.

PLANS FY79

Control experiments using a 9-layer spectral general circulation model will be conducted. These experiments are intended to study the generation, growth and decay of transient waves in the mid-latitudes by eliminating, one by one, the effect of geography, zonal-wave interaction, condensational heating and wave-wave interaction from the original model.

Experiments will also be conducted with a variety of zonally symmetric atmospheric models, examining the question of what one can learn about the tropospheric circulation (particularly in the tropics) without any zonally asymmetric eddies present at all. Theories will be tested which suggest that the width of the Hadley cell and the location of the ITCZ can be understood, to a first approximation.

Also, a theory for the direction of the horizontal momentum fluxes in unstable baroclinic waves, long a missing element in classical linear baroclinic instability theory, has been developed. It is planned to test this theory by comparing its predictions with numerically obtained exponentially growing waves on a variety of complex zonal flows.

1.6 MODEL DEVELOPMENT

1.6.1 Spectral Climate Model

ACTIVITIES FY78

It has been suggested that the spectral technique of evaluating the dynamical equations, because of its ability to compute spacial derivatives more accurately, is an attractive alternative to the finite difference technique. However, the full spectral technique has seldom been incorporated into high resolution climate models because the amount of computer time required for the numerical time-integration of the model increases rapidly with increasing spectral resolution. Fortunately, a scheme has been proposed for reducing the required amount of computer time by using the "transform method." This method computes the nonlinear terms as well as other terms in the prognostic equations at grid points and then transforms the results back into the spectral domain. The GFDL Experimental Prediction project has developed a spectral dynamical model (188) which incorporates this transform method. During the last three years, a spectral climate model has been constructed by combining their spectral dynamics with relevant physical processes. In addition, extensive evaluation of the ability of the model to simulate climate has been made. For this purpose, numerical time-integrations of this spectral climate model have been made with three different spectral resolutions. It is found that, as the spectral resolution is increased, tropical rainbelts become narrower and better defined, subtropical dry zones expand (see Fig. 1.6.1) and the sea-level pressure gradient between the subtropics and subpolar regions increases. While these spectral models maintain a level of eddy kinetic energy which is slightly less than observed, they tend to underestimate the transient component of eddy kinetic energy and overestimate the stationary component. In general, the spectral climate models are able to simulate many of the large-scale features of climate with the quality of the simulation improving with increasing spectral resolution.

Comparison is made between the performance of these spectral climate models and that of finite difference climate models which have been developed at GFDL. With some exceptions the simulated climates of the spectral models compare favorably with those of the finite difference models of comparable resolution.

Because of the ease of incorporating the so-called "semi-implicit" time differencing scheme, it is found that the spectral climate model consumes less computer time than GFDL-grid models of comparable resolution. A manuscript describing the results from this study has been completed and submitted for publication (ii).

PLANS FY79

Because of its cost-effectiveness, it is planned to use the spectral climate model extensively for future numerical experiments. For example, the atmospheric part of the comprehensive joint ocean-atmosphere model, described in Section 1.1, has already been replaced by the spectral model. The global joint atmosphere mixed-layer ocean model, to be used for the CO_2-sensitivity study, contains the spectral atmospheric model.

It is planned to conduct a series of numerical experiments which are designed to determine the basic causes of some failures of the spectral model to simulate the actual climate.

Exploiting the computational efficiency of the low resolution-spectral climate model, it is planned to investigate the interannual variability of the model climate and compare it with the actual variability as determined by the Observational Studies Project.

1.6.2 Radiative Transfer

ACTIVITIES FY78

The thermal structure of the atmosphere between 25 and 80 km is largely determined by the balance between ozone heating and cooling by infrared radiation from CO_2. General circulation models of this part of the atmosphere, therefore, require fast, accurate algorithms for calculating CO_2 cooling rates. Such an algorithm has been previously developed (204) and implemented in several circulation models, most notably the GFDL 40-layer stratospheric model. (See Section 2.2 of this report.) The method relies heavily on pre-calculated transmission functions, and its general utility, therefore, depends on the availability of these quantities.

A comprehensive set of CO_2 transmission function tables has been prepared, utilizing a line-by-line integration program. In conjunction with a special interpolation scheme, this allows the user to pre-calculate transmission functions for any vertical grid desired. After several years of effort, satisfactory intercomparison with other workers has been achieved. A paper currently in preparation describes the various algorithms used and contains an abbreviated set of tables. The full tables will be made available on magnetic tape.

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It is planned to extend the tables to higher CO_2 mixing ratios (four times the present value) and perhaps to parameters relevant to Mars.

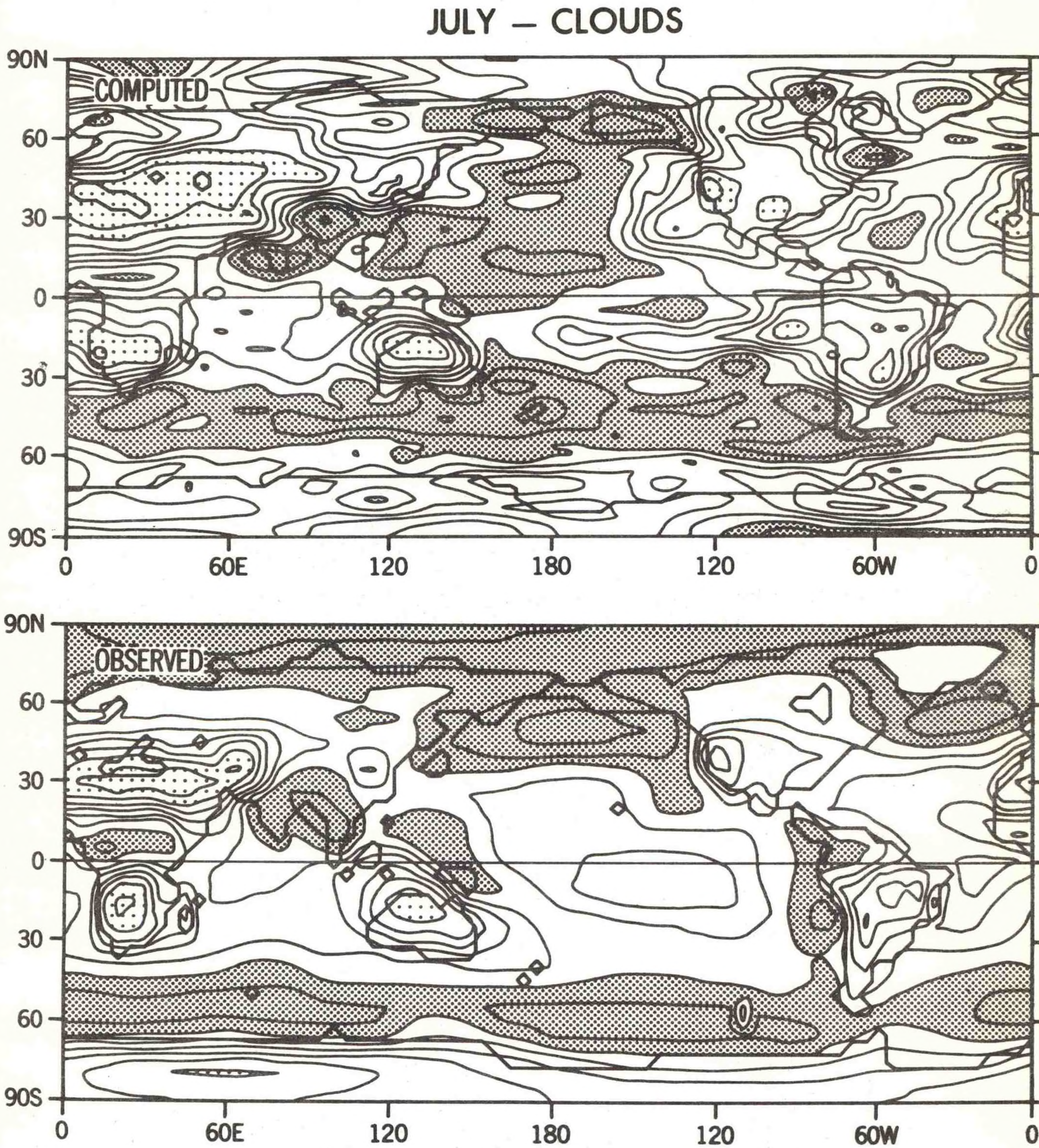

Figure 1.4.1 Global distribution of total cloud cover for July. Top: computed. Bottom: observed. Dark shade indicates values above 70%. Light shade indicates values below 20%. Contour interval is 10%.

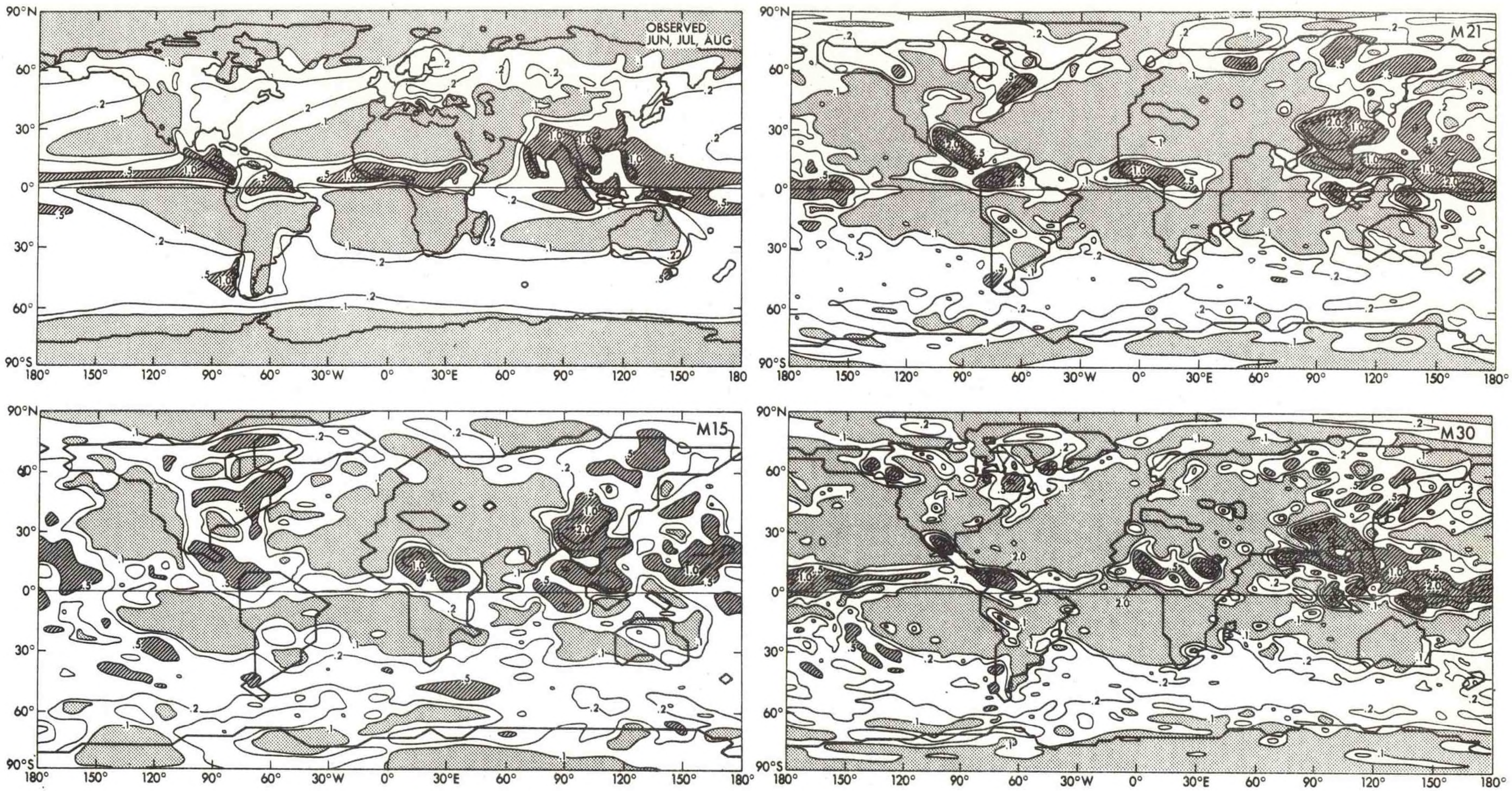

Figure 1.6.1 Geographical distributions of July mean rate of precipitation (cm/day) as simulated by three spectral models differing only in spectral resolution. These simulated distributions are labelled M15, M21, and M30, indicating that the spectral model has truncated all waves with zonal wavenumbers greater than 15, 21, and 30, respectively. For comparison, the June-July-August observed precipitation distribution of Möller (1951) is depicted in the upper left-hand corner.

2. MIDDLE ATMOSPHERE DYNAMICS AND CHEMISTRY

Objectives

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

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

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

2.1 ATMOSPHERIC TRACER STUDIES

ACTIVITIES FY78

2.1.1 Atmospheric N_2O Tracer Experiments

A 3-D experiment simulating the behavior of atmospheric N_2O, assuming a constant lower boundary source, has been integrated for nearly eight years. Through use of an effective re-initialization technique for this long-lived tracer (> 150 years) the model is within 0.5% of its long-term chemical-transport statistical equilibrium. Two other related experiments, one with the source removed, and the other with a highly non-uniform, land-based, rainfall-dependent source, have been started from the near-equilibrium of the above experiment. They have been run for 6 and 8 months, respectively, to examine local tropospheric response to various assumptions about the highly uncertain tropospheric N_2O source.

2.1.2 Analysis of Ozone Sampling Networks

Analysis has continued on the use of the 3-D "simple ozone" experiment to evaluate the capability of the Dobson Total Ozone Network to provide information about global means and trends. New analysis has been underway to evaluate, by collecting statistics on random networks of various sizes, the probable reduction of error to be expected for increases in network size. These results show that the current Dobson Network exhibits about the same sampling skill as that of random networks of similar size. The random network analysis also indicates that network sizes greater than about 100 well chosen stations are probably not necessary. Also, an effort to examine a possible effect of "fair weather" sampling bias on total ozone measurements has been underway. The results indicate some systematic error is produced, but the effect is smaller than that introduced by spatial and temporal sampling limitations.

2.1.3 Analysis of Instantaneous Source Experiment

The work on this tracer experiment, somewhat analogous to a nuclear weapons test, has been completed. Previously unreported results are: an improved understanding of the power and the limitations of atmospheric residence time concepts; a better grasp of the mechanisms for inter-hemispheric transport; and some success in illuminating the relationships between the cross-tropopause tracer fluxes and the mid-latitude and spring peaks in tropospheric radioactive fallout. Complete results on this experiment are presented in reference (308).

2.1.4 Stratospheric Aircraft Pollution Experiment

This experiment, begun in FY77, attempts to simulate the transport of gaseous effluents from an idealized stratospheric aircraft source. Although this experiment is being run on a computer backup basis only, it has now been integrated nearly 3 years from its initial condition obtained by the technique described in reference (153). It appears that another two to three years of model integration time will be required to obtain a satisfactory knowledge of its statistical equilibrium state.

2.1.5 Development of an Improved 2-D Tracer Model

Previous research (see reference (246)) has demonstrated that current 2-D tracer models have been formulated on the basis of fundamentally incorrect diffusion hypotheses. Employing insights gained from the 3-D tracer model, a 2-D tracer model is being explored which does not require those traditional assumptions. The approach employed is to utilize the hydrostatic "primitive" equations along with the tracer continuity equations to develop specific equations for the tracer eddy fluxes, variances, and other important covariances. Required inputs are various eddy meteorological statistics, in addition to the usual zonal mean quantities.

PLANS FY79

Analysis of the N_2O experiments is continuing and results are being prepared for publication. The N_2O distributions will be utilized to provide a source function for an "odd nitrogen" experiment, a fundamental prerequisite for a transport-chemistry consistent ozone experiment. The previously reported "simple ozone" experiments are being prepared for publication. The use of these "simple ozone" experiments to evaluate ozone sampling networks will undergo final analysis. Preparation for publication should be completed.

The aircraft pollution experiment is running completely on a backup basis, thus progress is dependent upon the computing load. For the 2-D tracer model, progress is determined by the usual uncertainties accompanying student research.

2.2. MODELS OF THE TROPOSPHERE-STRATOSPHERE-MESOSPHERE

ACTIVITIES FY78

2.2.1 Model Improvements

During FY78 work continued on various improvements for the 40-level troposphere-stratosphere-mesosphere GCM(SKYHI). A new short-wave radiation module which is faster and more accurate than previous codes is now a stable component of the model. The model now possesses the capability to include two extra dependent variables (probably ozone and total odd nitrogen). Currently, a tracer is being run passively for checkout of this added logic.

A new technique for specification of orography at various horizontal resolutions is now being utilized. High resolution (1°) mountains are spectrally filtered such that almost no forcing is allowed near the computational mode. In addition, a nonlinear smoothing is applied in such a manner as to flatten the oceans without sacrificing peak heights significantly.

2.2.2 Low Resolution (N10) Control Experiment

The low resolution (N10, 9°lat. x 10° long.) model has been run for 720 days to a state of near statistical equilibrium. The model currently employs annual mean insolation, prescribed clouds, and a fixed sea surface temperature. An especially interesting feature of this simulation is the presence of an equatorial westerly jet at about 40 km which is maintained by vertical momentum flux convergence against loss processes. This raises the hope that this model contains the requisite processes for simulating the quasi-biennial oscillation.

2.2.3 N10 50% Ozone Reduction Experiment

It is clear that large cooling in the low-latitude upper stratosphere is to be expected in the event of a large reduction in ozone amount. Considerably less clear, however, are the dynamical responses throughout the entire stratosphere and the climatic alteration near the earth's surface. As a means of helping to formulate longer term research strategy for attacking these problems, a preliminary SKYHI N10 experiment has been run from day 500 to day 720, assuming a uniform 50% ozone decrease.

The zonal mean temperature in this experiment shows a number of features which agree reasonably well with radiatively predicted changes. For example, substantial global mean cooling ($\sim$ 23°K) occurs in the model upper stratosphere and lower mesosphere. Considerably smaller mean cooling is calculated elsewhere, with values of about 6-8°K from 18-40 km, and ranging from 1° up to 6°K from 7-18 km. Although changes are observed in the lower troposphere, further work is required to assess their physical and statistical significance.

Another important model effect of the reduced ozone is that the stratopause height falls by about 6 km, while the tropical tropopause height rises by 1-2 km. In addition, the average meridional temperature contrast in the upper stratosphere is considerably diminished. The reduction in this contrast ranges from about 10°K near the stratopause to about 2°K in the 20-35 km region. At 15-20 km, the cooling acts to increase the magnitude of the reversed meridional temperature contrast by about 4-5°K. This arises because less cooling is occurring in high latitudes than above the tropical tropopause, an effect <u>opposite</u> to that predicted by comparison radiative-convective equilibrium calculations.

In mid-latitudes, the mean zonal winds decrease by 8-15 m sec^{-1} in the mesosphere, about 2-8 m sec^{-1} in the upper stratosphere and about 1-2 m sec^{-1} in the middle stratosphere. In the equatorial region, the mean zonal winds increase by about 10 m sec^{-1} in the mesosphere and decrease by 10-15 m sec^{-1} near the stratopause.

Although considerably more work is needed on this subject, the results indicate that significant climatic effects are to be expected from large ozone reductions, especially above the upper troposphere.

2.2.4 N10 Doubled Carbon Dioxide Experiment

In a comparison experiment to the 50% ozone reduction, the N10 SKYHI model is run from day 500 to day 720 with a doubled carbon dioxide mixing ratio. In contrast to other climate sensitivity CO_2 experiments (e.g., reference 192), the sea surface temperature is held fixed, thus strongly constraining the tropospheric climate against change. This was done because of the emphasis on the stratospheric response of the experiment.

The strongest effect of increased carbon dioxide is, as expected, a decrease in temperature of about 10°K near the stratopause. In general, the model changes everywhere agree well with predictions from comparison radiative-convective equilibrium model calculations, not only in global averages, but also at individual latitudes.

The chief dynamical response of the model is a 1-3 m sec^{-1} decrease in the strength of the mean zonal wind above 50 km.

2.2.5 Medium Resolution (N18) Control Experiment

An N18 (5° lat. x 6° long.) version of SKYHI has been started by interpolation from day 500 of the N10 experiment (2.2.1). Although this version has only run for about 100 days, substantial improvements over the N10 version have already been achieved.

In the troposphere, the maxima in zonal wind are moving poleward toward more realistic positions. Tropical easterlies are forming in the middle troposphere. The temperature at the tropical tropopause is increasing, thus becoming closer to observed values.

Above the troposphere, the cold polar bias of previous GFDL models is still absent. The simulation of the Aleutian anticyclone is considerably improved.

PLANS FY79

Analysis of the N10 control, halved ozone, and doubled CO_2 experiments will continue. The N18 control will be run to statistical equilibrium with continuing analysis. An N10 seasonal march model will be underway. Effort will continue on the problem of introducing self-consistent ozone photochemistry into these models. Progress in this area remains impeded by serious uncertainties in the relevant chemical processes.

3. EXPERIMENTAL PREDICTION

Objectives

* To develop or improve weather prediction models suitable for medium range (about 10 days), and meso-alpha scale (200-2000 km).

* To determine, with a physically based probabilistic approach, the degree of predictability of the atmosphere over the range of several weeks to several months, and of the temperature of the upper layer of the ocean over the range of a year; and to identify the controlling physical factors.

* To determine data requirements for various ranges of prediction and to develop techniques for optimal extraction of information from the available observations of the atmosphere and the upper layer of the ocean.

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

NOTE

Space discretization is an important and inevitable aspect of numerical modeling and a shorthand notation for model spacial resolution is introduced for convenience. An N48L9 model, for example, denotes a finite difference model with N=48 grid points between pole and equator and L=9 vertical levels corresponding to a 2° grid length in the meridional direction. Similarly, an R30L9 model, for example, denotes a spectral model with rhomboidal truncation limits at zonal (and meridional) wave number R=30 and L=9 vertical levels. The transform grid of R=30 contains 40 grid points from pole to equator.

3.1 OCEAN UPPER LAYER FORECASTS

ACTIVITIES FY78

3.1.1 Sea Surface Temperature (SST) in 1976 and 1977

Map analyses of monthly SST over the world ocean have been made by applying a Cressman-type objective analysis method (285) to ship and satellite data. The following characteristics of the SST variations over two years were investigated: frequency spectrum, the propagation of the anomalies, and the eddies. The relationship between the mid-latitude SST variation and the atmospheric forcing was also studied, using the 700 mb monthly mean geopotential analyses provided by NMC's Long-Range Prediction Group. The record-cold SST in July-August 1976 over the North Pacific Ocean appears to be explained in terms of the atmospheric forcing. A movie of the SST variation was produced.

PLANS FY79

Forecasts of the SST in the middle latitudes over the North Pacific will be carried out with the mixed layer model, using different versions of atmospheric forcing, i.e., 3-day, 10-day, and one-month mean forcings. The analysis of SST for 1975 and 1978 will be conducted. In the mixed layer model, the effects of up/down-welling and lateral advection will be incorporated.

3.2 GLOBAL MODELS

ACTIVITIES FY78

3.2.1 Effect of Resolution in the Spectral Model

The effect of horizontal resolution on forecast accuracy was examined using the Australian Numerical Meteorological Research Center (ANMRC) hemispheric 9-level spectral model.† This model includes physics pertinent to medium-range forecasts. The resolutions compared were R15, R21, R30, R45, and R63. The southern hemispheric forecasts for 10 days were surprisingly good for the models with resolution above R30. It has also been revealed that, in order to gain the benefit of increased resolution for medium range prediction, other features of models, such as the physics or the numerical aspect, must be improved.

3.2.2 Intercomparison of Spectral Models

Ten-day forecasts of the GFDL and ANMRC general circulation spectral models were compared. Although the two models had a common source, a

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†Burke, W. "A Multi-level Spectral Model I. Formulation and Hemispheric Integrations." Monthly Weather Reviews, Vol. 102, 1976, pp. 687-701.

spectral barotropic model, their evolutions followed different paths, especially in the detailed formulation of certain physical processes and in computer code structure. In view of these differences, the forecast performances were surprisingly similar.

3.2.3 Construction of R30L18 Model

The R30L18 model will be used for data assimilation during the FGGE. In order to reduce computer memory requirements, a new input/output system has been developed, and an efficient R30L18 model has been constructed.

3.2.4 Fels-Schwarzkopf (F-S) Radiation

The F-S radiation scheme (204) was incorporated into the R21L18 spectral model, and was validated against the conventional GFDL radiation scheme (26) by 10-day comparative integrations. Radiation parameters such as cloud absorptivity, cloud albedo and the solar constant were also varied. The F-S radiation seems to provide better temperature profiles over the summer Antarctic. It is also much more cost effective.

3.2.5 Virtual Temperature

Inclusion of virtual temperature presumably represents a model improvement. However, a comparative integration with and without inclusion of virtual temperature suggests the contrary. A possible explanation is that other thermodynamic effects of the same order must be simultaneously introduced.

3.2.6 Time and Vertical Finite Difference Schemes

Using the R30L9 hemispheric spectral model, three leapfrog time differencing schemes were tested: semi-implicit with Δt=20 minutes, semi-implicit with Δt=4.8 minutes, and explicit with Δt=4.8 minutes. The respective hemispheric forecasts began to diverge noticeably after 6 days. Although the explicit scheme appeared to yield a slightly sharper mid-Atlantic ridge at 10 days, the semi-implicit forecast with Δt=20 minutes was of comparable overall quality. Two vertical finite difference schemes were also tested.

PLANS FY79

The R45L9 model will be made more economical to run. The study of the F-S radiation scheme will be continued, and a 30 day integration will be completed. An attempt will be made to speed up the finite difference modified Kuri-grid and latitude-longitude grid models.

3.3 LIMITED DOMAIN FORECASTS

ACTIVITIES FY78

3.3.1 HIBU Local Area Model

A model, brought from the Federal Hydrometeorological Institute and Belgrade University (HIBU), Yugoslavia, (see 3.4.3 in 1977 report) has been further developed into a full weather prediction model. New features included are: 9 vertical levels, all the usual physics of a general circulation model, and the vectorization of the code. In particular, the F-S radiation, the Monin-Obukhov process in the boundary layer, the heat conduction in soil, a new soil moisture scheme, and ∇^2 lateral diffusion specially designed to handle steep mountains have all been incorporated.

3.3.2 Soil Moisture Effect

The analysis of the 24 January and July forecast cases with the "1967 version" hemispheric gridpoint model revealed that the specification of soil moisture is crucial for the low-level forecasts even in the 2- or 3-day range. This is particularly true over Africa, Europe, and America. For example, an inappropriate treatment of soil moisture caused spurious evaporation over the North American continent in summer, which in turn led to a very poor simulation of rainfall over the United States.

3.3.3 HIBU Hemispheric Model

The HIBU limited area model has been expanded to include the entire hemisphere. The polar filtering necessary for efficiency has been successfully included. At the pole and surrounding grid points, differencing schemes have been implemented which maintain integral properties maintained by schemes used at points away from the pole (conservation of total mass, moisture and energy in horizontal advection and "omega alpha" terms; conservation of total enstrophy in advection by the rotational component of the wind). The model has already been using the forward-backward explicit scheme for time differencing, but even further economizing has been accomplished by splitting the faster and slower terms of the governing equations.

3.3.4 Finer Resolution Hemispheric Spectral Model

The hemispheric model is being recoded to accommodate much finer horizontal and vertical resolutions, e.g., as high as R72L9 or R50L18.

PLANS FY79

The HIBU local area model will be applied to several cases of Genoa cyclogenesis. The model will also be nested and applied to the GATE area and then embedded in the global spectral model. The ∇^4 lateral diffusion will be included in the HIBU model. The implementation of the "1976 version" (N80L18) hemispheric model will be continued for the January cases. Limited domain forecasts with the 34 km nested grid model will be produced for additional cases over the United States. Recoding of the hemispheric fine resolution version of the spectral model will be completed and the effect of increased horizontal and/or vertical resolution upon 10 day forecasts will be studied.

3.4 PARAMETERIZATION

ACTIVITIES FY78

3.4.1 Turbulent-Closure Scheme

A 30-day forecast of the March 1965 case was completed with the N48L18 model, which included the turbulent closure process and the constant-flux layer theory of Monim-Obukhov but excluded the dry convective adjustment. The 10-day forecast was shown by a figure in the previous report. Although the simulation of the cut-off low was very impressive, the eddy kinetic energy seems excessively large; this kind of situation has rarely happened in the past. In this connection, the role played by the dry convective adjustment was re-examined, and a remedy has been considered within the context of the turbulent closure theory.

3.4.2 UCLA Cumulus Convection Scheme

A 30-day forecast, including the mixed-layer theory of Randall and the cumulus convection theory of Arakawa-Schubert (A-S), revealed deficiencies in the mixed layer in the polar regions, a lack of tropical disturbances, and a shortage of moisture in the free atmosphere. In order to remove these deficiencies, the mixed-layer process of Randall was replaced by the turbulent closure process. However, the A-S cumulus convection parameterization was retained. The model was run for 30 days, and the results indicate that some of the earlier shortcomings have been rectified.

But both models mentioned above produced very similar 30-day average rainfall patterns (see figure 3.4.2) irrespective of the mixed layer parameterization. The rain belts were too broad. The Intertropical Convergence Zone occurred erroneously in both hemispheres across the equator. This effect influenced the large-scale circulation at the 200 mb level, for example. The correction of these problems is being considered.

3.4.3 Cloud-Radiation Interaction

Previously, our radiation calculations have utilized zonal-mean distributions of cloudiness. But it is hoped that more realistic cloud coverages can produce improved medium and longer range forecasts. To this end, clouds are being generated by two approaches. First, an "observed" monthly mean cloudiness is being reconstructed. Input data include NOAA satellite long-wave radiative flux and NMC monthly mean temperature and moisture. Second, time-varying cloudiness may be predicted from the model's own forecast. One scheme, for example, instantaneously predicts 100% cloudiness if the relative humidity exceeds a latitude-dependent critical value, but 0% otherwise. The 12-hour mean predicted cloudiness is put into the radiation calculation. Even though the scheme must be further refined, preliminary results indicate a substantial model response at 10 days.

3.4.4 Sea-Ice Heat Conduction

Previously, surface temperature over sea ice was specified as a fixed monthly mean value independent of geographical position. This could cause excessive zonally symmetric forcing over the polar ice cap. This situation is being rectified in two stages. In the first stage, the temperature over sea ice is determined by a surface heat balance and heat conduction through the ice with the sea ice thickness set equal to 2 meters. In the nearly completed second stage, the climatological ice thickness for the North Polar region has been reconstructed. Moreover, the compactness and ice extent in the Arctic, based upon the Fleet Numerical Weather Facility data, is being put into the model.

3.4.5 Variable Surface Roughness

Topography-related variations in surface roughness, which one may call "form drag", are important. Their influence upon the large-scale circulation may yield improved extended range forecasts, for example, by capturing the correct amount of low-level deepening. To this end, two simple parameterization schemes for topography-related surface roughness are being developed.

PLANS FY79

The study of cloud-radiation interaction will be continued. The prediction with the N48L18 model with the conventional physics will be extended from the 20th to the 30th day. An improved model of the turbulent closure process will be established. The mountain form drag will be properly included.

3.5 FGGE PREPARATION AND IMPLEMENTATION

ACTIVITIES FY78

3.5.1 Assimilation with Spectral Models

The R30L18 spectral model has been successfully applied in a four-dimensional data assimilation mode. The computing speed has been considerably increased compared with that for assimilation with finite difference models. However, the surface drag scheme in the R30L18 model needs revision. The damping viscosity employed in the original Simmonds' version is not being routinely utilized, and further tests of damping schemes seem necessary.

3.5.2 Preliminary Data Processing and Optimum Interpolation Analysis

Continuous efforts are being expended in this area. A global optimum interpolation analysis is applied. Using the solution from the dynamical four-dimensional analysis instead of the climatological monthly normals, as the initial guess, yields improved results. For the production of the insertion data, however, the climatology is still used in the local optimum interpolation. Climatologies for most variables at all levels up to the 2 mb level have been prepared for each month.

A number of detailed items have been tested: such as specifying the priority of different sources of insertion data, the hydrostatic check, the use of the thickness instead of point temperature, and the modification of the scheme for time interpolation of insertion data.

3.5.3 Preparation for Operation

The major achievements so far are: reading of the rehearsal tapes mailed from the Level III-b Data Centre in Sweden; the program to produce the microfilms review catalogues; the system to print a list of rejected data; the addition of vertical velocity to the output from the assimilation; archiving of precipitation and cloudiness reports; the enlarged maps of the product which will be used for monitoring and comparison with FAX; and the production of a movie explaining the four-dimensional analysis procedure.

3.5.4 The Assimilation Scheme and the Model

In order to incorporate the effect of diurnal variability in the spectral model, we included the planetary boundary layer physics of Monin-Obukhov, heat conduction through the soil, and the diurnal variation of radiation.

An arrangement is being made in the data assimilation that, whenever the temperature data are inserted, corresponding geostrophic winds are used, if the wind data are not available.

3.5.5 Archiving of BDS and GATE Level III Data

The analysis was completed and archived for November 4-9, 1969, i.e., the case of Basic Data Set. After including supplementary data, the dynamical four-dimensional analysis for the Phase III of GATE (August 23-September 19, 1974) was repeated. Compared with the previous analysis conducted in the near-real time in 1974, the tropical analysis has been improved appreciably. Yet the detailed feature of circulation in and near the GATE A/B-net area off the African west coast has not been sufficiently resolved by the R30L9 model.

PLANS FY79

In October 1978, the operational procedure of the GFDL four-dimensional analysis will be fixed. Sometime in 1979 the operation will start. Meantime, revision and modification of the assimilation and optimum interpolation system will continue. Presently the following items are being considered: forward-backward assimilation, weighted insertion, vertical optimum interpolation, geostrophic insertion, inclusion of Australian Bogus data, water vapor insertion, a revised time-interpolation of insertion data, correction of error covariance of satellite soundings, more optimal blending of various types of insertion data by using the proper error assignment, and the radiation correction of the stratospheric radiosonde data.

3.6 76/77 EVENT

ACTIVITIES FY78

The general tactic in studying this phenomenon is to test quickly the model's sensitivity by use of an economical hemispheric R30L9 model in a prediction of, say, 10 days, thereby gaining preliminary knowledge on the factors of concern. Upon consideration of the results of these preliminary tests, a more elaborate and perhaps more expensive model is run for the full 30-day range.

3.6.1 SST Effect

As reported in the previous year, a one-month forecast using R30L9 with SST climatological normals did not at all agree with observations after the 15th day. This time, therefore, the actual January 77 SST was applied to the R30L9 model. As anticipated, the result of the 10-day forecast was not appreciably different. Although the 30-day forecast was changed significantly, it did not improve.

3.6.2 Other Factors

One of the major difficulties is that the blocking ridge over Alaska starts to move eastward after the 8th day in the model, and simultaneously the deep trough over the eastern United States becomes shallow, whereas in reality the blocking ridge remains fixed at the same longitude throughout January. In order to identify the mechanisms needed to maintain the block in the simulation, internal as well as external factors were tested. The factors in the former category were: the cloud-radiation and moisture-radiation interaction, heat conduction through the sea ice, the removal of the virtual temperature, the inclusion of the Monin-Obukhov process and heat conduction through the soil, the vertical finite difference scheme, the vertical resolution, and the lateral spectral resolution. The factors in the latter category were: the SST anomalies, the land-surface albedo (see below), and the sea ice thickness and compactness.

Of all the tests on these factors performed thus far none have given a successful forecast. In particular, the blocking ridge began to move on the 8-10th day, and the trough over the eastern United States did not deepen sufficiently. Nevertheless, much information has been gained on the sensitivity and on the effects of westerly wave amplification. Note that the effect of the mountain form as well as that of the sea ice thickness and compactness have yet to be studied. Also, the cloud-radiation scheme is being improved.

3.6.3 Surface Albedo and Snow Cover

The effect of more realistic surface albedos over the snow-covered surfaces was investigated by using observed snow cover data obtained from NESS and monthly mean satellite brightness data obtained from Lamont-Doherty Observatory. In some experiments monthly mean surface albedos were imposed, whereas in others the surface albedo over snow was re-computed by the model from the evolving snow cover field. The observed surface albedo at middle latitudes departed by as much as 25% to 50% from climatology and from previously model-computed values. Similarly, large departures from the previously used initial snow cover based upon the model's climatology were noted. Nonetheless, the model's overall response was relatively small. Perhaps the rather weak solar radiation available over the snow surface during January and enhanced static stability in the boundary layer was responsible.

3.6.4 Initial Condition

Analyzing the forecast results, one may notice that a cyclone over the North Pacific was excessively developed by the model, and the intensified westerlies over the eastern Pacific may have caused the blocking ridge to move. It is known that error development is particularly large in winter over the Aleutian area. It is likely, therefore, that the initial condition of vorticity over the western Pacific is very crucial. If this speculation is right, our experience implies that the initial condition could change the entire course of a forecast even one month ahead. Presently the GFDL four-dimensional analysis is being applied to Level II data for December 1976; the result will be used for another test.

PLANS FY79

The new initial condition will be applied to see whether our inference is true. A number of tests will be made on the impact of time-varying predicted clouds, the influence of heat conduction through sea ice as well as realistic ice thickness and compactness, and the effect of the new parameterizations of mountain "form drag."

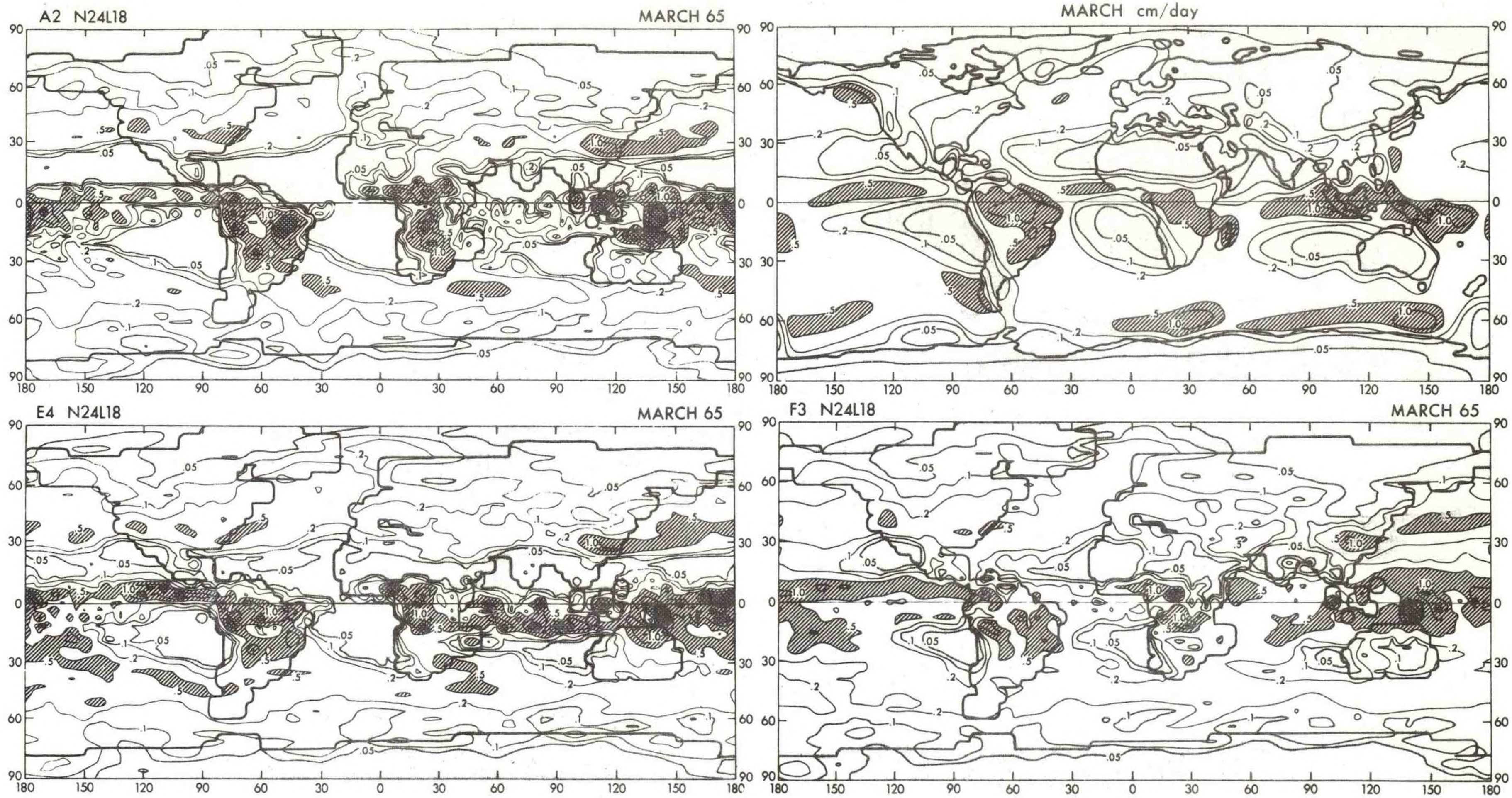

Figure 3.4.2 Global distribution of rainfall for March 1965 simulated by three models, differing in the parameterization of sub-grid scale processes.
Upper right - March climatology, upper left - A2 model which includes moist convective adjustment, conventional mixing length eddy viscosity and Prandtl type surface layer; lower right - F3 model which has the Arakawa-Schubert cumulus parameterization scheme, the Mellor-Yamada level 2.5 turbulent closure scheme, a Monin-Obukhov surface boundary layer and no dry adiabatic adjustment; lower left - E4 model which is the same as the F3 model except that moist convective adjustment is used instead of the Arakawa-Schubert parameterization.

4. OCEANIC CIRCULATION

Objectives

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

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

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

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

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

4.1 DYNAMICS OF TROPICAL OCEANS

ACTIVITIES FY78

4.1.1 Generation of Equatorial Currents

In the Indian Ocean the sudden intensification of the winds over the equator in the spring and autumn of each year generates a complex system of equatorial currents. A study of this phenomenon with a two-dimensional model that neglects zonal variations shows that eastward equatorial jets are considerably more intense, narrower and deeper than westward equatorial jets. Hence, fluctuating winds that reverse direction can give rise to currents with a complicated vertical structure (11). The presence of meridional coasts will modify the results of the two-dimensional model because they support pressure gradients which are established by equatorially trapped waves. As a prelude to a study with a fully three-dimensional model, the effect of the equatorial jets on these equatorial waves has been studied by using a simplified numerical model. Kelvin waves are found to be relatively unaffected by the jets but the gravest non-dispersive Rossby waves are significantly modified (o). The net effect of non-linearities is to increase the time it takes the ocean to come into equilibrium.

4.1.2 Transient Response of Equatorial Oceans

Atlantic Ocean

Rapidly fluctuating winds excite oceanic waves, but, if the winds vary gradually, it is possible that the oceanic response is always in equilibrium with the winds so that the ocean in effect passes through a series of steady states (mm). The time-scale that separates the two types of responses is a function of latitude, and also depends on the size of the ocean basin. Results from the GATE oceanographic experiment have been summarized in the light of these considerations. An equilibrium response to cross-equatorial winds is reached very rapidly. This permits the use of a simple model to study the effect of fluctuating cross-equatorial winds on upwelling along the northern coast of the Gulf of Guinea (k).

In the Tropical Atlantic Ocean the seasonal signal in temperature structure and dynamic topography is very large. The data coverage is also good relative to other oceans. Following an earlier study of the response to wind stress (c), an exploratory study of seasonal changes has been completed with a linear baroclinic model with a detailed vertical structure. The model domain extends from 50°N to 20°S and is driven by a seasonally varying wind stress provided by Woods Hole Oceanographic Institution. The linear model provides an excellent simulation of dynamics topography and surface currents outside of the immediate vicinity of the equator, where nonlinear effects appear to be important. The phase of the seasonal changes of the Guiana Current, the North Equatorial Counter Current and the Florida Current agree very well with historical surface drift data.

Indian Ocean

The Somali Current is the only major ocean current which reverses with season. Satellite data indicate that as the Somali Current grows in strength during the Southeast Monsoon it breaks up into large eddies. A detailed eddy-resolving model has been used to study (258,e,g) the transient behavior of the Somali Current. A series of experiments shows that the angle of the coastline with respect to a meridian is critical. Eddies propagate along a coastline which trends away from the equator to the north or northwest, but they do not in the case of a coastline like that of the Horn of Africa which trends to the northeast. Since non-linear effects are dominant, the speed of propagation is critically dependent on the amplitude of the alongshore wind component.

PLANS FY79

Considerable differences between the seasonal cycle in the Atlantic and Pacific Oceans appear to be due to their different size and shape. In response to the NOAA and NORPAX field programs, a model study of the tropical Pacific will be initiated. A careful comparison of numerical experiments with similar models of the Atlantic and of an idealized rectangular basin will be made to isolate factors which lead to differences in seasonal and long-term variations in sea surface temperature and currents.

4.2 WORLD OCEAN STUDIES

ACTIVITIES FY78

4.2.1 Model Development

The World Ocean circulation model designed for climate studies has been entirely recoded. The new program is faster, simpler and better documented. Tests have been carried out with a new method which allows a much more efficient convergence to equilibrium solutions in the abyssal waters of the world ocean (p, f). The new method is expected to be extremely useful for joint ocean-atmosphere calculations investigating the problem of climate sensitivity.

As a test of the new method, a calculation has been carried out for a case in which the geometry of the continents is like that of 80 million years ago. The model handled the radically different geometry of the continents without difficulty. Thermohaline effects cause the ocean circulation to be radically different from previous reconstructions based on wind-driven circulation theory.

Another method has been developed for climate studies involving air-sea interaction on time scales of four decades or less. The deep ocean is forced towards the observed state by Newtonian damping of the temperature and salinity fields. The method appears to be extremely promising because it allows an adjustment between the density field and the bottom topography so that both the density equation and the momentum equations are satisfied, and the temperature and salinity fields at depth are kept very close to observed values.

PLANS FY79

More tests will be carried out with the World Ocean model with prescribed boundary conditions, testing its properties for short-term climate variability studies and long-term climate equilibrium research. The resolution will be refined to provide a better simulation of equatorial upwelling.

Work will be continued on examining the effect of continental drift on ocean circulation with the prospect of final calculations with a coupled ocean-atmosphere model.

4.3 MID-LATITUDE VARIABILITY

ACTIVITIES FY78

4.3.1 Oceanic Response to Large-Scale Atmospheric Disturbances

An analysis of the spatial and temporal scales of surface winds in the subtropics and mid-latitudes has been completed (s). The response of a hierarchy of progressively more complicated ocean models to these winds has been analyzed. At periods between 1 and 200 days the oceanic response to large-scale disturbances is depth independent. The response is most energetic at periods between a week and a month. In this frequency range Rossby waves are excited. At longer periods there is a Sverdrup balance in the oceanic interior, and variability with a large amplitude in the western boundary layer. The spectrum of the response at these periods is white. At periods less than 10 days the response is in the form of forced waves even though coherence with atmospheric variability may be low. The spectrum of the response in this frequency range has a slope of about -2.5. These results are in agreement with current measurements at Site D and bottom-pressure measurements in the Mode area.

4.4 GEOCHEMICAL TRACERS

ACTIVITIES FY78

The distribution of short-lived tracers such as tritium and bomb-produced C^{14} in the ocean provide valuable clues as to how the ocean circulation operates. These tracers also provide the best experimental data on which to base a prediction of the rate of ocean uptake of CO_2 produced by fossil fuel burning. For this reason the Ocean Circulation Group has initiated a study of tracers using ocean circulation model results for the Atlantic to determine the trajectory of bomb-produced tracers after they are introduced in the ocean. Preliminary results are found to have an overall correspondence with GEOSECS experimental data in low and middle latitudes.

PLANS FY79

Tracer experiments will be continued introducing winter-time convection and a specification of tritium inflow from the Greenland Sea.

5. PLANETARY CIRCULATIONS

Objectives

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

5. PLANETARY CIRCULATIONS

5.1 JUPITER/SATURN/EARTH CIRCULATIONS

ACTIVITIES FY78

Calculations with a quasi-barotropic circulation model were made in order to explore questions concerning the basic character of the Earth's circulation. Enstrophy cascade and vortex separation by the β effect were found to control the shape of mid-latitude eddies and jet formation. More general calculations showed that westerly equatorial jets can easily be produced on any rotating planet when the energy source lies symmetrically about the equator.

Analysis and documentation of Jupiter's quasi-geostrophic response revealed some new items about that circulation. In particular, it was found: that baroclinic instability occurs on three time and space scales; that the Great Red Spot is a warm core of a large, almost-neutral baroclinic wave; that the planetary circulation is mainly horizontal, i.e., there are no large-scale vertical motions; that cloud formation differs from Earth's and is associated with quasi-isothermal compression effects.

PLANS FY79

Analysis of the parametric variation of the quasi-geostrophic terrestrial regime will be completed. The relationship between this regime and the Jovian one will be used to define the Jupiter-Earth connection. Conditions for the production of a different climate will also be examined.

For Jupiter, further isolation of the circumstances under which the Great Red Spot occurs will be attempted from analysis of the simulated form. The value of further modelling of the Jovian circulation will be reconsidered in the light of calculations to date and results from the imminent Voyager encounters. Modelling developments will also depend on the outcome of the first Pioneer encounter with Saturn, an event that will provide a definitive test of current theory about the Jovian planets.

5.2 VENUS CIRCULATION

ACTIVITIES FY78

A general circulation model of the atmosphere of Venus was constructed from the 9-level, 15-wavenumber spectral model of the Experimental Prediction Group by omitting topography, condensible constituents and vertical diffusion, and by replacing the radiative transfer calculation by a Newtonian relaxation of temperature towards radiative equilibrium.

The first experiment, a "spin-up" calculation from a motionless isothermal state, was made with a radiative equilibrium temperature that is independent of longitude (i.e., the diurnal effect is omitted) and that has a super-adiabatic lapse rate at latitudes equatorward of 65° latitude. A preliminary assessment of this calculation reveals the properties of a deep, slowly rotating atmosphere: 1) The mean thermal state is nearly barotropic and statically stable; 2) The lapse rate is maintained primarily by the mean meridional circulation, except at low latitudes where intermittent convective activity is important; 3) The eddies transfer less heat than the meridional circulation but play a more important role in the angular momentum balance; 4) The eddies result from the barotropic instability of a polar jet. A kind of index cycle occurs with strong Equator-to-Pole temperature contrasts producing strong meridional flows--that consequently eliminate the temperature contrast--and a polar jet which breaks down into eddies that transport angular momentum equatorward. 5) In contrast to observations, no 4-day wind is produced by the model.

PLANS FY79

Further analysis of the first Venus experiment is planned. A second experiment will examine the effect of introducing diurnal upper-atmosphere temperature variations into the relaxed state of the first experiment. Such a calculation may show whether the diurnal effect can act to convert more of the eddy kinetic energy into the zonal kinetic energy and produce a 4-day wind.

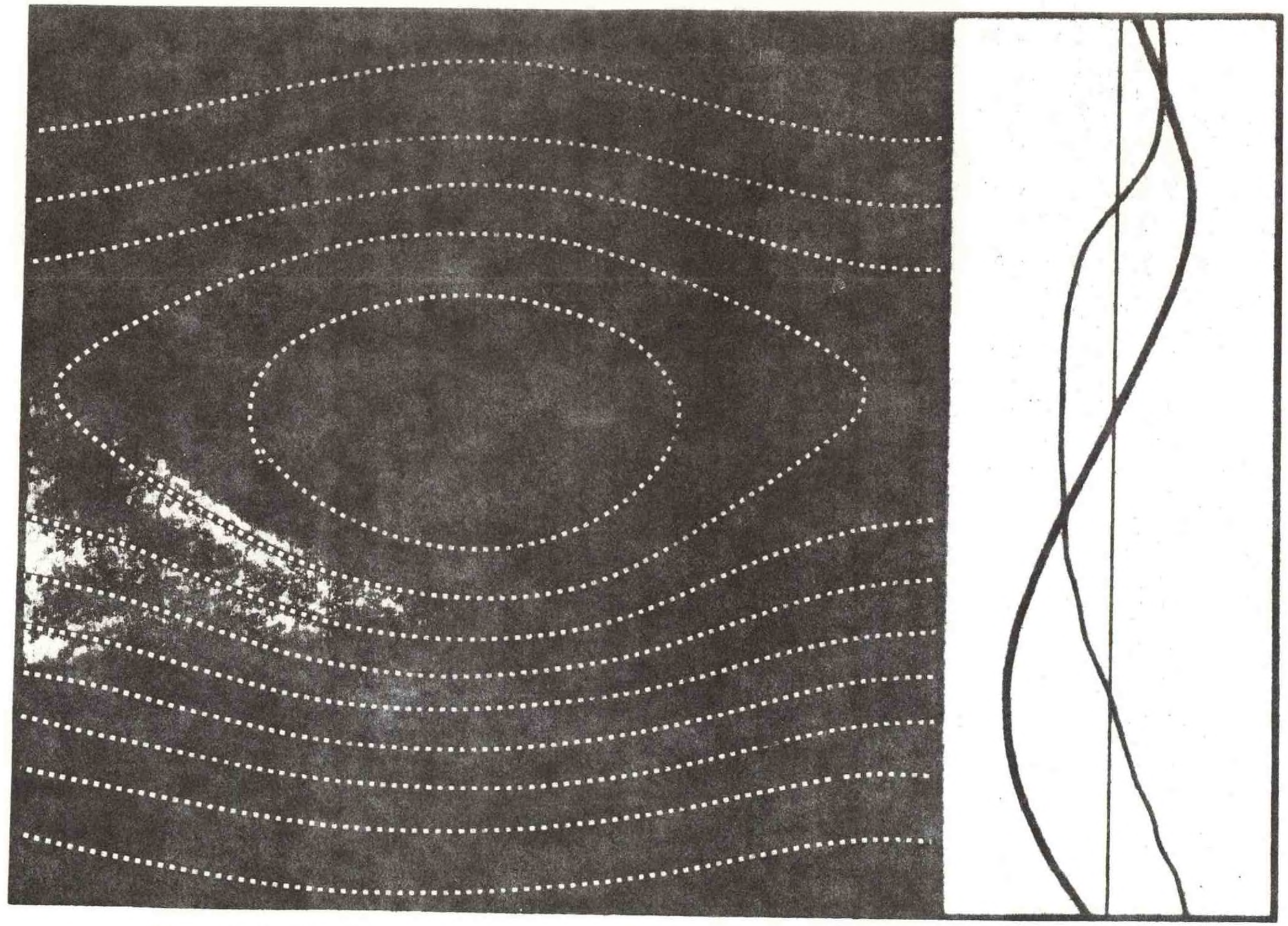

Fig. 5.1 Isobars of a gyre analoguous to Great Red Spot, from a numerical solution.

6. OBSERVATIONAL STUDIES

Objectives

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

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

6.1 ATMOSPHERIC ANALYSIS

ACTIVITIES FY78

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

A comprehensive, 3-dimensional description of the global atmosphere based on a 15-year set of rawinsonde data has been one of the major research goals of the Observational Studies Group at GFDL since FY75. A project of this scope required many passes through the data before a satisfactory final analysis could be obtained. Finally, during FY78, the stage seems to have been reached where obvious major errors in the data or data processing have been identified and corrected, and the analyses have been completed. Thus, analyses for each month of the 180 months and for each of the 23 atmospheric parameters (including mean winds, temperatures, pressures and humidities, as well as their temporal variances and covariances) are available in a uniform format on a global latitude-longitude grid at 11 levels in the vertical, ranging between the surface and about 20 km height. The Southern Hemisphere distributions (only available from 1963 through 1973) should still be considered as tentative and used with much caution because of the almost complete lack of rawinsonde stations in the 30°-60°S latitude belt. The principal results are being prepared for publication, and all grid point data will be made available to the scientific community. In fact, the Climate Dynamics and Experimental Prediction Groups at GFDL already make frequent use of these products.

Considerable thought and preliminary work has gone into exploring how to describe the nature of the interannual variability on a regional scale in order to be able to better understand this variability. As a first attempt, global distributions of interannual standard deviations for the various monthly-mean fields have been calculated. Simple formulas were derived to interrelate the observed geographical patterns for the multitude of available atmospheric parameters. The computed integral time-and-space-scales turn out to be of considerable interest.

6.1.2 The Historical Ocean Surface Ship Data

To supplement the rawinsonde data set in the Southern Hemisphere a study was begun of the available historical surface ship reports (the so-called Marine Deck TDF 11) containing information on daily wind, atmospheric temperature, pressure, humidity and sea surface temperature. The first results looked quite promising, and therefore during FY78 a similar, but much more extensive, file of Northern Hemisphere surface ship reports were also obtained from the National Climatic Center in Asheville, N.C. The combined global data set should lead to a much better description of the oceanic surface conditions during the 1958-73 period. In addition, it will be interesting to study, where possible, what the longer climatic records look like. In some areas, such as the North Atlantic, the records of air and sea surface temperature go back to the early 1900's.

This may make it possible to put the climatic fluctuations of the 1958-1973 period in a better perspective.

The possible importance of third order terms in the kinetic energy budget was studied based on the 1968-73 data. It was found that these terms are frequently as important as the second order terms. This may have important implications for the atmospheric closure program.

PLANS FY79

A comprehensive, pictorial description of the mean climate in the global atmosphere and its variability during the 1958-1973 period will be prepared for publication. Much of the huge amount of information on geographical variations may be included in microfiche form. This new geographical dimension, going beyond the zonal mean representation as used in previous publications, seems to be needed for an improved understanding of local climates as well as for verification of the increasingly realistic results of general circulation models. Besides this more or less descriptive work, the main emphasis during FY79 will be on a further understanding of the interannual variability at the various space-and-time-scales. Further, daily atmospheric analyses for the FGGE period (to be generated during FY79 and FY80 by the Experimental Prediction Group at GFDL) will be investigated at space-and-time-scales not available in the other data sets.

6.2. OCEANIC ANALYSIS

ACTIVITIES FY78

6.2.1 Global Analysis of Oceanic Data

Also in the oceanic project, FY78 has been a year of improving upon preliminary analyses made in previous years. Additional recent data from the National Oceanographic Data Service (NODS) were incorporated in the basic set, the analysis of sharp gradients (e.g., near the Gulf Stream)was improved, and additional error-checks (e.g., for density instabilities) were incorporated. The final analysis phase should begin early in FY79. Use of the preliminary analyses in diagnostic calculations by the Oceanic Circulation Group at GFDL have shown interesting results for the global oceanic heat transport and its annual variation, in fairly good agreement with indirect observational estimates reported earlier. Judging from reactions to the publication of some preliminary results(285) there seems to be a great interest among atmospheric and oceanographic modelers, as well as other groups such as paleo-oceanographers, in these analyses of temperatures, salinity, density and oxygen.

6.2.2 Studies of the Entire Climate System

Some preliminary work has begun on the study of the angular momentum budget of the atmosphere-ocean-earth system. There seems to be a fair agreement (as one would expect) between the observed angular momentum convergence in the atmosphere and the torque exerted by the oceans on the continents as derived from independent oceanographic data.

PLANS FY79

A comprehensive 3-dimensional description of the mean climate in the global oceans and its normal annual cycle will be prepared for publication. Although less comprehensive than in the atmospheric case because of the lack of information on both short- and long-term variations, this should complete the description of the principal features of the atmospheric and oceanographic components of the climate system. The main thrust of further oceanographic research during FY79 will be toward the understanding of the spatial and seasonal variability, the determination of oceanic heat transports, and possibly some aspects of the year-to-year variability.

7. HURRICANE DYNAMICS

Objectives

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

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

7. HURRICANE DYNAMICS

7.1 DYNAMICS OF TROPICAL DEPRESSIONS

ACTIVITIES FY78

Numerical simulations have been made to investigate the genesis mechanisms of a tropical depression. The numerical model used is an eleven-level primitive equation model with the open lateral boundaries at the north and the south. A cyclic condition is assumed in the west-east direction. Realistic initial conditions are specified for both the initial easterly wave and the basic background flow. The basic environmental conditions presently used are the GATE Phase III data of wind, temperature and humidities over the western Atlantic. Those data were provided by NHEML/NOAA. A few numerical experiments have been carried out with a coarse resolution model. Results from these preliminary experiments indicate that the adiabatic heating effects, both due to the condensation of water vapor and due to the radiational transfer, may play important roles in the genesis of a depression. At the same time, observed meteorological data in the past several years over the Caribbean were analyzed to learn about the interannual variability of the atmospheric conditions and its relationship to the variation in hurricane activities.

PLANS FY79

Simulation studies on the genesis of tropical depressions will continue. In addition to the thermodynamical effect, the dynamical effects such as the vertical and the horizontal wind shear will be taken into consideration. Also, experiments with a fine resolution model are planned.

7.2 NESTED MESH MODEL

ACTIVITIES FY78

The nested grid eleven-level model has been debugged and tested for a simple case. The accompanying static initialization scheme as well as the dynamic initialization scheme have been established. In one experiment, a strong dry vortex was successfully advected by a mean flow of 10 m s^{-1}. The integration was extended to 48 hours which involved over 50 inner nest movements. This particular test case used a triple nested grid system with 2:1 (between medium and fine) and 3:1 (between coarse and medium) grid size ratios. Although noise was excited when a mesh moved, it was suppressed in about three minutes after the mesh movement. In terms of the maximum vertical velocity, the suppressed noise level was in the order of 0.1 mm sec^{-1}.

PLANS FY79

The construction of a nested grid model will be complete with the inclusion of the effects of surface friction and moisture. Those effects will be added to the present model. Then, the model will be utilized to investigate the effect of model resolution on the movement of a vortex. Preparation for experiments using real data may start.

8. MESOSCALE DYNAMICS

Objectives

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

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

8.1 FRONTAL CIRCULATION AND SEVERE STORM OUTBREAKS

ACTIVITIES FY78

8.1.1 3-D Modeling Experiment

The three-dimensional model of the Mesoscale Dynamics Group is designed to model mesoscale phenomena in a limited-area domain using either the hydrostatic or anelastic assumption. The model uses z as a vertical coordinate with analytic stretching permitted. The lateral boundaries employ a modified version of the open boundary conditions described by Orlanski (249), appropriate to quasi-geostrophic flow. A nonlinear eddy viscosity is presently used which is dependent upon the local Richardson number.

A modeling experiment is currently being carried out which attempts to simulate the movement of a surface cold front taken from 12-hour observational data of the National Meteorological Center (NMC) 1977 point grid. This data has been transferred to the N40 stereographic grid of GFDL's Experimental Prediction Group using that group's objective analysis routines and then from the N40 grid to a coarse mesh Cartesian grid. After integrating the model for 24 hours, the data was used as a boundary condition for a fine mesh model. The frontal system chosen for the experiment occurred over Texas and Oklahoma on 12Z of May 1, 1967, and was moving in a south-easterly direction. Squall lines were observed to occur in association with the frontal system during the ensuing 36-hour period as the frontal system moved into the Gulf of Mexico.

The initial coarse model (MCRS.2) configuration chosen for this experiment incorporates a cartesian grid with x:y:z dimensions of 15x13x11 grid points. Grid increments are $\Delta x = \Delta y = 246$ km and $\Delta z = 1000$ m and imply a domain size of 3690:3198:9 km. The time step of 3 minutes is the same as that used in the fine mesh (MFIN) model with dimensions 40 x 30 x 11 grid point ($\Delta x = \Delta y = 60$ km, $\Delta z = 1000$ m).

After the Meso coarse model ran for 24 hours with data input from 12Z May 1 to 12Z May 2, the fine mesh model took as initial conditions and boundary data the spatial interpolated numerical solution of the Meso coarse, when an inflow condition was required. Since the time steps are the same in both models there was no need for time interpolation and less possibility for transient behavior due to initial conditions.

The fine mesh model started after 6 hours of the Meso coarse solution, and, after the completion of the 18-hour integration, both the coarse and fine solutions were very well correlated. In the fine mesh, a noticeable intensification of the front was observed, as expected. The lack of moisture prevented a full comparison with observations.

8.1.2 2-D Numerical Simulation

The effect of moisture on the dynamics of mature idealized cold front systems was investigated using a two-dimensional numerical model

(296). Lifting produced by the initial cross-stream frontal circulation previously studied (277) was shown to saturate the warm moist air above the nose of the front when initial humidity levels were sufficiently high. If the atmosphere was convectively unstable, this saturated air developed into deep convection with the convection-induced circulation overwhelming the initial frontal circulation. The initial development of convection was also shown to produce a gravity wave exhibiting similar scales to those of the convective zone. This wave propagated into the warm air at a much faster speed than the moving front-cloud system. Comparisons were made of the intensity of convection for different initial humidity and temperature conditions with and without a low-level capping inversion present.

As a test of sensitivity of the convective circulation associated with cold fronts in more stable atmospheres such as those characteristic of semi-arid zones, the warm air mass of the frontal model was initialized using monthly average soundings for temperature and relative humidity profiles at Bet-Dagan, Israel for January, April and October. The resulting solution (301) showed October and January to be more convectively unstable than April.

8.1.3 The Generation Interaction and Decay of Cyclones at High Latitudes

A linear stability study of the south hemispheric circulation shows that two sources of baroclinic instability, the well-known one at mid-latitudes and a second located at 55°S, are present. This study was extended through the use of a three-level spectral model in which cyclones were generated by baroclinic instability at midlatitudes. These midlatitude cyclones then migrated to higher latitudes and regenerated due to the local baroclinic zone. Comparison with actual observation is underway.

8.1.4 The Structure of the Diurnal Tide in the Lower 10 km

The theories describing the diurnal tide are satisfactory with regard to the stratospheric amplitude and phase. However, actual observations in the lower atmosphere show large discrepancies with these previous studies. A study, which includes the effects of variability of the boundary layer static stability and topography, has been started in order to explain the discrepancies.

PLANS FY79

The major effort in this coming year will be to complete the 36-hour simulation of a realistic frontal system by including realistic features in the 3-D model such as moisture effects, boundary layer physics and Reynolds stresses. Work on the generation, interaction and decay of cyclones at high latitudes will be completed after a comparison with observations. The work on the structure of the diurnal tide in the lower 10 km will be continued.

8.2 LABORATORY EXPERIMENTS

ACTIVITIES FY78

8.2.1 Resonant Interaction

Experiments involving the resonant interaction of internal gravity waves were performed at the Geophysical Fluid Dynamic's experimental laboratory. An internal gravity wave mode was excited in the experiment tank with frequency ω_1. A perturbation was then introduced at ω_2, such that a resonant "triad" interaction occurred; that is, energy was drawn from the primary ω_1 mode into the ω_2 mode, and a mode with frequency ω_3 then appeared.

The resonant process appears to be important in understanding the observed spectra of internal gravity waves in the ocean. Our experimental results show the energetics of the resonance process, and have been interpreted in light of a theoretical model developed by P. Ripa (ff) and numerical simulations using the Orlanski and Ross (160) model.

The results described in (gg) show that traid resonance is important to transfer energy when discreet waves are concerned. However, in the presence of a continuous spectra finite amplitude interaction is more important.

PLANS FY79

It is planned to study under what condition a saturation spectra for internal waves is achieved, and if the spectra that can be obtained in the tank have some relevance to the actual oceanic spectra.

8.2.2 Available Energy in Stable Stratified Fluids

A complete discussion of when and how a stably stratified fluid can decay into another stable stratification was presented in (hh). Under special conditions stable flows can lower their center of gravity and decay to a more stable fluid, the excess potential energy being released to produce mixing. This concept can modify our view of stable finite amplitude perturbations in stratified fluids. In nature the very long and thin microstructure that is observed in the ocean can be produced and maintained by such mechanisms.

PLANS FY79

The laboratory has the ability to produce different stable stratified profiles. We would like to test the possibility previously discussed.

9. CONVECTION AND TURBULENCE

Objectives

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

* To develop numerical models capable of simulating turbulence in 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 our understanding of its fundamental mechanisms.

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

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

9.1 CONVECTION

ACTIVITIES FY78

Research during the past year has focussed upon the improvement of subgrid-scale turbulence parameterization in numerical models simulating isolated dry thermals and clouds. It has been found that a model using K-theory, in which the vertical and horizontal coefficients of turbulent heat flux are equal, gives better results than the previous model using a simplified diagnostic second-order closure scheme to represent the sub-grid-scale turbulence.

This conclusion is shown most definitively in the simulation of an isolated three-dimensional dry thermal rising in a neutral environment. The laboratory data of Scorer and Woodward indicate the angle of spread α of a self-similar thermal to be α=13.2° and the ratio of the maximum upward velocity w_{max} to the strongest downward velocity w_{min} to be 4.2. Their data also show that the the maximum outflow velocity u_{out} is nearly equal to the maximum inflow velocity u_{in}. The numerical model with second order closure gives α=1.8°, the ratio $w_{max}/w_{min} \approx 30$. and u_{out} 3-5 times larger than u_{in} . The present model with K-theory gives α= 11.5°, $w_{max}/w_{min} \approx 5.2$ and $u_{out} \approx u_{in}$. The values of these parameters as well as the general appearance of the flow fields indicate that the K-theory model gives a far superior simulation of the laboratory thermals.

The K-theory model has also been used to simulate warm rain clouds when no mean wind is present. For one case, the cloud reached a maximum height of 5600 m and had a maximum vertical velocity w_{max} =14 m/sec and a maximum perturbation potential temperature $(\theta')_{max}$ = 1.9°C. The surface had a maximum cooling of 1.2°C and the total rain was 1.4 cm at the center of the shower. Although not as definitive as for the dry thermal, the K-theory numerical model does appear to give more realistic results for the warm rain cloud than the model using second order closure: the width to height ratio of the cloud is in better agreement with observations; the turbulence reaches the interior of the cloud; and the cold air pool formed at the ground due to the evaporation of rain remains throughout the time of the shower.

PLANS FY79

The numerical simulations for the dry thermal in a neutral environment will be completed and some calculations with a stable stratification will be made. The results of the dry thermal simulations will be summarized and submitted for publication. The above calculations for the warm rain cloud will be continued and the ability of the K-theory model to simulate deep moist convection with a vertical wind shear present will be tested. The model will also be tested for sensitivity to changes in the cloud physics parameterization.

Three-dimensional calculations are planned for shallow, intermediate and deep moist convection. A primary objective of these computations will be to study how moist convection acts to transfer water vapor, heat and momentum in the vertical. A long-term goal is to use the knowledge gained from convection modelling for improving cumulus-scale parameterizations in large-scale general circulation models.

9.2 TURBULENCE

ACTIVITIES FY77

9.2.1 Atmospheric Boundary Layer Simulations

A paper has been completed (aa) on simulations of the BOMEX data. A second moment turbulence closure model now includes condensation physics (261) and allows the prediction of mean liquid water specific humidity, liquid water variance and cloud fraction. These initial results are encouraging, but further comparisons with data and, probably, further model development are required.

9.2.2 Oceanic Boundary Layer Simulations

The second moment closure model has been applied to ocean surface boundary layers to simulate processes specific to low latitudes (bb). Some improvements in the "Level two and a half" model (185) have also resulted.

9.2.3 Laboratory Experiments

Two papers (cc, dd) describing laboratory studies of neutral and stratified decaying turbulence have been completed. In the stratified experiment the turbulence decay rate and correlation function were initially identical to the neutral data. Then the "turbulence" abruptly transisted to a random field of internal waves, the decay rate decreased greatly and the correlation function slowly changed.

PLANS FY79

During this period the effort on boundary layer simulation may be minimal but will probably be revived in FY80. Consideration of fundamental improvements in the basic closure scheme will continue.

9.3 ATLANTIC OCEAN COASTAL DYNAMICS MODEL

ACTIVITIES FY78

The three-dimensional coastal ocean model which predicts dynamical and thermodynamical behavior has become operational. The model has successfully incorporated a modified "sigma" coordinate system and the turbulence closure scheme discussed in 9.2.2. Since this model also accounts for tidal forcing, simulations were conducted (297) investigating the influences of density variations on the tidal dynamics. Also, various advection schemes were analyzed (1) to determine their numerical characteristics.

PLANS FY79

The coastal ocean dynamics model is currently being applied to the Middle Atlantic Bight. The problems associated with open boundary conditions will now become a key item of research. An attempt to gather synoptic observations will get underway and a program using these observations to verify the model will proceed. Other plans include the studying of coastal upwelling and shelf/slope interactions via a simplified version of the coastal model.

APPENDIX A

GFDL Staff Members

and

Affiliated Personnel

during

Fiscal Year 1978

* Affiliation Terminated Prior to September 30, 1978

Joseph Smagorinsky, Director
Leona Olschewski, Secretary
Howard M. Frazier, Executive Assistant
Janice Lizura, Secretary

CENTRALIZED SUPPORT SERVICES

Administrative and Technical Support

Shaffer, Daryl	Administrative Officer	FTP
Byrne, James	Jr. Technician	FTP
Caivano, Joan	Clerk (Summer)	FTT
Conner, John	Sr. Technician	FTP
D'Amico, Elaine	Administrative Clerk	FTP
Pope, Ingrid	Secretary	FTP
Kenety, Stephen	Jr. Technician	FTP*
Tunison, Philip	Sr. Technician	FTP
Ellis, William	Jr. Technician	FTP
Zadworney, Michael	Jr. Technician	FTP
Williams, Betty	Secretary	FTP
Kennedy, Joyce	Secretary	FTP

Computer Support

Welsh, James	Sr. Computer Sys. Ana.	FTP
Baker, Philip	Computer Systems Analyst	FTP
Lewis, Lawrence	Computer Systems Analyst	FTP
Newman, James	Computer Systems Analyst	FTP
Reek, Thomas	Sr. Computer Technician	FTP
Ent, Peter	Junior Fellow	PTT
Haines, James	Computer Technician	FTP
Uveges, Frank	Sr. Computer Technician	FTP
Franckowiak, Helen	Keypunch Operator	FTP
Heinbuch, Ernest	Sr. Computer Technician	FTP
Deuringer, Howard	Computer Technician	FTP
Kreuger, Mark	Computer Technician	FTP
Smith, Robert	Computer Technician	FTP
Schwartz, Henry	Sr. Computer Technician	FTP
Barber, Ellis	Computer Technician	FTP*
Brandbergh, Gerald	Computer Technician	FTP
Conover, Leonard	Computer Technician	FTP
Cordwell, Clara	Computer Technician	FTP
Hirsh, Merril	Clerk (Summer)	FTT*
King, John	Computer Technician	FTP
Miller, Almore	Computer Technician	FTP
Shearn, William	Sr. Computer Technician	FTP
Hand, Joseph	Computer Technician	FTP
Henne, Ronald	Computer Technician	FTP
Hopps, Frank	Computer Technician	FTP
Taylor, Thomas	Computer Technician	FTP

CLIMATE DYNAMICS

Manabe, Syukuro	Sr. Research Scientist	FTP
Fels, Stephen	Research Scientist	FTP
Hamilton, Kevin	Student	PU
Schwarzkopf, M. Daniel	Research Associate	FTP
Hahn, Douglas	Sr. Research Associate	FTP
Daniel, Donahue	Research Associate	FTP
Dimmick, Lanny	Senior Technician	FTP
Green, Edwin	Research Associate	FTP
Hayashi, Yoshikazu	Research Scientist	FTP
Golder, Donald	Research Associate	FTP
Held, Isaac	Research Scientist	FTP
Vacancy	Research Associate	FTP
Holloway, J. Leith Jr.	Sr. Research Associate	FTP
Thompson, Edna	Secretary	FTP
Meleshko, Valentin	Visiting Scientist	WG *
Spelman, Michael	Sr. Research Associate	FTP
Stouffer, Ronald	Research Associate	FTP
Trosnikov, I.V.	Visiting Scientist	WG *
Wetherald, Richard	Sr. Research Associate	FTP

MIDDLE ATMOSPHERE DYNAMICS AND CHEMISTRY

Mahlman, Jerry	Research Scientist	FTP
Lee, Yen-Huei	Student	PU
Levy, Hiram	Research Scientist	FTP
Moxim, Walter	Research Associate	FTP
Sinclair, Russell	Research Associate	FTP
Narvaez, Carmen	Junior Fellow	PTT

EXPERIMENTAL PREDICTION

Miyakoda, Kikuro	Sr. Research Scientist	FTP
Belle, Kenneth	Student	PU
Bourke, William	Visiting Scientist	PU *
Gordon, Charles	Research Scientist	FTP
Hovanec, Russell	Research Associate	FTP
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Sirutis, Joseph	Research Associate	FTP
Sheldon, John	Research Associate	FTP
Strickler, Robert	Sr. Research Associate	FTP
Chludzinski, Julius	Research Associate	FTP
Terpstra, Theodore	Research Associate	FTP
Jobson, C. T.	Research Associate	FTP
Ploshay, Jeffrey	Research Associate	FTP
White, Robert	Jr. Technician	FTP
Umscheid, Ludwig	Sr. Research Associate	FTP
Caverly, Richard	Research Associate	FTP
Davis, William	Research Associate	FTP

OCEANIC CIRCULATION

Bryan, Kirk	Sr. Research Scientist	FTP
Anderson, David	Visiting Scientist	PU *
Cox, Michael	Sr. Research Associate	FTP
Johnson, Clark	Research Associate	FTP
McGuirk, David	Research Associate	FTP
Seigel, Anne	Research Associate	FTP
Hellerman, Solomon	Research Associate	FTP
Hibler, William	Visiting Scientist	PU *
Hutchinson, Cynthia	Junior Fellow	PTT
Jackson, Martha	Sr. Technician	FTP
Philander, Samuel	Research Scientist	FTP
Pacanowski, Ronald	Research Associate	FTP
Strub, Paul	Student	PU *
Sardeshmukh, Prashant	Student	PU
Sarmiento, Jorge	Visiting Scientist	PU
Willebrand, Juergen	Visiting Scientist	PU *

PLANETARY CIRCULATIONS

Williams, Gareth	Sr. Research Scientist	FTP
Rossow, William	Visiting Scientist	PU *

OBSERVATIONAL STUDIES

Oort, Abraham	Sr. Research Scientist	FTP
Cilino, Laura	Junior Fellow	PTT*
Levitus, Sydney	Research Associate	FTP
Maher, Mary Ann	Junior Fellow	PTT
Rosenstein, Melvin	Senior Technician	FTP
Stefanick, Michael	Student	PU

HURRICANE DYNAMICS

Kurihara, Yoshio	Sr. Research Scientist	FTP
Bender, Morris	Research Associate	FTP
Gaeta, Andrew	Student	PU *
Tuleya, Robert	Sr. Research Associate	FTP

MESOSCALE DYNAMICS

Orlanski, Isidoro	Sr. Research Scientist	FTP
Cerasoli, Carmen	Visiting Scientist	PU
Garraffo, Zulema	Student	PU
Mechoso, Carlos	Student	PU
Polinsky, Larry	Research Associate	FTP
Ross, Bruce	Sr. Research Associate	FTP
Shaginaw, Richard	Research Associate	FTP
Wackter, David	Research Associate	FTP*

CONVECTION AND TURBULENCE

Lipps, Frank	Research Scientist	FTP
Hemler, Richard	Research Associate	FTP
Mellor, George	Professor	PU
Blumberg, Alan	Visiting Scientist	PU
Sun, Wen-yih	Visiting Scientist	PU
Rajkovic, Borivoje M.	Student	PU

GFD PROGRAM

Phinney, Robert	Professor	PU
Crough, Thomas	Visiting Scientist	PU
Longmuir Carolyn	Secretary	PU
Olsen, Esther	Secretary	PU
Spera, Frank	Visiting Scientist	PU

PERSONNEL SUMMARY

September 30, 1978

FTP - Full Time Permanent (GFDL)	95
Vacancies for FTP Positions (GFDL)	1
PTP - Part Time Permanent (GFDL)	0
Junior Fellows (GFDL)	6
Visiting Scientists (PU)	6
Students (PU)	8
Professors(PU)	2
Secretaries (PU)	2
Visiting Scientists (WG) - Through U.S.-U.S.S.R. Bilateral Agreement for Protection of the Environment Group VIII	3
	123

APPENDIX B

GFDL

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APPENDIX C

Computational Support

APPENDIX C

Computational Support

The average monthly Central Processing Unit hours (CPU-hrs.) realized during FY78 (see Table below) was about 5% less than the CPU-hrs. realized during FY77 and about the same as the average monthly CPU-hrs. obtained during FY76. In September 1977 the source of electrical power for GFDL was changed by Princeton University from an unusually "stiff" 138KV feeder to a more typical public utility (in terms of "stiffness") 26KV feeder. The 26KV source exhibited daily minor voltage fluctuations which one or more internal ASC power supplies reacted to, on occasion, by turning themselves off. Apparently, the expansion and contraction of ASC parts which resulted from the ensuing heating and cooling cycling, produced component failures which in turn took considerable time to identify and correct. Texas Instruments made modifications to the internal ASC power supplies and Princeton University installed capacitors in the GFDL substation early in FY79. These "fixes" seemed to reduce, but did not eliminate the problem.

The video tape portion of the Mass Storage System delivered by TI under a contract amendment continued to be unusable throughout the year. While the system passed its acceptance test in December 1976, it could not demonstrate subsequently, the interchangeability of tapes. That is, a tape written on one drive could not be read on another drive at a future time with the error rates specified in the acceptance tests. Texas Instruments made a major effort during FY77 and during the first three quarters of FY78 to correct this latent design defect. It apparently was not able to do so, and, on its own initiative ceased work on the video tape portion of the mass storage system and removed the drives from the GFDL building in mid-April 1978. Failure of the video tape subsystem (very high density tapes) requires GFDL to either double the size of its 20,000 reel tape library (the physical space for so doing is not conveniently available) or limit the tape library to its present size by scratching the results of ongoing experiments. Solutions were being sought at the end of the fiscal year.

A Request for Proposal (RFP) for replacing the Laboratory graphics recorder (SC-4020) was issued by the Department of Commerce on July 5, 1978. Vendor responses to the RFP were due early in the first quarter of FY79. Installation of the new graphics system is anticipated during the third quarter FY79. The new system will have resolution significantly greater than the SC-4020.

Preliminary specifications for a computer system to replace the ASC by FY81 were prepared during FY78. A request for proposal for a system with at least five times the throughput capability of the ASC is planned for release in mid FY79.

A feasibility study by Princeton University to add about 20,000 square feet to the existing GFDL building to house the new computer was completed in September 1978. The one-year construction phase of the addition is planned to begin in early summer 1979.

Table C-1 ASC and 4020 Usage

Month	ASC CPU-hours	4020 Frames
Oct. 77	513	53,782
Nov. 77	417	61,944
Dec. 77	519	56,866
Jan. 78	457	60,493
Feb. 78	481	39,861
Mar. 78	488	48,981
Apr. 78	517	60,135
May 78	430	54,387
Jun. 78	536	57,491
Jul. 78	566	62,611
Aug. 78	523	64,824
Sep. 78	517	70,508
Ave. per month, FY78	497.0	
Ave. per month, FY77	522.5	
Ave. per month, FY76	498.7	

APPENDIX D

Seminars Given at GFDL

During Fiscal Year 1978

October 5, 1977	"Mesoscale Eddies with Open Boundaries" by Dr. Dale B. Haidvogel, Harvard University, Cambridge, Massachusetts
October 5, 1977	"Can the Tides in the World Ocean be Determined from a Knowledge of the Tidal Potential Alone?" by Professor C. L. Pekeris, Weizman Institute, Tel Aviv, Israel
October 7, 1977	"Climate Feedback Mechanisms" by Professor Robert D. Cess, State University of New York at Stony Brook, Stony Brook, New York
October 12, 1977	"Preliminary Results of a General Circulation Model at the Laboratoire De Météorologie Dynamique" by Ms. Katia Laval, Laboratoire De Météorologie Dynamique, Paris, France
October 14, 1977	"Convection of Viscous Fluids: Energetics, Self-Similarity, Experiments, Geophysical Applications and Analogies" by Professor George S. Golitsyn, Institute of Atmospheric Physics, Academy of Sciences of the U.S.S.R., Moscow, U.S.S.R.
October 14, 1977	"Some Problems Concerning Lagrangian Motion of Air Particles in the Stratosphere" by Dr. Taroh Matsuno, National Center for Atmospheric Research, Boulder, Colorado
October 19, 1977	"The Effect of Upper Ocean Frontogenesis on the Temperature Field in a Numerical Model" by Dr. Malcolm MacVean, Institut für Meereskunde an der Universität Kiel, Federal Republic of Germany
October 19, 1977	"Forced Barotropic Model of the Venus Stratosphere" by Dr. William B. Rossow, GFD Program, Princeton, New Jersey
October 21, 1977	"Deep Antarctic Convection West of Maud Rise" and "Oceanic Meridional Heat Flux: Northern and Southern Hemispheres" by Dr. Arnold L. Gordon, Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York
October 25, 1977	"On the Accuracy of Determination of the Height of 500 mb Surface Using the System of World Weather Watch Stations and a Simulated Satellite Measuring System" by Dr. V. A. Ryasin, U.S.S.R. Hydrometeorological Centre, Moscow, U.S.S.R.
October 26, 1977	"Global Tectonics" by Dr. Thomas Crough, GFD Program, Princeton, New Jersey
November 2, 1977	"Numerical Simulation of Baroclinic Waves" by Dr. Ian James, United Kingdom Meteorological Office, Bracknell, United Kingdom
November 4, 1977	"The Structure and Energetics of Synoptic-Scale Disturbances in Western Africa and the Eastern Atlantic During GATE" by Dr. Robert W. Burpee, Weather Modification Program Office, National Hurricane and Experimental Meteorology Laboratory, Coral Gables, Florida

November 9, 1977	"A Continental Shelf Model" by Dr. Alan F. Blumberg, GFD Program, Princeton, New Jersey
November 10, 1977	"Regional Scale Numerical Weather Prediction" by Professor Carl W. Kreitzberg, Drexel University, Philadelphia, Pennsylvania
November 16, 1977	"A Movable Nested Mesh Model" by Dr. Yoshio Kurihara and Mr. Morris Bender, GFDL, Princeton, New Jersey
November 28, 1977	"Diagnostic Calculations Using GFDL Density Data" by Professor A. S. Sarkisyan, Shirshov Institute of Oceanology, Moscow, U.S.S.R.
November 28, 1977	"On the Problem of Baroclinic Instability of Ocean Currents" by Dr. Yu. Ivanov, Shirshov Institute of Oceanology, Moscow, U.S.S.R.
November 28, 1977	"A Uniform Treatment of Non-Ekman Boundary Layers for a Rotating Fluid" by Dr. Roger Gans, University of Rochester, Rochester, New York
November 29, 1977	"Eddy-Resolving General Circulation Model" by Dr. D. Seidov, Shirshov Institute of Oceanology, Moscow, U.S.S.R.
November 29, 1977	"Internal Wave Theory" by Dr. L. Cherkesov, Marine Hydrophysical Institution, Sevastopol, U.S.S.R.
November 30, 1977	"Atmospherically-Forced Oceanic Variability" by Dr. Juergen Willebrand, GFD Program, Princeton, New Jersey
December 7, 1977	"Control Experiments of Tropical Planetary Waves" by Dr. Yoshikazu Hayashi and Mr. Donald Golder, GFDL, Princeton, New Jersey
December 14, 1977	"Medium Range Weather Forecasts in Summer" by Dr. Kikuro Miyakoda, GFDL, Princeton, New Jersey
December 15, 1977	"Energetics Diagnosis of the NCAR General Circulation Model" by Mr. Wayman E. Baker, University of Missouri - Columbia, Columbia, Missouri
December 21, 1977	"Precipitation in the Hemispheric Prediction Model" by Mr. Daniel G. Hembree, GFDL, Princeton, New Jersey
January 3, 1978	"A Three-Dimensional Numerical Model of an Isolated Thunderstorm: Results of an Experiment with Directional Ambient Wind Shear" by Mr. Robert E. Schlesinger, University of Wisconsin, Madison, Wisconsin
January 12, 1978	"Internal Modes of a Stratified Fluid: Part I. Internal Gravity Waves in a Shear Flow" by Dr. S. A. Thorpe, Institute of Oceanographic Sciences, Surry, England
January 12, 1978	"Internal Modes of a Stratified Fluid: Part II. Turbulence on Loch Ness; Studies in a Natural Laboratory" by Dr. S. A. Thorpe, Institute of Oceanographic Sciences, Surry, England Held at Guyot Hall, Princeton University, Princeton, New Jersey

January 26, 1978	"Monsoon Predictability" by Dr. Jagadish Shukla, Massachusetts Institute of Technology, Cambridge, Massachusetts
February 2, 1978	"Origin and Structure of Easterly Waves Over Africa and the Eastern Atlantic" by Professor Richard J. Reed, Department of Atmospheric Sciences, University of Washington, Seattle, Washington
February 11, 1978	"Time Scales for Oceanic Mixing as Seen from the GEOSECS Results" by Dr. Wallace S. Broecker, Columbia University, Lamont-Doherty Geological Observatory, Palisades, New York
February 27, 1978	"Social Aspects of Ecological Problems" by Academician Yevgeni K. Federov, U.S.S.R.
February 28, 1978	"Regional Kinetic Energy Budgets in Turbulent Flows: The Gulf Stream and Mesoscale Motions" by Dr. D. E. Harrison, Harvard University, Cambridge, Massachusetts
March 2, 1978	"Dynamic-Thermodynamic Sea-Ice Model" by Dr. William Hibler, U.S. Army Cold Regions Research & Engineering Laboratory, Hanover, New York
March 3, 1978	"On the Three-Dimensional Structure of the Observed Transient Eddy Statistics of the Northern Hemisphere Wintertime Circulation" by Mr. Ngar-Cheung Lau, University of Washington, Seattle, Washington
March 30, 1978	"Some Results from Simulations of January Climate with a Main Geophysical Observatory Model" by Dr. Valentin P. Meleshko, Main Geophysical Observatory, Lenningrad, U.S.S.R.
April 7, 1978	"Observations of Time Dependent Motions in the Equatorial Atlantic" by Professor Robert H. Weisberg, North Carolina State University at Raleigh, Raleigh, North Carolina
April 11, 1978	"Modeling Activities at Meteorological Office, Bracknell, England" by Mr. Andrew Gilchrist, Deputy Director, Dynamical Research, Meteorological Office, Bracknell, Berkshire, England
April 12, 1978	"Equatorial Jets" by Dr. S.G.H. Philander, GFDL, Princeton, New Jersey
April 14, 1978	"Another Look at Long and Short Waves" by Dr. Frederick Sanders, Department of Meteorology, Massachusetts Institute of Technology, Cambridge, Massachusetts
April 24, 1978	"Large Scale Aspect of Cumulus Convective Activity over the GATE Area" by Dr. Masato Murakami, Research Institute of Japan Meteorological Agency, Tokyo, Japan
April 26, 1978	"Mesoscale Circulation Development Along the California Coast as Observed by Satellite Imagery" by Dr. Robert Bernstein, Norpax Project, Scripps Institute of Oceanography, University of California at San Diego, La Jolla, California

April 27, 1978	"A Mechanism for the Estuarine Turbidity Maximum: the Physics of a Negative Dispersion Process with Some Application to the New York Bight" by Dr. Donald V. Hanson, Director, Physical Oceanography Laboratory, Atlantic Oceanographic & Meteorological Laboratory, Miami, Florida
April 28, 1978	"Earth and Mars: Some Meteorological Comparisons" by Professor Conway Leovy, Department of Atmospheric Sciences, University of Washington, Seattle, Washington
May 1, 1978	"Boundary Layer Flow over Topography" by Dr. P.J. Mason and Dr. R.I. Sykes, Bracknell, Berkshire, England
May 4, 1978	"The Effects of Bottom Topography and Benthic Stratification on the Formation of a Western Boundary Current" by Dr. Nubuo Suginohara, Geophysical Institute, University of Tokyo, Tokyo, Japan
May 5, 1978	"Recent Fine Resolution Tests at the National Meteorological Center (NMC)" by Dr. Norman Phillips, National Meteorological Center, National Weather Service, National Oceanic & Atmospheric Administration, Washington, DC
May 5, 1978	"A Simulation of the BOMEX Data by a Second-Order Closure Model Including an Ensemble Condensation Scheme" by Dr. Tetsuji Yamada, Atmospheric Physics Section, Radiological & Environmental Research Division, Argonne National Laboratory, Argonne, Illinois
May 9, 1978	"The Closure Problem of the Time-Averaged Atmosphere" by Dr. Huug van den Dool, Royal Netherlands Meteorological Institute, De Bilt, Netherlands
May 10, 1978	"The Vertical Scale of an Unstable Baroclinic Wave" by Dr. Isaac Held, Center for Planetary Physics, Department of Atmospheric Sciences, Harvard University, Cambridge, Massachusetts
May 18, 1978	"Mixing in the Deep Ocean: the Importance of Boundaries" by Dr. Lawrence Armi, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
May 23, 1978	"Energy Balance Climate Models" by Dr. Huug van den Dool, Royal Netherlands Meteorological Institute, De Bilt, Netherlands
May 25, 1978	"Poleward Heat Flux and Conversion of Available Potential Energy in Drake Passage" by Dr. Harry Bryden, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
May 26, 1978	"Exact Solutions for Edge Waves and Billows in a Rotating Fluid" by Professor Erik Mollo-Christensen, Department of Meteorology, Massachusetts Institute of Technology, Cambridge, Massachusetts
June 7, 1978	"Recent Results from a Sensitivity Study Including Changes in CO_2" by Richard Wetherald, GFDL, Princeton, New Jersey
June 13, 1978	"Isolated Vortices: Modons. Application to Atmospheric Predictability and Blocking" by Dr. James McWilliams, National Center for Atmospheric Research, Boulder, Colorado

June 15, 1978	"NWP Experiments with a Spectral Model" by Dr. William Bourne, Australian Numerical Meteorology Research Centre, Melbour,e Victoria, Australia
June 15, 1978	"A Study in Tornado-Like Vortex Dynamics" by Dr. Richard Rotunno, Cooperative Institute for Research in Environmental Sciences, University of Colorado, National Oceanic & Atmospheric Administration, Boulder, Colorado
June 21, 1978	"Space-Time Spectral Analysis of Transient Wave Packets" by Dr. Yoshikazu Hayashi, GFDL, Princeton, New Jersey
June 22, 1978	"Winter Monsoonal Surges over East Asia" by Dr. Takio Murakami, Department of Meteorology, University of Hawaii, Honolulu, Hawaii
June 28, 1978	"On the Thermodynamic Equation for Deep Moist Convection" by Dr. Frank Lipps and Mr. Richard Hemler, GFDL, Princeton, New Jersey
July 13, 1978	"Recent Observations of the Equatorial Undercurrent in the Pacific Ocean" by Dr. David Halpern, University of Washington, National Oceanic & Atmospheric Administration, Seattle, Washington
July 21, 1978	"Organization of the European Centre for Medium Range Weather Forecasts Spectral Model" by Dr. Fons Baede, European Centre for Medium Range Weather Forecasts, Bracknell, Berkshire, England
July 28, 1978	"Beta-Spiral and Absolute Velocities in Different Oceans" by Professor Friedrich Schott, Institut für Meereskunde an der Universität Kiel, Kiel, Germany
September 11, 1978	"Numerical Simulation of the Equatorial Ocean Circulation" by Dr. A.J. Semtner, National Center for Atmospheric Research, Boulder, Colorado
September 18, 1978	"A Potential-Enstrophy Conserving Scheme and the New UCLA General Circulation Model" by Professor Akio Arakawa, Department of Meteorology, University of California, Los Angeles, California
September 20, 1978	"Global 3-D Cloud Distribution and its Climatic Implication" by Dr. Valentin P. Meleshko, Main Geophysical Observatory, Leningrad, U.S.S.R.
September 27, 1978	"Boundary Layer Forcing for a Squall Line Formation" by Mr. Wen-yih Sun, Geophysical Fluid Dynamics Program, Princeton, New Jersey
September 28, 1978	"Numerical Simulation of Tides and Internal Waves Induced by Tides" by Dr. N. Grijalva, Centro de Ciencias de la Atmosfera, Universidad Autonoma de Mexico, Mexico

APPENDIX E

TALKS, SEMINARS AND PAPERS PRESENTED OUTSIDE GFDL

DURING FISCAL YEAR 1978

FY-78

TALKS, SEMINARS AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1977 through September 30, 1978

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
October 10, 1977	Mr. Theodore B. Terpstra "GFDL Plan for FGGE Level III-b Data"	Second Session of the Board of Review of Level III-b Data for the First GARP Global Experiment Bracknell, England
October 12, 1977	Mr. Sydney Levitus "Global Analysis of Oceanographic Data"	Lawrence Livermore Radiation Laboratory Livermore, California
October 13, 1977	Dr. Isidoro Orlanski "The Dynamics of Atmospheric and Oceanic Fronts"	Chapman Conference on Oceanic Fronts New Orleans, Louisiana
October 18, 1977	Dr. Kikuro Miyakoda "An Attempt at One-Month Forecasts of the Event of January 1977"	Climate Diagnostics Workshop, 1977 Scripps Institute of Oceanography La Jolla, California
October 19, 1977	Mr. Sydney Levitus "Global Analysis of Oceanographic Data" "Present Status of Climate Data in Oceanography - the Heat Storage Problem"	NOAA Climate Diagnostics Workshop Scripps Institute of Oceanography La Jolla, California
October 19, 1977	Dr. Jerry D. Mahlman "Some Aspects of Climatic Response to Large Ozone Reductions"	Committee Meeting on Impacts of Stratospheric Change National Academy of Sciences Harrisburg, Pennsylvania
October 21, 1977	Dr. Kikuro Miyakoda "Comparative Studies on the Subgrid-Scale Transports"	Department of Meteorology UCLA Los Angeles, California
October 26, 1977	Dr. Isidoro Orlanski "Numerical Studies of the Relationship of Atmospheric Parameters to the Outbreak of Severe Storms"	Mesoscale Modeling Workshop ERL Boulder, Colorado

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TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1977 through September 30, 1978

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
October 26, 1977	Dr. Bruce B. Ross "Numerical Studies of the Relationship of Atmospheric Parameters to the Outbreak of Severe Storms"	Mesoscale Modelling Workshop ERL Boulder, Colorado
October 31, 1977	Dr. Isidoro Orlanski "Circulation Associated with a Cold Front for Dry and Moist Conditions"	Int'l Conference on the Meteorology of Semi-Arid Zones Tel Aviv, Israel
December 5, 1977	Mr. Michael D. Cox "A Numerical Study of Surface Cooling Processes During Summer in the Arabian Sea"	Joint IUTAM/IUGG Symposium on Monsoon Dynamics New Delhi, India
December 13, 1977	Dr. Yoshio Kurihara "A Movable Nested Mesh Primitive Equation Model"	11th Technical Conference on Hurricanes and Tropical Meteorology of AMS Miami Beach, Florida
December 13, 1977	Dr. Yoshikazu Hayashi "Control Experiments of Equatorial Planetary Waves Simulated by a GFDL General Circulation Model"	11th Technical Conference on Hurricanes and Tropical Meteorology of AMS Miami Beach, Florida
January 10, 1978	Mr. Theodore B. Terpstra "GFDL Use of Satellite-Derived Winds in Producing FGGE Level III-b Data Sets"	Working Meeting on Quality Control Aspects of Satellite-Derived Winds Madison, Wisconsin
January 16-25, 1978	Dr. Kirk Bryan "Ocean Circulation and Climate"	Four lectures at the Institute of Oceanography University of British Columbia
January 27, 1978	Dr. Kirk Bryan "Coupled Ocean Climate Models"	Institute of Oceanographic Science, Environment Canada, Patricia Bay British Columbia
February 3, 1978	Mr. Sydney Levitus "Global Analysis of Oceanographic Data"	National Oceanic Data Center Washington, DC

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TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1977 through September 30, 1978

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
February 14, 1978	Dr. Syukuro Manabe "Mathematical Models and the Sensitivity Study of Future Climate"	AAAS Annual Meeting Washington, D.C.
February 15, 1978	Dr. Jerry D. Mahlman "GFDL Research on Modeling of Atmospheric Transport and Chemistry"	Meeting of Panel on Middle Atmosphere Program (MAP) Boulder, Colorado
March 9, 1978	Dr. Abraham H. Oort "The Global Climate System"	Department of the Geophysical Sciences University of Chicago Chicago, Illinois
April 3, 1978	Mr. Richard T. Wetherald "Response to Changed Solar Constant and CO_2"	GARP/WMO Conference on Climate Modeling and Climate Sensitivity Washington, D.C.
April 3, 1978	Dr. Kirk Bryan "Review of Oceanic General Circulation Models"	GARP Conference on Climate Models Washington, D.C.
April 3, 1978	Dr. Syukuro Manabe "Climate Simulations Using Spectral Models"	JOC Study Conference on Climate Models National Academy of Sciences Washington, D.C.
April 3, 1978	Mr. Douglas G. Hahn "A GFDL AGCM Response to Ice-Age Boundary Conditions"	JOC Study Conference on Climate Models National Academy of Sciences Washington, D.C.
April 3, 1978	Dr. Joseph Smagorinsky "Overview of the Climate Modeling Problem"	JOC Study Conference on Climate Models National Academy of Sciences Washington, DC

TALKS, SEMINARS AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1977 through September 30, 1978

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
April 3, 1978	Dr. Abraham H. Oort "Views of the Future Development, Application and Validation of GCM's"	JOC Study Conference on Climate Models Washington, DC
April 4, 1978	Dr. Jerry D. Mahlman "Evaluation of Various Total Ozone Sampling Networks Using the GFDL 3-D Tracer Model"	Meeting of the "Working Group on Monitoring of the Stratosphere" of the "Federal Committee for Meteorology and Applied Meteorology Research" Rockville, Maryland
April 12, 1978	Mr. Theodore B. Terpstra "GFDL Quality Control Information Needs for FGGE Level II-b Data"	NCAR Meeting of Experts on Quality Control Boulder, Colorado
April 22 - May 4, 1978	Mr. Theodore B. Terpstra "GFDL Plan of FGGE Level III-b Data Interfacing"	Three lectures given at Obninsk, U.S.S.R. Norrköping, Sweden Bracknell, England
April 24, 1978	Dr. George Philander "The Equatorial Undercurrent"	Tropical Oceanography Meeting New York, New York
May 15, 1978	Dr. George Philander "The Oceanic Circulation and its Variability as Observed During GATE"	GATE Symposium on Oceanography Kiel, Germany
June 13, 1978	Mr. Richard T. Wetherald "Sensitivity Studies of Climate Involving Changes in CO_2 Concentration"	Conference of Man's Impact on Climate (MIC) sponsored by Umweltbundesamt Department of the Interior Berlin, Federal Republic of Germany

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TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1977 through September 30, 1978

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
June 26, 1978	Mr. Walter J. Moxim "Evaluation of Various Total Ozone Sampling Networks Using the 3-D GFDL Tracer Model"	WMO Symposium on the Geophysical Aspects & Consequences of Changes in the Composition of the Stratosphere Toronto, Canada
June 26, 1978	Mr. Russell W. Sinclair "Simulated Response of the Atmospheric Circulation to a Large Ozone Reduction"	WMO Symposium on the Geophysical Aspects and Consequences of Changes in the Composition of the Stratosphere Toronto, Canada
June 26, 1978	Dr. Hiram Levy, II "Simulation of the Three-Dimensional Structure and Variability of Atmospheric N_2O"	WMO Symposium on the Geophysical Aspects & Consequences of Changes in the Composition of the Stratosphere Toronto, Canada
June 26, 1978	Mr. Daniel Schwarzkopf "Sensitivity of a General Circulation Model to a Change in Short Wave Radiation Code"	Third Conference on Atmospheric Radiation Davis, California
June 26, 1978	Dr. Stephen B. Fels "Stratospheric Effects of Doubled CO_2 Concentrations in a G.C.M." "An Accurate Fast Algorithm for the Calculation of CO^2 Stratospheric Cooling Rates"	Third Conference on Atmospheric Radiation Davis, California
July 14, 1978	Dr. Jerry D. Mahlman "Some Preliminary Results from the GFDL Troposphere-Stratosphere-Mesosphere General Circulation Model"	NCAR Summer Colloquium on the General Circulation of the Atmosphere Boulder, Colorado
July 20, 1978	Dr. Jerry D. Mahlman "Large-Scale Atmospheric Tracer Behavior: Implications from General Circulation Model Experiments"	NCAR Summer Colloquium on the General Circulation of the Atmosphere Boulder, Colorado

TALKS, SEMINARS, AND PAPERS PRESENTED OUTSIDE GFDL
October 1, 1977 through September 30, 1978

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
August 21, 1978	Mr. Michael D. Cox "Numerical Study of Somali Current Eddies"	"Pine" Workshop (Numerical Modellers of Ocean Circulation) NCAR Boulder, Colorado
August 24, 1978	Dr. Abraham H. Oort "On the Oceanic Heat Transport"	NORPAX Climate Group Scripps Institution of Oceanography La Jolla, California
August 24, 1978	Dr. Kirk Bryan "Circulation of the North Atlantic and Tracer Studies"	"Pine" Workshop on Numerical Models in Ocean Circulation NCAR Boulder, Colorado
September 18, 1978	Mr. Michael D. Cox "Numerical Models of the Indian Ocean"	Workshop on Numerical Modelling of Ocean Circulation Paris, France
September 18, 1978	Dr. George Philander "Variability of the Tropical Oceans"	Workshop on Numerical Modelling of Ocean Circulation Paris, France
September 25, 1978	Dr. Jorge Sarmiento "Tritium and Bomb Radiocarbon Dispersion in the GFDL Atmospheric Driven Ocean Model"	Tracer and Mixing Seminar Series Lamont-Doherty Geological Observatory Palisades, New York
September 29, 1978	Dr. Syukuro Manabe "Studies of the Sensitivity of Climate to Variation in Cloudiness and/or its Treatment in Climate Models"	JOC Study Conference on the Parameterization of Extended Clouds and Radiation for Climate Models" London, England