GFDL

GEOPHYSICAL FLUID DYNAMICS LABORATORY

ENVIRONMENTAL RESEARCH LABORATORIES

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

ACTIVITIES - FY77

PLANS - FY78

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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-term 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 1977; 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 FY78; a listing of seminars presented at GFDL during Fiscal Year 1977; a listing of seminars and talks presented during Fiscal Year 1977 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 1977

The low resolution joint ocean-atmosphere general circulation model was integrated for a period of five model years, with seasonally varying insolation. A preliminary analysis of the results indicates that the responding seasonal variation of hemispheric mean surface air temperature and oceanic heat storage are well simulated. This is especially significant in view of the fact that the cloud distribution is pre-specified and constant in time.

In a related study, the effects of cloud-radiation feedback on surface temperature were examined in a general circulation model equipped with a simple cloud prediction scheme. Experiments in which the solar constant was altered somewhat from its present value were conducted, and the results compared with a parallel experiment in which cloud cover was pre-specified. It was found that although both cloud amount and cloud height are altered by changes in the insolation, the two effects cancel to a large extent, leading to only a small cloud-feedback effect, for the particular cloud parameterization used.

Using the three-dimensional tracer model, a successful short-cut technique has been employed which, for the first time, allows a full investigation of nitrous oxide, a long-lived trace constituent of great importance in atmospheric chemistry. The model results show very encouraging agreement with available observations. Predictions from this model on the expected variability of nitrous oxide are already being utilized to guide strategies for in-situ observations of this and similar trace constitutents.

Using a high-resolution numerical model, it was shown that mesoscale disturbances which develop in the Somali current are effective in carrying the cold water which wells up at the Somali Coast into the interior of the Arabian Sea. The behavior of those meanders is very closely linked to the thermal and hydrologic regime of the Arabian Sea. Satellite sea surface temperature data for the Somali current as well as ship-based measurements confirm this conclusion.

A relationship between the Jovian and Terrestrial circulation regimes was discovered by use of a single general circulation model run under various parameter settings. The greater number of jets on Jupiter results from its large size and high rotation rate relative to the Earth, while their higher zonality may be due to the absence of large surface drag.

The effect of surface roughness, as well as the distribution of latent energy, was found to play an important role in the change in a hurricane's intensity after landfall. Analysis of experiments performed with a previously constructed three-dimensional model shows that increased roughness acts to strengthen the boundary layer inflow, so that were not evaporation suppressed over land, such a model storm could actually deepen upon landfall.

In the course of investigating the effects of moisture on the dynamics of frontal systems, it was found that the effect of a capping inversion is to delay the onset of convection until it is finally triggered by frontal lifting. It is thought that the scale and intensity of storms produced by this mechanism will be greater than those which would be triggered by diurnal heating in the absence of the capping inversion.

A study of three different parameterizations of subgrid-scale vertical mixing in a numerical weather prediction model was begun. That with the turbulent closure parameterization of Mellor and Yamada gave a 10 day forecast significantly better than that produced when a conventional mixing length scheme and a dry convective adjustment were used.

Using a nested grid model, which consisted of a fine resolution limited-area (covering the entire contiguous United States) mesh embedded in a coarser grid hemispheric model, an experiment was carried out which produced a detailed rainband structure associated with a front. The sea level pressure pattern has increased variance and sharpness compared with that of the coarser grid model. The fine grid had horizontal resolution of 34 km, while that of the hemispheric model was 135 km.

SOME IMMEDIATE OBJECTIVES

An experiment to assess the climatic effect of doubled CO_2 will be run using a simplified ocean-atmosphere model with idealized continental distribution under seasonally varying insolation. It is hoped that this will lead to improved understanding of the global and regional effects of seasonal variation on climatic sensitivity.

Radiative-convective studies will be carried out to examine the possibility that large changes in atmospheric composition may have resulted in significant temperature changes in the geologic past. Attempts to place limits on changes in chemical composition will continue.

The hypothesis that the combined effects of sea-surface temperature, land albedo, sea-ice extent, and sea-ice temperature may have important effects on the prediction of anomalous interannual events will be examined in a spectral model, using the January 1977 event as a test case.

A spectral model will be used for four-dimensional assimilation of data for FGGE (First GARP Global Experiment). This will entail considerable reprogramming of the existing model.

The ability of the World Ocean Model to form water masses will be exploited in a number of experiments designed to study tracers such as oxygen, C^{14}, and tritium. Comparison of the results with data from the GEOSECS program should provide insight into the role played by the ocean in the uptake of CO_2 produced by the burning of fossil fuels.

Analysis of the global atmospheric data for the period May 1958 through April 1973 will be completed. Long term mean and seasonal statistics will be discussed, as well as interannual variability, providing a basic climatological reference for the interpretation of FGGE results.

A numerical investigation of the formation of a tropical depression from an easterly wave will be begun. The model will use a low order turbulent closure scheme, rather than the presently employed dry convective adjustment.

In order to produce a more realistic 36 hour simulation of a frontal system, moisture effects, boundary layer physics, and Reynolds stress terms will be included in a three dimensional mesoscale model.

A three dimensional model of the Atlantic coastal region will be used for studies of the Middle Atlantic Bight. A data set already constructed for this region will provide both boundary conditions and verification data for a year-long climatological simulation. Pollution dispersion simulations for this region will be carried out with the models using both Eulerian and Lagrangian methods.

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

ACTIVITIES FY77

This project is a collaborative effort between the Oceanic Circulation Group and the Climate Dynamics Group of the Geophysical Fluid Dynamics Laboratory. The immediate goal of this project has been the construction of a mathematical model of the joint ocean-atmosphere system which simulates the seasonal variation of the climate and oceanic state. During this fiscal year, the numerical time integration of a joint model with seasonal insolation was completed. The finite difference grid size was about 250 km for the atmospheric part and about 500 km for the oceanic part of the joint model. A detailed analysis of the results from this integration is currently in progress. It is of interest that the seasonal variations of hemispheric mean values of the oceanic heat storage and surface air temperature are well simulated despite the model assumption of constant cloud distribution with time. In Figure 1.1, the geographical distribution of the annual range of surface air temperature derived from the joint model is compared with the corresponding distribution for the actual atmosphere. According to this comparison, there are significant differences between the computed and observed distributions. Nevertheless, it is encouraging that the general features of the distributions over both the Pacific and the Atlantic Ocean are successfully simulated. In addition, the results indicate that the phases of the seasonal variations of surface air temperature over both continents and oceans were accurately reproduced by the model. Further improvement in simulating the seasonal variation of ocean surface temperatures may be accomplished by increasing the vertical grid resolution near the ocean surface.

PLANS FY78

Encouraged by the success in simulating the response of the joint system to an external forcing, namely, the seasonal variation of insolation, we plan to use a joint model for the study of climate sensitivity. One of the most serious obstacles to the use of a joint model for extensive experimentation is the large amount of computer time required for the numerical integration of the model over extended periods of time. Specifically, a major part of computer time has been spent for the integration of the atmospheric part of the model. Therefore, an economical version of a joint ocean-atmosphere model will be constructed, in which a finite difference model of the atmosphere is replaced by a highly truncated spectral model. Such a model requires relatively little computer time for time integration because of high spectral truncation and the usage of a semi-implicit time differencing scheme. Nevertheless, it is very useful for obtaining a preliminary estimate of climate sensitivity. During the next fiscal year, the major emphasis of this project will be directed towards the development and the validation of this economical version of the joint model.

SURFACE AMBIENT TEMPERATURE (AUG.-FEB.)

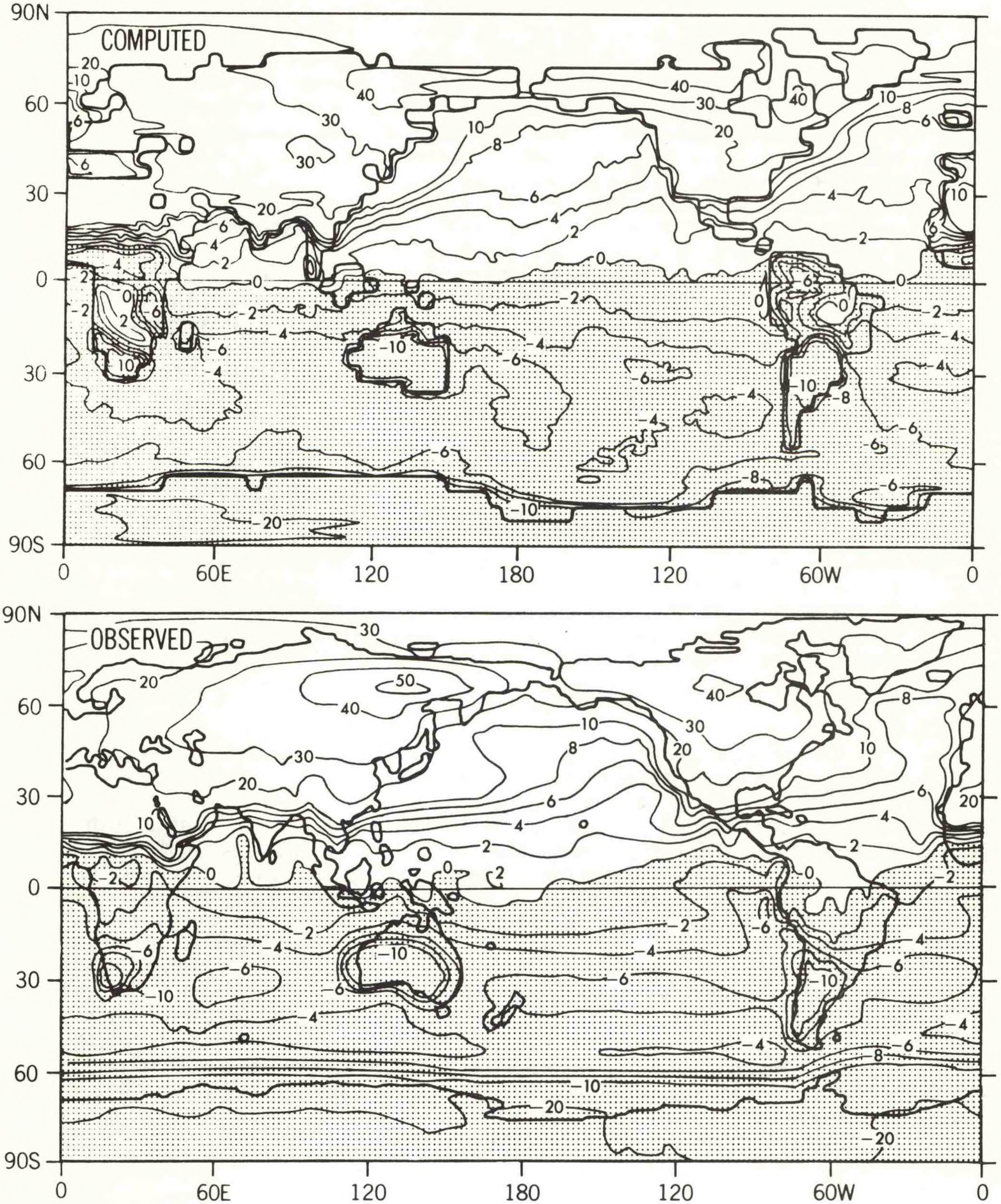

Figure 1.1. Geographical distribution of the annual range (August-February) of surface air temperature (degrees).

1.2. CLIMATE SENSITIVITY

1.2.1. Cloud-Radiation Feedback

ACTIVITIES FY77

It is known that cloud cover strongly affects the field of radiation in the atmosphere by reflecting solar radiation and emitting terrestrial radiation, and it has been suspected that the cloud cover-radiation feedback mechanism significantly affects the response of climate to external or internal stimuli. During the previous and current fiscal year, we have investigated how this feedback mechanism influences the sensitivity of climate to the change in the solar constant. For this study, we used a so-called sector atmospheric model in which a pie-shaped computational domain is bounded by two meridians and the equator and occupies one third of the hemisphere. It is further assumed that half of this domain is occupied by continent and the other half is a wet swamp-like ocean with no heat capacity. The prognostic scheme of cloud cover is made as simple as possible for ease of interpretation: whenever air is saturated, cloud cover is assumed. However, zero cloudiness is predicted in the case of undersaturation.

To evaluate the influence of cloud radiation feedback mechanisms, two series of numerical experiments are conducted. In the first series, the sector model is used with the cloud prediction scheme described above. In the second series, the sector model is assumed to have a given distribution of cloud. In both sets of experiments, the equilibrium climates of the model are obtained for various values of the solar constant through a long term integration of the model. A comparison of the results from these two sets of experiments indicates that the cloud radiation feedback mechanism has little effect upon the overall magnitude of the response of the model climate to a change in solar constant. It is found that in lower latitudes the increase of the solar constant intensifies the hydrological cycle, increases the magnitude of vertical velocity, increases the precipitation rate of moisture and thus reduces the area-mean relative humidity and cloudiness in the middle and upper troposphere. The net effect of these changes is the reduction of both cloud amount and effective cloud height. The reduction of cloud amount reduces the reflected solar radiation and the reduction of effective cloud height increases the outgoing terrestrial radiation. The cancellation between these two effects is responsible for the small magnitude of the influence of cloud radiation feedback upon the sensitivity of the model climate.

PLANS FY78

In view of the large uncertainty involved in the determination of the optical properties of clouds, it is planned to investigate how the sensitivity of the model climate, which is described above, is affected by the choice of the values of the optical parameters (i.e., the albedo of cloud).

It is also planned to validate the cloud prediction scheme utilizing global distributions of total cloudiness and of reflected solar radiation and outgoing terrestrial radiation which are determined by satellite observations. For this purpose, a numerical time integration of a global atmospheric model with a cloud prediction system is in progress. The model assumes realistic distributions of sea-surface temperature and geography as a lower boundary condition.

1.2.2. CO_2-Experiment

ACTIVITIES FY77

The sector climate model (with a cloud-radiation feedback mechanism), which is described above, is also used for evaluating the climatic response to the doubling of CO_2 content of the atmosphere. In general, the results obtained from this experiment are similar to those from an earlier study of a similar kind (192). It is of interest that the geographical distribution of the change in model climate in response to the increase of CO_2 is far from uniform. For example, the following changes are noted:

1. A general poleward shift of climatic zones. In particular, aridity of the latitude belt 35-45° increases due to the poleward shift of the rainbelt in middle latitudes.

2. A general reduction of the aridity in the eastern half of subtropical continents.

Qualitatively similar changes of model climate occurred in response to the increase of solar constant (see Section 1.2.1).

PLANS FY78

It is planned to repeat the CO_2-doubling experiment by use of a sector-atmospheric-ocean model in which seasonal variation of insolation is taken into consideration. For the economy of computation, the oceanic part of the model will consist of a simple one-layer mixed layer. Through this study, it is hoped to get some insight into the effect of seasonal variation upon the sensitivity of climate.

1.3. PALEOCLIMATE

1.3.1. Reconstruction of Ice Age Climate

ACTIVITIES FY77

Recently, reconstruction of the conditions which prevailed during the last major ice age (last Wisconsin glaciation) has been undertaken by a group of geologists, the CLIMAP group. Using data from deep sea cores and other geological data, they have reconstructed the global distributions of sea surface temperature, continental ice sheets and albedo during the last major ice age which took place approximately 18,000 years ago. Using these data as a boundary condition, we have attempted to simulate an ice age climate by means of a long-term integration of a global general circulation model developed at GFDL. It is hoped that this study will yield some insight into how climate and general circulation are maintained during an ice age. In addition, this research may indicate how climate responds to anomalous distributions of sea-surface temperature and ice cover.

Analysis of the results from this numerical experiment reveals that, during an ice age, the climate in low latitudes is much drier than at present, in agreement with available geological evidence. The results show that the atmospheric temperature during the ice age was reduced much more over continents than over oceans. The altered land-sea temperature contrast weakens the monsoonal inflow from oceans (or strengthens the outflow from continents), and reduces the precipitation over land.

PLANS FY78

The period of numerical time integration will be extended from one season to a few years. (This extension is possible because the CLIMAP group has recently completed the compilation of sea-surface temperature maps for both February and August). When this integration is completed, it will be possible to evaluate the simulated ice age climate in the light of paleontological data available. In addition, special emphasis will be placed upon the analysis of a simulated snow budget over continental ice sheets. This analysis may yield some insight into how the extensive ice sheets were maintained during the ice age.

1.3.2. Atmospheric Composition

ACTIVITIES FY77

A preliminary radiative-convective study has shown that large fluctuations in the amount of N_2 and O_2 in the atmosphere can significantly alter the surface temperatures. In collaboration with several members of Princeton University's Department of Geological and Geophysical Sciences, an investigation has been undertaken to assess the likelihood of climatically significant variations in these or other gases having taken place in the paleozoic or mesozoic periods.

PLANS FY78

The collaboration with the staff members of the Geological and Geophysical Sciences Department will continue, with special emphasis on the possibility of large CO_2 variations as a possible cause of climatic change.

1.4. ATMOSPHERIC DISTURBANCES

ACTIVITIES FY77

1.4.1. Wave Analysis of the 11-Layer General Circulation Model

A preliminary analysis of tropical and extratropical disturbances of the 11-layer general circulation model during the period from April through September has been made.

A space-time spectral formula in complex representation has been derived to make use of the maximum entropy method in order to analyze waves whose amplitude and period change with time. This method is applied to the wave analysis of the numerical experiment described below.

1.4.2. Wave Experiment

Using a new 13-layer general circulation model, numerical experiments have been conducted to study the generation and development of equatorial planetary waves which are well simulated in the present model. Mid-latitude disturbances are eliminated from the model to determine whether equatorial planetary waves develop by themselves. It is found that in the absence of mid-latitude disturbances, Kelvin waves still appear in the model, whereas, mixed Rossby-gravity waves disappear.

PLANS FY78

A detailed spectral analysis will be made of tropical and extratropical disturbances of the GCM. In the wave experiments, further analysis and supplementary experiments will be conducted to clarify the results of the experiments.

1.5. MODEL DEVELOPMENT

1.5.1. Spectral Climate Model

ACTIVITIES FY77

A spectral model, in which fields of variables are decomposed into spherical harmonics, has been developed by the Experimental Prediction Group at GFDL. The model has been adapted to the form suitable for climate studies. Currently, several versions of spectral climate models with varying degrees of spectral truncation are integrated over extended periods to time in order to evaluate their performance in simulating climate.

Because of the ease of incorporating the so-called "semi-implicit" time differencing scheme, this spectral model consumes much less computer time than do GFDL-grid models of comparable resolution. Therefore, it is highly desirable to obtain a preliminary result from numerical experiments with a highly truncated spectral model before performing a very expensive integration with a high resolution model. In this connection, it is encouraging that the quality of climate simulation deteriorates less rapidly with decreasing resolution (increasing spectral truncation) than that of a GFDL-grid model.

PLANS FY78

It is planned to make extensive use of spectral climate models with varying degrees of spectral truncation for the studies of climate sensitivity. Evaluation and validation of a hierarchy of spectral models will be continued during the next fiscal year.

1.5.2. Solar Radiation Scheme

ACTIVITIES FY77

A new short-wave radiation scheme, using Lacis-Hansen parameterizations for ozone and water absorption and for Rayleigh scattering and allowing for multiple reflections from clouds was developed. It is expected to be especially useful for more accurately evaluating sensitivity of climate in high latitudes, where reflection by snow cover and by Rayleigh scattering is important.

PLANS FY78

The short-wave scheme will be incorporated into a wide variety of GFDL models, both grid-point and spectral. It is planned to re-evaluate the sensitivity of climate to the change in solar constant by incorporation of this scheme into the sector climate model with a cloud-radiation feedback mechanism.

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 FY77

2.1.1. Atmospheric N_2O Tracer Experiment

A three-dimensional experiment simulating the behavior of atmospheric N_2O has been integrated for 4 model years. A methodology has been established which allows the equilibrium solution to be found for this long-lived tracer (> 150 years) to within 1% but requiring less than 7 years of total integration time.

The zonal mean structure agrees well with observations. Although observations are currently lacking for eddy statistics, analysis of the numerical experiments has suggested a number of aspects of variability to be expected for such a tracer. In fact, the model eddy statistics are currently being used to provide guidance for planning field measurement programs for N_2O, as well as for similar tracers.

2.1.2. Analysis of Ozone Sampling Networks

Results from a simple three-dimensional ozone experiment have been used to evaluate the ability of the Dobson Total Ozone Network to provide information on global means and trends. The results are encouraging in that accurate, well sampled measurements from such a network can yield usable information about global trends, even though systematic errors occur in estimating the global mean. When the effect of limited temporal sampling is introduced, significant degradations in skill are observed. These degradations, however, are improved noticeably when a carefully chosen 20-25% increase in the number of stations is introduced.

2.1.3. Analysis of Instantaneous Source Experiment

This experiment, somewhat analogous to dispersion of debris following a nuclear weapons test, has been integrated for 4 years and the analysis is now complete. Highlights of the new results are: new insights on the interhemispheric transfer of tracers; resolution of the conflict of interpretation between $C^{14}O_2$ and particulate debris releases into the stratosphere; improved understanding of the dynamical processes leading to large local correlations between tracers and potential vorticity; improved theoretical interpretation of zonal mean tracer balances and their seasonal variation.

2.1.4. Stratospheric Aircraft Pollution Dispersion Experiment

A new experiment is now underway which analyzes the transport of gaseous pollutants from an idealized stratospheric aircraft source. This source function has since been adopted as a standard by which the performance of models of varying levels of complexity can be evaluated. To conserve computer resources, the initial condition was obtained from the 4 years of integration of the experiment described above in 2.1.3. by using the technique introduced in reference (153).

PLANS FY78

Analysis of the N_2O and simplified ozone experiments should be completed and prepared for publication. The N_2O distributions will be used to provide an input source function for an "Odd Nitrogen" experiment. This in turn will be used to begin an improved ozone experiment. The ozone sampling analysis will be completed. The aircraft pollution experiment will be finished and analysis should be underway.

2.2. MODELS OF THE TROPOSPHERE-STRATOSPHERE-MESOSPHERE

ACTIVITIES FY77

2.2.1. New Physical Processes

In the past year a number of physical processes and parameterizations have been added to the new 40-level GCM to make it more appropriate for use in the middle atmosphere. A revised formulation for vertical subgrid scale transfer has been added which includes a Richardson number functional dependence and a parameterization of the effect of grid size. The scheme is applied continuously from the boundary layer to the mesopause. In addition, a parameterized loss of energy by transport to the thermosphere is included.

The previously tested long-wave radiation module and the radiative-photochemical damping parameterization are now stable components of the model. An improved short wave radiation code is in the testing stage.

2.2.2. Effect of Upper Boundary Condition

To understand the effect of adding the physical processes listed above, a number of experiments have been performed at low horizontal resolution (9° lat. x 10° long.) and annual mean radiation. The effect of the upper boundary condition was examined by comparing the "lid condition" control against a version in which reflections are almost completely eliminated. The results showed a significant effect near the top model level, but almost no effect elsewhere. This result suggests that a simplified upper boundary condition is appropriate for the type of model being constructed here.

A separate experiment was performed to examine possible reasons why this present GCM does not obtain the excessively cold polar regions of previous GFDL models. A "lid" boundary condition was imposed at the first interface above the 31.9 km level. Results from this experiment suggest that it is the improved vertical resolution which contributes most to removing this previous model defect.

2.2.3. Zonally Symmetric Model

As part of an attempt to understand the effect of planetary waves upon the stratospheric structure, a zonally symmetric version of the 40-level model has been prepared to determine stratospheric structure in the absence of such disturbances. The results show substantial increases in the meridional temperature gradients with concomitant increases in zonal wind and a complete change in the structure of the meridional circulation.

This model currently contains a 2.2 day period equatorial gravity wave of very high amplitude which appears to be totally non-physical. Its existence seems, in part at least, to be due to a parametric instability excited by too infrequent calls to the radiative transfer code.

PLANS FY78

Work will continue on developing the 40-level GCM with further emphasis on examining its performance and sensitivity under a variety of conditions. Tests will begin at medium (5° lat. x 6° long.) and high (3° lat. x 3.5° long.) horizontal resolutions. Evaluations of the effects of annual cycle radiation and diurnal cycle radiation will begin. Work will be in progress to include ozone as a self-determined dependent variable.

3. EXPERIMENTAL PREDICTION

Objectives

* To advance the knowledge of simulation and prediction of the transient part of atmospheric behavior and weather based mainly on physically sound approaches, but partially on statistical aids.

* To develop models suitable for short range (less than 5 days), and meso-alpha scale (200 to 2000 km) prediction.

* To determine the theoretical limit as well as the practical level of predictability of atmospheric motion and precipitation within the deterministic framework.

* To determine the degree of predictability of the atmosphere over the range of several weeks to several months with a physically based probabilistic approach 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.

* 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 FY77

3.1.1. Mixed Layer Temperature Forecasts

A 9-level one-dimensional mixed-layer model of Gill and Turner was used for simulating the seasonal thermocline of the world ocean. The conditions specified externally were: global atmospheric temperature and numidity as functions of space and time (115), atmospheric radiation from the atmospheric general circulation model, and wind stress (from Hellerman's data) (55). In contrast to a previous experiment, these data were given at one-month intervals instead of 4-month intervals, and the matching calculation was made with a time increment Δt=10 days instead of Δt=1 month. Compared with the observed three-dimensional distribution of sea temperature of Levitus and Oort (w), the newly simulated temperature was markedly improved with respect to the phase and amplitude of seasonal variation. However, discrepancies were also noticed in the equatorial and subarctic regions and in the Kuroshio and Gulf Stream regions.

3.1.2. Sea Surface Temperature Data

Monthly mean maps of normal sea surface temperature compiled from various sources (The U.S. Naval Hydrographic Office, NCAR, RAND, R. L. Dickson (long-range forecasting), and S. Levitus, A. Oort) were compared quantitatively. In addition, mean sea surface temperature data for the months of January 1976 and 1977(provided by D. McLain of the National Marine Fisheries Service), were analyzed and compared with the values derived from satellite measurements.

Plans FY78

An attempt will be made to incorporate horizontal coupling into the ocean portion of the mixed-layer model in cooperation with the GFDL Oceanic Circulation Group. Reasonable composite maps of sea surface temperature for individual months of 1976 and 1977 will be constructed using ship and satellite data.

3.2. GLOBAL FORECASTS

ACTIVITIES FY77

3.2.1. Improvements of Physics

The impact of three parameterizations of subgrid-scale eddy transport on solutions of a global finite difference model were studied. The first, the "reference" parameterization, utilized the conventional mixing length approach as well as the dry-convective and moist-convective adjustments. The second included turbulent closure models of Mellor and Yamada and the constant flux layer theory of Monin and Obukhov, and excluded the dry-convective adjustment. The third model was based on the mixed layer method of Randall and Arakawa and the recent theory of cumulus convection by Arakawa et al. Each of the three parameterizations was tested by

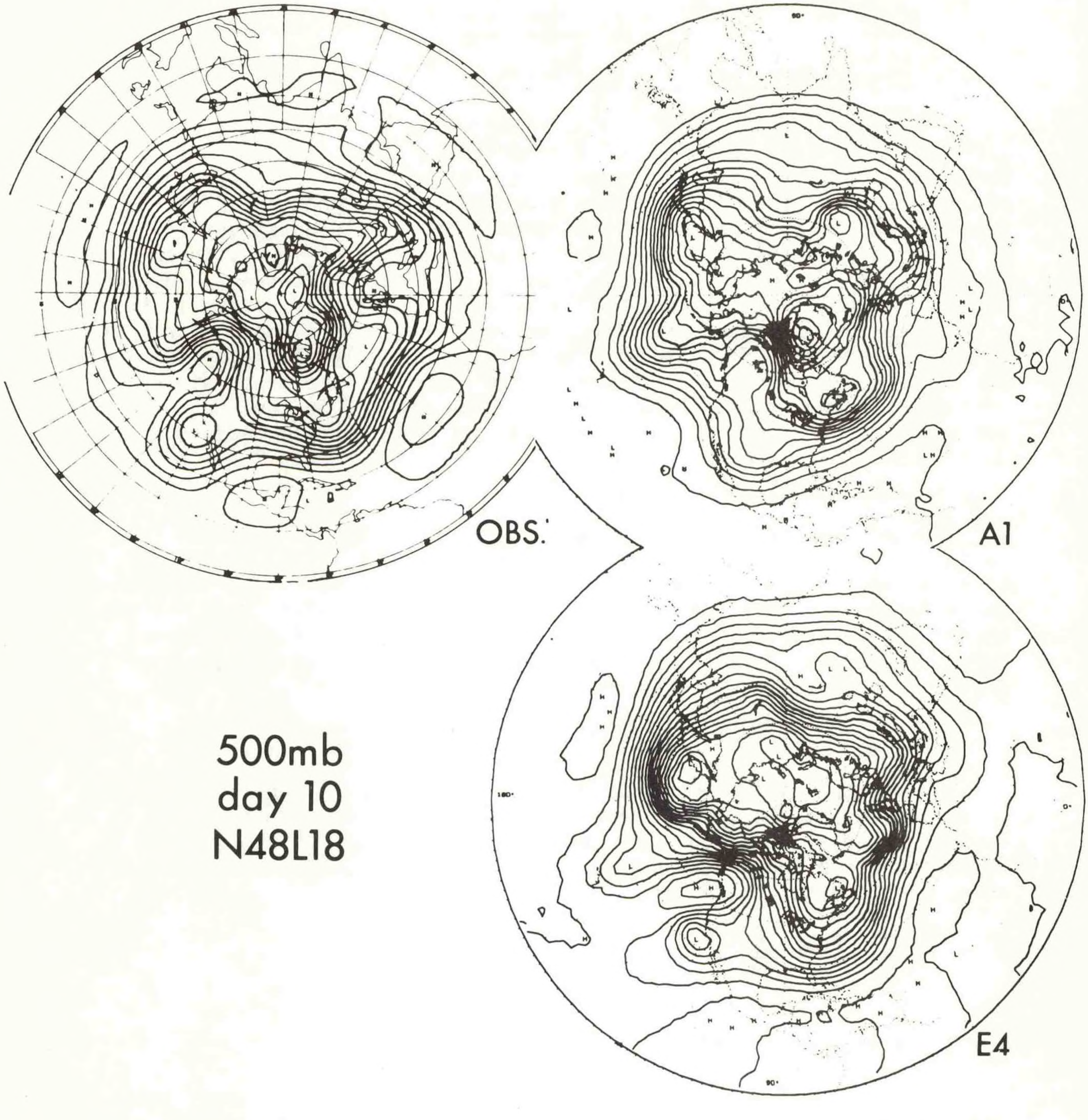

Figure 3.1. March 1965, day 10 Northern Hemisphere 500 mb geopotential heights. Observed, A1 model (reference model), E4 model (Mellor-Yamada level 2.5 closure model). The contour interval is 60 m.

incorporating it into the N24L18 model and carrying out a 30-day integration. However, it became increasingly evident that a model's spatial resolution must be fine enough to detect delicate differences of physics. Accordingly, a test on the N48L18 model was essential. The first and second models of N48 resolution were run for 20 days. In this one case, the forecasts seemed improved. In particular, the eddy kinetic and potential energies were appreciably increased, and the cut-off lows were intensified. (See Fig. 3.1).

3.2.2. Spectral/Finite-Difference Model Forecast Comparison

The capability of the R30L9 spectral model for extended range prediction has been tested using a few initial data sets. In particular, a forecast comparison between this model and the N48L9 grid point model was made from March 1, 1965 initial data. Both models used the reference parameterization of subgrid-scale processes.

The results were quite similar. Overall, both models exhibited modest skill at predicting the large scale features of the 500 mb geopotential height 10-15 days in advance. For the first five days the spectral model predictions were somewhat better, due mainly to lower phase error. However, after the fifth day, the lower phase error was compensated by slightly greater reduction in wave amplitude.

3.2.3. High Resolution Studies with Spectral Models

Insufficient spectral resolution is an important factor in the under-predicted amplitudes of disturbances. Therefore, an R42L9 hemispheric spectral model version has been constructed which requires no disk-memory I/O scheme. Moreover, an R41L9 global model and R63L9 hemispheric model are being constructed by Dr. William Bourke, a visiting scientist from the Australian Numerical Meteorological Research Centre.

3.2.4. Sensitivity Experiments

Using the R30L9 spectral model, the semi-implicit and explicit time differencing schemes produced forecasts of comparable overall quality out to 10 days. However, differences in the intensity of individual disturbances were clearly apparent by the 10th day. In two 15-day comparative integrations, the hemispheric spectral model performed at least as well in the Northern Hemisphere extra-tropics as the global model for 5 to 10 days. Of the various horizontal diffusion schemes tested in the spectral model, linear ∇^2 and spectrally computed non-linear diffusion performed better than linear ∇^4 diffusion. A linear ∇^2 with the eddy coefficient dependent wave number also gave satisfactory results.

PLANS FY78

It is possible that the combined effect of sea-surface temperature, land-surface albedo, sea-ice extent, and sea-ice temperature and cloud feedbacks may have a substantial impact upon the prediction of anomalous events. Therefore, these effects will be incorporated more accurately into the spectral model, and the hypothesis will be tested on the January 1977 event.

The European Centre for Medium Range Weather Forecasts has adopted the GFDL global finite difference model and then modified it by including the Arakawa scheme for conserving enstrophy. The performance of the European Centre's model appears good. By mutual agreement, GFDL will adapt this model.

3.3. FOUR-DIMENSIONAL ANALYSIS

ACTIVITIES FY77

3.3.1. Assimilation Scheme with Spectral Model

Four-dimensional assimilation using a spectral model of R21L9 was successfully applied to a real data set of August 1975 (DST5). Next, a global optimum interpolation analysis was carried out, using the output of the four-dimensional assimilation as a first guess field and interpolating the observed data to the modified Kuri-grid. The results were satisfactory, and the computing speed of the dynamical assimilation has been increased by a factor of 20, compared with the assimilation with finite difference N48L9 model.

3.3.2. Improvement of Optimum Interpolation Analysis

The optimum interpolation analysis scheme has been improved by use of better covariance functions, which are based on observed data. Instead of the single function with circular symmetry used previously, non-circular, latitude-dependent covariance functions were used. In addition, appropriate errors are specified for each observation as functions of height and latitude.

3.3.3. DST Study

The impact of satellite temperature soundings on map analysis and weather forecasts was evaluated, using the Data Systems Test (DST) data sample for August-September 1975. Two series of global analysis were made: one with and one without satellite temperatures. By comparing the two analyses with each other and with the NMC (National Meteorological Center, Washington, D. C.) analyses, a systematic bias in the 17-day mean temperature was found. The lower and middle troposphere was substantially warmer in the analysis which utilized satellite soundings;

the upper troposphere was substantially colder. Yet in the 5-day weather forecasts, positive impact in some verification scores was obtained over data-rich areas.

PLANS FY78

For FGGE (First GARP Global Experiment), it is being planned that the spectral model R30L18 be used for the four-dimensional assimilation. In order to achieve this, a considerable amount of modification of the model is needed so that it will fit the available computer memory. The assimilation spectral model will also incorporate a new radiation scheme developed by Fels and Schwarzkopf.

The augmented GATE data set for A, A/B and B-scale areas over the Atlantic Ocean has finally arrived. This data will be added to the global data set transmitted in real time during the GATE period, and the four-dimensional analysis will again be carried out for phase three.

3.4. LIMITED DOMAIN FORECASTS

ACTIVITIES FY77

3.4.1. Hemispheric Model in 1976 Version

The construction of the 1976 version model has been completed. The model has N80L18 resolution on the Cartesian coordinates of a stereographic projection map, includes steep mountains, incorporates the constant-flux layer transfer of Monin and Obukhov with differential surface roughness between land and sea, and uses an improved distribution of soil moisture.

The initial condition is obtained by first applying Kurihara-type spin-up of the boundary layer structure (v) and then using forward-backward adjustment (r).

3.4.2. Hemispheric Summer Prediction with the 1967 Version Model

The diagnostic and statistical analysis of forecasts for 12 July cases with the 1967 version model has been completed. The predictability skill became zero at about 9 days in terms of correlation coefficients and root-mean-square errors for geopotential height patterns. The predictability limit of this model is, therefore, almost the same as for the winter case. The stratospheric forecasts have no skill in the summertime, even for the first day. The variance of zonal wavenumber 5-9 is large in the belt of 50°-70°N in July compared with 30°-50°N in January. The predicted cyclone tracks agree less well with the observed summer case than those in winter case.

With the 1967 model, the mean maps of predicted rainfall for 12 samples did not present a good simulation over the United States for either January or July.

3.4.3. Local Area Model

The hemispheric general circulation model with the N80L9 resolutions has been used for a limited domain model over the United States with a grid spacing of 34 km. This local model was nested inside the hemispheric N80L9 model with the grid ratio of 1:4 between fine and coarse meshes. The lateral interface conditions for the local model were obtained by using the "boundary adjustment" (166), Orlanski's radiation condition (249) and the "sponge" treatment, although the "sponge" was not absolutely needed. The solution of this model showed a detailed rainband structure associated with a front. (See Fig. 3.2).

In conjunction with the above, the model of the Federal Hydrometeorological Institute and Belgrade University (HIBU), Yugoslavia, will be further developed by a visiting scientist, Dr. Fedor Mesinger. Special features of the model are: use of the Arakawa E-system grid; a fourth-order horizontal advection scheme conserving enstrophy and energy for the rotational component of wind; the forward-backward economical explicit scheme for time differencing; a calculation method for the pressure gradient force avoiding a false height-staggering of velocity components due to steep terrain height; and a specially designed hydrostatic equation minimizing the vertical discretization error.

3.4.4. <u>GATE Area Model</u>

The GATE area nested model has been developed by modifying the stereographic projection model to a Mercator projection. This fine mesh GATE area model is embedded inside the coarser grid of a global modified-Kuri-grid. The grid ratio is approximately 1:4. The objective is to use this system for the study of parameterization of cumulus convection, tropical planetary boundary layer structure and for research on the dynamics of tropical easterly waves.

PLANS FY78

The HIBU model will be developed into a full weather prediction model. The vertical resolution will be increased from 5 to 9 layers; water vapor will be included; a GFDL standard physics package will be added; and a nesting routine will be applied.

The further sophistication and refinement of the GATE area model will be continued.

The accumulation of 12 winter forecasts with the hemispheric 1976 version model will proceed. In the meantime, the economical explicit scheme for time differencing will be applied to the 1976 model.

3.5. FGGE IMPLEMENTATION

ACTIVITIES FY77

3.5.1. Preparation for Implementation

The final refinement of the four-dimensional analysis system to be implemented at GFDL during FGGE has been undertaken. The major items achieved so far are: the set-up of the FGGE Level III data tape archiving in the specified international format; the streamline-isotach print-out of global wind fields; the optimum interpolation analysis of water vapor in terms of dew point temperature; and the updating and improvement of climatological normals of various parameters (for example: the stratospheric data provided by Labitzke and the water vapor data supplied by Jenne).

3.5.2. BDS Study

The basic data set (BDS) of November 1969, has been processed, and Level III data have been produced by an assimilation/analysis system. For the dynamical four-dimensional analysis, the N48L18 prediction model was used, and the two-dimensional optimum interpolation analysis was applied every 12 hours for parameters at 19 mandatory pressure levels. Using this analysis as the initial condition, a 3 day forecast was performed from November 4, 1969. The results compared better with the observation than did the forecasts starting with the Montreal analysis as the initial condition.

PLANS FY78

The DST study indicated that there was a systematic bias in the analyzed temperature field when the satellite retrieval temperature was used. A remedy to avoid this bias will be investigated.

3.6. PHENOMENOLOGICAL STUDIES

ACTIVITIES FY77

3.6.1. 76/77 Event

The end of January 1977 was marked by record-breaking cold over the eastern United States and a severe drought on the west coast. In order to investigate the cause of this extraordinary event, a one-month forecast was attempted, using the R30L9 spectral model with a climatologically normal sea surface temperature. As was anticipated, the forecast did not agree with the observation at all after the 15th day. The resulting flow pattern was quite different over North America as the deep trough was missing. Presumably, the actual distribution of sea surface temperature is needed, but the appropriateness of the particular prediction model has to be further examined.

3.6.2. Genoa Cyclone

Cyclogenesis in the Gulf of Genoa is an intriguing process and a important phenomenon of practical importance as well. A recent study of Bleck has demonstrated the feasibility of simulating Genoa cyclogenesis and the importance of the height of orographical obstacles. In order to increase the understanding of numerical requirements for simulation and of the physical mechanisms of this phenomenon, forecasting experiments with the HIBU model and a diagnostic study of the results are being conducted.

PLANS FY78

For the study of the 76/77 event, the real sea surface temperature for January 1977 will be specified for a one-month forecast. In parallel, a higher resolution spectral model, R41L9, will be constructed and applied to this study.

For the study of Genoa cyclogenesis, the HIBU model will be refined by increasing the resolution and including condensation, and appropriate analysis techniques will be developed.

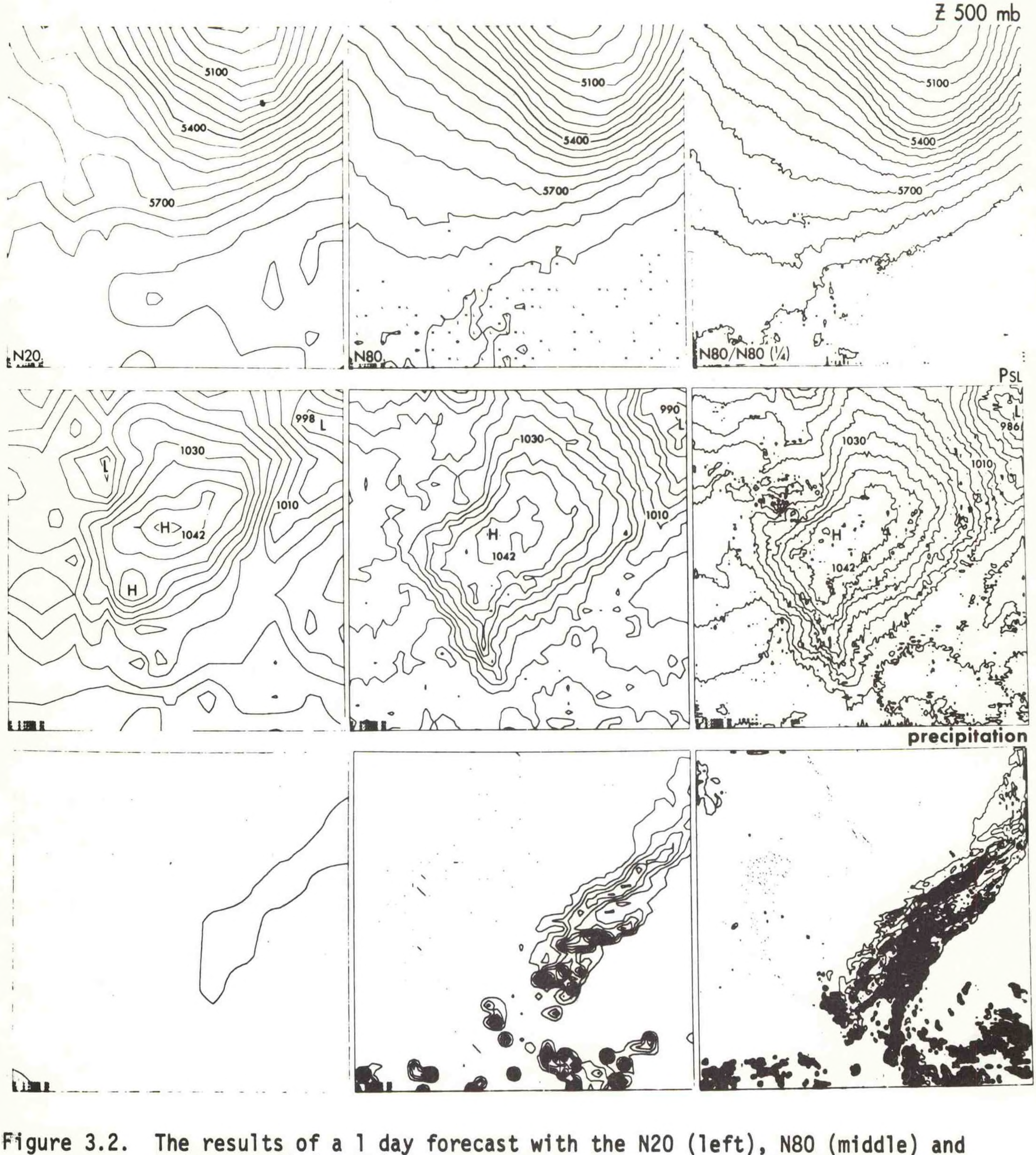

Figure 3.2. The results of a 1 day forecast with the N20 (left), N80 (middle) and N80/N80(1/4) (right) models. Upper; geopotential height (m) at 500 mb (Z500); contour interval is 60 m. Middle: sea level pressure P_{SL}. Lower: rate of precipitation; contour interval is 9.8 cm deg^{-1}.

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 FY77

4.1.1. Instabilities of Equatorial Currents

Ocean variability in the tropics could be due to the variability of atmospheric forcing, or due to instabilities of the time-averaged currents. During FY77, simplified numerical models have been used to investigate whether instabilities could explain observed variability in the tropical oceans. A stability analysis of currents derived from GATE data reveals that the shear in the surface layer of the ocean could give rise to westward propagating waves with a period of about 1 month and a wavelength of 1000 km. Thirty-day fluctuations are indeed evident in the longer time-series measurements made during GATE. More striking confirmation of such waves with the above scales come from recent satellite sea surface temperature patterns in the central equatorial Pacific.

4.1.2. Indian Ocean Temperature Anomalies

The link between anomalies of sea surface temperature in the Arabian Sea and monsoon rainfall over India suggested by a recent study with an atmospheric model (194) has motivated further study of the circulation of the Indian Ocean. Earlier work with numerical models have been successful (88, 258) in explaining the seasonal variations of the Somali Current. A high resolution model has been developed to make detailed calculations of the mesoscale disturbances that develop in the Somali Current. These disturbances are found to be an effective mechanism for carrying the cold water formed by upwelling at the Somali coast into the interior of the Arabian Sea. The calculations show that the growth and movement of these disturbances are very sensitive to fluctuations in the wind and to details of the coastal geometry. These conclusions are verified by new data on the Somali Current based on satellite temperature patterns and measurements from ships of opportunity passing to and from the Persian Gulf.

4.1.3. Transient Response to the Equatorial Atlantic

The low latitude response to wind was also investigated in a preliminary study (dd) of the North Atlantic. As a basis for a more detailed study of the seasonal response, idealized, zonally averaged winds are "switched on" over a resting, uniformly stratified ocean. The model adjusts itself in a complex way by wave motion over a whole range of frequencies. Calculations are first carried out without bottom topography in order to check wave propagation against known analytical results. When topography is introduced the total transport field exhibits low frequency variations, due to a linkage with baroclinic Rossby waves. This mechanism can cause transport changes with a period of many years.

PLANS FY78

In the case of the Indian Ocean, a high resolution model will be used to determine how much of the observed seasonal variation of surface temperature can be explained in terms of the surface heat balance and a shallow mixed layer without currents and upwelling. The effect of currents and upwelling will then be added at a later stage. Strong surface evaporation under the Southwest monsoon and upwelling at the Somali coast are competing effects causing cooling in the Arabian Sea. The high resolution experiments are aimed at evaluating the relative importance of these two mechanisms.

The Atlantic model will be enlarged to include the South Atlantic. Seasonal wind stress patterns have been obtained from Woods Hole Oceanographic Institution to drive the model. Data is available from GATE and previous expeditions which indicate large variations of dynamic topography with season in the Equatorial Atlantic. This data will be used to verify the model results in a series of numerical experiments in which more realistic elements will be introduced one at a time.

4.2. WORLD OCEAN STUDIES

ACTIVITIES FY77

4.2.1. Seasonal Changes in Poleward Heat Transport

A recent study of global heat balance (245) indicates that ocean currents may transport a significant amount of heat from the summer hemisphere to the winter hemisphere, moderating seasonal extremes in climate. A semi-analytic model (274) with the approximate dimensions of the Pacific Ocean has been used to investigate this effect in a simple context. It is shown that intensification of normal wind patterns in the winter hemisphere, and weakening of wind patterns in the summer hemisphere, lead to a surface flow of water across the equator which is largely compensated by a return flow, uniformly distributed in the whole water column. Since the surface waters are much warmer than the average for the water column, this is a very effective heat transport mechanism. In the semi-analytic model the cross-equatorial flow is greatly complicated by baroclinic Rossby waves excited at the eastern boundary. It turns out that these waves have no significant effect on heat transport.

4.2.2. World Ocean General Circulation Model

Calculations for the World Ocean model developed for climatic studies on a 2 1/2° x 2 1/2° grid were carried out for the first time in a fully predictive mode. Since realistic climatological boundary conditions are used to drive the model, simulation of temperature and salinity fields are much more accurate than can be expected in the joint ocean-atmosphere model.

Paticularly important results obtained in study are: 1) the existence of large seasonal variations in heat transport, but not in "salinity" transport; 2) the deep salinity minimum of the Southern Oceans is largely found equatorward of the Circumpolar Current in an area of concentrated sinking off the coast of Chile.

Parameter studies with the World Ocean model indicate that the depth of the thermocline is an indicator of the level of total energy in the ocean circulation. Changes in the winds or turbulent closure parameters which make the total energy increase lead to a deeper thermocline and vice-versa. Surprisingly, heat transport is not extremely sensitive to the depth of the thermocline, but, at low latitudes at least, heat transport is very sensitive to the strength of the trade winds.

PLANS FY78

The World Ocean model will be used in a series of experiments to use its ability to form water masses to study other tracers such as oxygen, C^{14} and tritium. The GEOSECS program has provided some excellent data sets for model verification. The results should lead to important improvements of the model, and provide insight into the role of the ocean in the uptake of CO_2 produced by large-scale burning of fossil fuels.

4.3. MID-LATITUDE VARIABILITY

ACTIVITIES FY77

4.3.1. North Atlantic and Pacific Observational Studies

To understand the variability of ocean currents it is necessary to know the spatial and temporal scales of the surface winds that are the dominant factor in driving surface currents. Twelve-hourly pressure data, on a 250 x 250 km grid for the North Atlantic and Pacific Oceans from the National Meteorological Center in Washington, D. C. have been analyzed to determine these scales. Preliminary results indicate that the most energetic fluctuations are associated with large eastward moving cyclones. At periods longer than 10 days, there are weather disturbances propagating both eastward and westward. The westward propagating components may excite Rossby waves.

4.3.2. Low Frequency, Large-Scale Temperature Anomalies in the North Pacific

Recent studies carried out in the NORPAX program have shown that the large-scale, low frequency temperature anomalies of the North Pacific extend well down into the main thermocline. The surface temperature patterns tend to move eastward, but there is a puzzling phase difference between the anomalies at the surface and at lower levels where long-term records are available. A simple analytical model (s) has been constructed to study the dynamics of these anomalies. In the model the near surface pattern is dominated by wind forcing, and the anomaly at lower levels by westward moving baroclinic Rossby waves, formed by reflection at the eastern wall. The results are very well verified by data from ocean weather ships 'P' and 'N'.

PLANS FY78

A study of ocean response with observed winds will be carried out to understand the role of individual weather disturbances in generating ocean variability. A hierarchy of models (linear with flat bottom, non-linear with flat bottom, linear with topographic features) will be used.

5. PLANETARY CIRCULATIONS

Objectives

* To examine the basic physical processes that could occur in the atmospheres and oceans of the planets and to deepen our understanding of these fundamental mechanisms.

5.1. JUPITER/SATURN/EARTH CIRCULATIONS

ACTIVITIES FY77

In FY75-76, the relevance of terrestrial type circulation models for Jupiter and Saturn was established and a system of circulation dynamics proposed. New calculations have shown that the Jovian flow regime can occur over a wide range of parameteric conditions including those thought to exist.

The relationship between Jovian and Terrestrial regimes has been explored. Multiple jet states endemic to Jupiter can be produced in the Earth environment when suitable parameter changes are made. The reduced zonality of Earth jets compared to the Jovian ones can be attributed to the large surface drag of the former planet.

PLANS FY78

The completion, analysis and publication of recent investigations is a major present aim. Construction of a global primitive equation model to examine equatorial dynamics is to begin shortly thereafter.

5.2. VENUS CIRCULATION

ACTIVITIES FY77

An investigation of the large-scale dynamics of the Venus stratosphere using a one layer barotropic model was carried out. The form of the observed wind was found to be the only stable configuration possible for a non-rotating planet. Relaxation of most flow forms to the same final state makes it difficult to isolate the pertinent vertical and energizing mechanism.

The Y shaped cloud feature of the Venus stratosphere was reproducible by allowing for diurnal flow variations. However, for stability requirements the Y should be associated with vorticity or vertical velocity.

PLANS FY78

Development of a simple but physically realistic general circulation model is anticipated. A version of the spectral model already being used by the Experimental Prediction Group for simulating the Earth's circulation will be simplified by substituting a qualitatively correct heating function for a detailed radiative transfer calculation and by eliminating any calculation of condensible trace constituents such as water vapor. These modifications will decrease the running time of the model sufficiently so that systemetic investigation of the dynamic regimes in the Venus atmosphere can begin.

5.3. MARS/VENUS/JUPITER. CLOUD MICROPHYSICS

ACTIVITIES FY77

The relative importance of the microphysical processes of condensation, sedimentation, turbulent mixing, coagulation and coalescence in the formation of planetary clouds have been examined. Conclusions are: 1) Venus clouds most closely resemble smog and haze layers on Earth, with coagulation, sedimentation and turbulent mixing predominant. No precipitation occurs; 2) the water ice clouds of Mars resemble tenuous, nonprecipitating cirrus clouds on Earth. Condensed water occurs only from surface fogs or surface condensation; 3) the ammonia-water and ammonia-ice clouds on Jupiter produce precipitation. Strong latent heat effects are expected to occur in the low ammonia-water clouds.

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 FY77

6.1.1. Preparation of 15-Year Global Data Set

The analysis of the 1968-1973 data set was completed, but the analysis of the 1963-1968 set is still in progress (the 1958-1963 analyses were completed earlier).

Significant progress was made in establishing, for the first time in a quantitative manner, the uncertainty in general circulation statistics based on the rawinsonde network. Thus, the probable errors were shown with the aid of model output from a GFDL numerical general circulation experiment "ZODIAC" (bb). The most important source of error was found to be the existence of spatial data gaps, especially, of course, in the Southern Hemisphere. We found that the stationary eddy and mean meridional circulation fluxes cannot be determined in the SH without new additional data sources. The inclusion of more plentiful surface ship reports, as well as the possibility of incorporating satellite information to alleviate the problems in defining the crucially important monthly-mean circulation in the Southern Hemisphere are being studied.

An exploratory, more local, budget study for the monsoon region was attempted in order to study at what space-scales budget studies can be done fruitfully with the present data (u). In spite of the sizable area (about 1/8th of the globe) studied, only general and gross conclusions could be drawn concerning the nature of the angular momentum and kinetic energy budgets. It seems evident that detailed, local budget studies must wait until better data samples become available during the FGGE period (such as, for example, the daily four-dimensional analyses planned by the Experimental Prediction Group at GFDL).

6.1.2. Interannual Variability (1958 through 1973)

A report on the range of year-to-year variations in zonal-mean parameters for the Northern Hemisphere is in press for the 1958-1963 and 1968-1973 periods (h). Similar tests with the ZODIAC model as discussed above show the probable reliability of the results.

Global patterns of year-to-year variations are presently being investigated with the aid of empirical orthogonal functions.

Considerable assistance was given during FY77 to various international committees charged with establishing a global data base for climate studies in connection with the GARP climate objective and the US-USSR Agreement on Protection of the Environment.

PLANS FY78

The full analysis of the 15 year global data set (May 1958 through April 1973) should be accomplished during FY78. Tentative Southern

Hemisphere analyses will be made only for the latter half of the period. The results will be prepared for publication. They include discussions of the long-term mean state and the seasonal cycle, as well as interannual variations of the atmosphere. This material should constitute a reasonable climatological reference for interpreting later and more detailed FGGE results.

Studies of the year-to-year spatial patterns will continue. Attempts will be made to relate these atmospheric anomalies to similar observed anomalies in oceanic and snow-ice cover conditions.

6.2. OCEANIC ANALYSIS

ACTIVITIES FY77

6.2.1. Global Analysis of Oceanic Data

A description of the analysis scheme and of the global distributions of the available oceanic observations of temperature, salinity, density and oxygen was prepared (w). New updates (since 1973) of the data sets available at the NOAA National Oceanographic Data Center are presently being incorporated in our oceanographic data library.

The problem of accounting for the recent estimates of a very substantial oceanic heat transport in the Tropics was studied extensively. This was a joint study of the Oceanic Circulation and Observational Studies Groups at GFDL.

6.2.2. Studies of Entire Climate System

A joint study with Drs. T. H. Vonder Haar and J. S. Ellis of Colorado State University resulted in a consistent picture of the annual variation in the earth's net radiation balance observed by satellites and the in situ measured heat storage in the world oceans. In August, the oceans were found to be the equivalent of about 1°C colder (averaged over a 50 m thick layer) than in March, in good agreement with radiation requirements. Figure 6.1 summarizes these results.

PLANS FY78

The immediate task is to complete a global analysis of the long-term mean oceanic structure and its annual variation, and to prepare a comprehensive report describing the results.

The possibility of defining decade-to-decade (or possibly shorter) variations in ocean structure will be investigated.

The global studies of the annual cycle in the budgets of heat, water substance and angular momentum for the entire climate system will be continued.

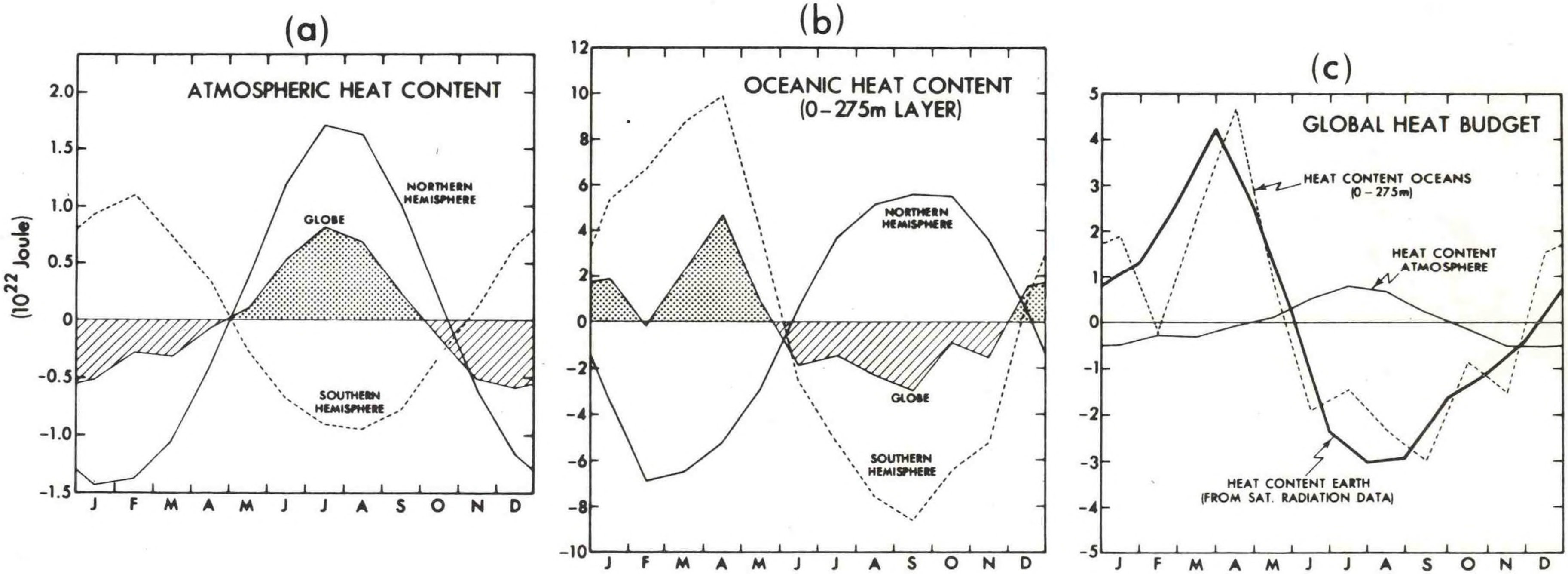

Figure 6.1. The observed seasonal cycle in the global heat budget. Shown are the variations in the energy contained in the atmosphere (a), the energy contained in the oceans (b), and the total heat content of the earth as inferred indirectly from satellite radiation observations (c). The atmosphere and ocean values are based on very large samples of in situ observations. It is clear from plot (c) that the excess or deficit of radiational energy during the course of a year is stored in or released from the world oceans (The radiation data were supplied by T. H. Vonder Haar and J. S. Ellis of Colorado State University.).

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.

7.1 SIMULATION OF HURRICANES' LANDFALL

ACTIVITIES FY77

A previously constructed three-dimensional tropical cyclone model was applied to a simple situation where a mature tropical cyclone drifts onto flat land. In such a case, the landfall can be simulated by changing the position of coastline in the computational domain. As the coastline moves with a specified speed, the surface boundary conditions were altered at the shore from those for the ocean to those for the land by increasing the surface roughness length and also by suppressing the evaporation.

In the model, notable asymmetries in the wind, moisture and precipitation fields were observed relative to the coastline at the time of landfall. Roughness induced, quasi-steady convergence and divergence zones, as well as the zones of abnormal positive and negative relative vorticity at the surface, were formed along the shoreline. The increase in the radial inflow in the planetary boundary layer over the land causes greater mass convergence. The effect of surface roughness increases, and with the distribution of latent energy over land determines a decay rate for the hurricane upon landfall. The supplementary experiments suggested that, if the supply of latent energy to a storm was sufficient, a storm could deepen when it encountered an increase in surface roughness. The budget analyses indicated the simultaneous broadening and weakening of the storm system in the decay process.

PLANS FY78

Numerical experiments will be carried out to investigate the genesis of a tropical depression from an easterly wave. In the formulation of vertical diffusion processes in the model, a turbulence closure scheme of low order will be used to replace the dry adiabatic adjustment scheme.

7.2. NESTED MESH MODEL

ACTIVITIES FY77

Extensive tests were performed with a one-dimensional primitive equation model to find a reasonable scheme for allowing the movement of a nested fine mesh area within a coarse mesh domain. A major problem was to construct grid data in a portion of the coarse resolution area which becomes a fine mesh area when a nest moves, and vice-versa. An interpolation and averaging scheme was designed to obtain grid data in the affected area without changing total domain integrals of mass, momentum and internal energy. The method was then incorporated into a three-dimensional nested model. The problem of initialization was studied for simple one-dimensional cases. It was assumed that the balance equation would be solved inversely at an analysis stage of initial data.

PLANS FY78

An initialization scheme of a three-dimensional nested model will be formulated and tested. A time integration of the model may start to examine the performance of the model.

8. MESOSCALE DYNAMICS

Objectives

* To understand the generation and breakdown of internal gravity waves that are strongly connected to the generation of turbulence in the atmosphere and ocean.

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

8.1. FRONTAL CIRCULATION AND SEVERE STORM OUTBREAKS

ACTIVITIES FY77

8.1.1. 2-D Numerical Simulation

The effect of moisture upon the dynamics of mature idealized cold front systems was investigated using a two-dimensional numerical model (z). Lifting produced by the initial cross-stream frontal circulation previously studied (f) 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 and when a low-level capping inversion was present.

In order to model atmospheric conditions which are more representative of actual frontal initiation of severe storms, we have produced a set of solutions (Fig. 8.1) in which the magnitude $\Delta\theta_I$ of a low-level capping inversion was varied from 0° to 8°C for the case of a dry front overtaking a moist air mass with diurnally-varying surface heating included. When no inversion was present, the surface heating was found to produce convection before the front could affect the moist air. However, as the inversion jump $\Delta\theta_I$ was increased, triggering due to surface heating was suppressed, and frontal lifting was needed in addition to diurnal heating in order to produce convection. Because of the coarse model resolution, the convection triggered by diurnal heating in the case without an inversion is nearly as intense as that produced by the frontal lifting. However, one may infer that, in the real atmosphere, such heat-triggered convection will consist of small-scale cumulus clouds which will be more easily eroded by entrainment than will those produced by the more organized frontal lifting. Hence the tendency of the inversion to prevent the release of the moist instability by small-scale heated plumes permits the frontal lifting to produce moist convection which exhibits a broader scale and which may therefore develop into a more intense storm.

8.1.2. 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. Lateral boundaries will employ the open boundary conditions described by Orlanski (249) where needed. A nonlinear eddy viscosity is presently used which is dependent upon local Richardson number.

A modeling experiment is currently being carried out which attempts to simulate the movement of a surface cold front as taken from 12-hour observational data of the National Meteorological Center (NMC) for its 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 the current fine mesh Cartesian grid.

The frontal system chosen for the experiment occurred over Texas and Oklahoma on 12Z of May 1, 1967 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 model configuration chosen for this experiment incorporates a Cartesian grid with x:y:z dimensions of 51:26:10 grid points with grid increments $\Delta x = \Delta y = 40$ km and $\Delta z = 1000$ m (constant vertical grid size) implying a domain size of 2000:1000:9 km. The grid is initially oriented so that the cold front is along a line of constant x. The front therefore spans the narrower of the two horizontal dimensions (y) and moves along the larger of the two grid dimensions (x). A successful 12 hour run was recently performed with open boundary conditions and a dry atmosphere.

PLANS FY78

The major effort in this coming year will be to include realistic features in the 3-D model such as moisture effects, boundary layer physics and Reynolds stresses, in order to complete the 36 hour simulation of a realistic frontal system.

8.2. MESOSCALE AIR-SEA INTERACTION OCEANIC FRONTS

ACTIVITIES FY77

Recently it has been recognized that oceanic mesoscale dynamics can be generated by atmospheric forcing. In recent months we have tested the assumption that atmospheric fronts could, under special conditions, generate oceanic fronts. Surface conditions from the numerical solution of an atmospheric front that we have studied (f) were applied as boundary conditions to an ocean 2-D model. It was found that, if the atmospheric front becomes stationary for more than one day, the front will generate a baroclinic jet in the ocean which is in geostrophic balance with a thermal frontal structure.

PLANS FY78

We plan to continue this study to find out if moving atmospheric fronts could also generate oceanic fronts. So far the translatory speed is less than the Rossby radius of deformation times the coriolis parameter.

8.3. LABORATORY EXPERIMENTS

ACTIVITIES FY77

Experiments involving the resonant interaction of internal gravity waves were performed at the Geophysical Fluid Dynamics Program'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 (Fig. 8.2); 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 frequency and wavenumber, $\underline{k}$, of these modes would satisfy the resonance conditions,

$$\omega_1 = \omega_2 \pm \omega_3$$

$$\underline{k}_1 = \underline{k}_2 \pm k_3.$$

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 and numerical simulations using the Orlanski and Ross (160) model. This work is being prepared for publication.

Our experimental facilities have been upgraded during the past few years. A system for exciting internal gravity waves was developed using sealed chambers placed at the free surface in conjuction with motor driven pumps. The system is very stable and extremely versatile. Internal modes may be excited alone or in combination in a very repeatable manner. Conductivity probes are used for density measurements so that we now have an efficient system whereby probe data is digitized and Fourier analyzed numerically.

PLANS FY78

Our plans are to continue the triad resonance work. Theoretical results derived by Ripa have shown the existence of long period oscillations of individual waves in the triad. We plan to measure these oscillations as a function of the controlling parameters (wavenumber, frequency, phase); as this time scale is very important in statistical models which attempt to describe the oceanic internal wave spectra by triad resonance.

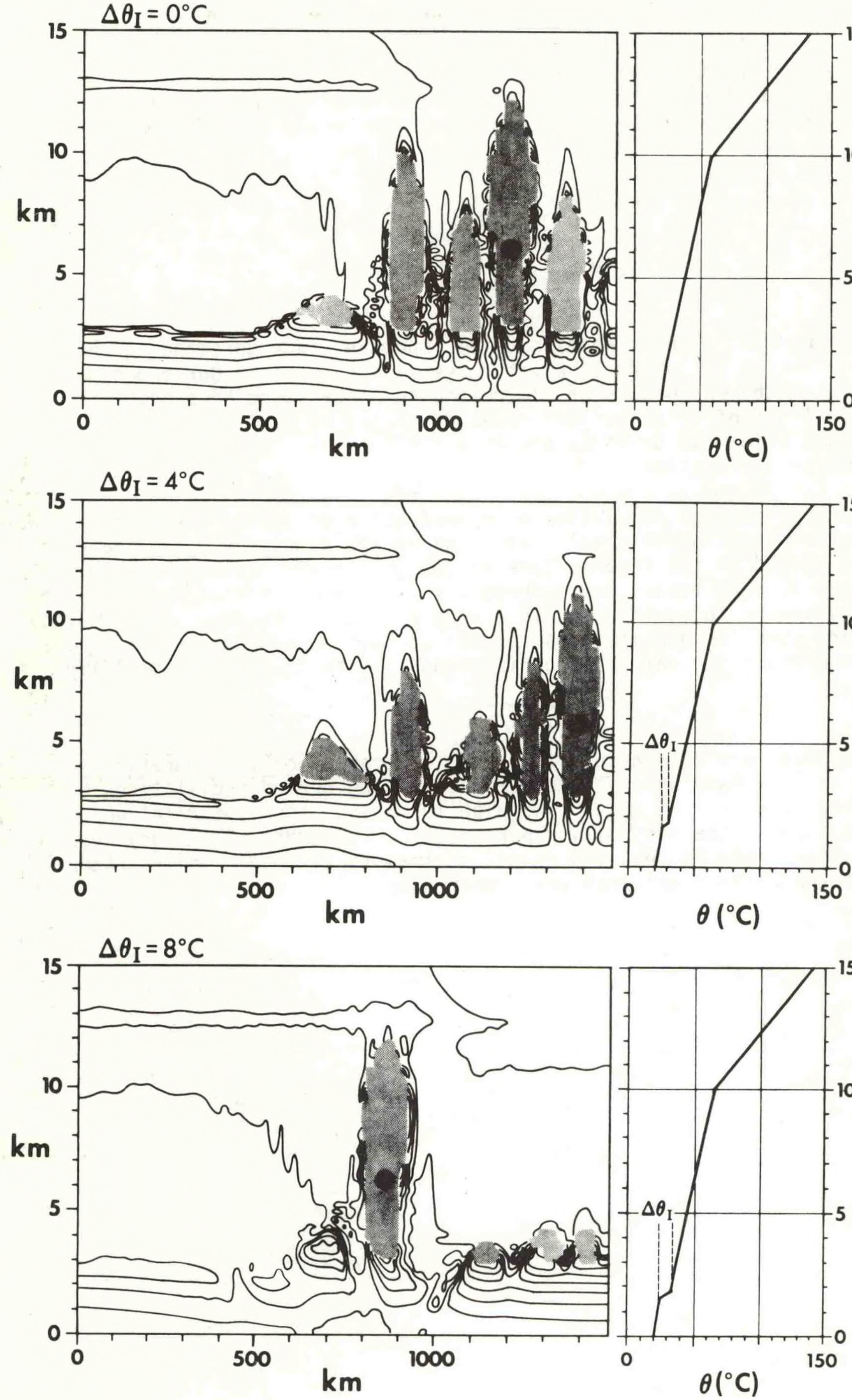

Figure 8.1. Composite plots showing fields of relative humidity (contours) and condensed water (shaded region) for three moist front solutions for different potential temperature jumps $\Delta\theta_I$. Each frame shows conditions in the solution at the time of maximum vertical velocity (the location of which is marked by a bulls-eye): t = 15.97 hr for $\Delta\theta_I$ = 0°C, t = 19.55 hr for $\Delta\theta_I$ = 4°C, and t = 24.80 hr for $\Delta\theta_I$ = 8°C. The graph to the right of each plot shows the initial potential temperature profile on the warm air side of the front. The contour interval for relative humidity is 10%.

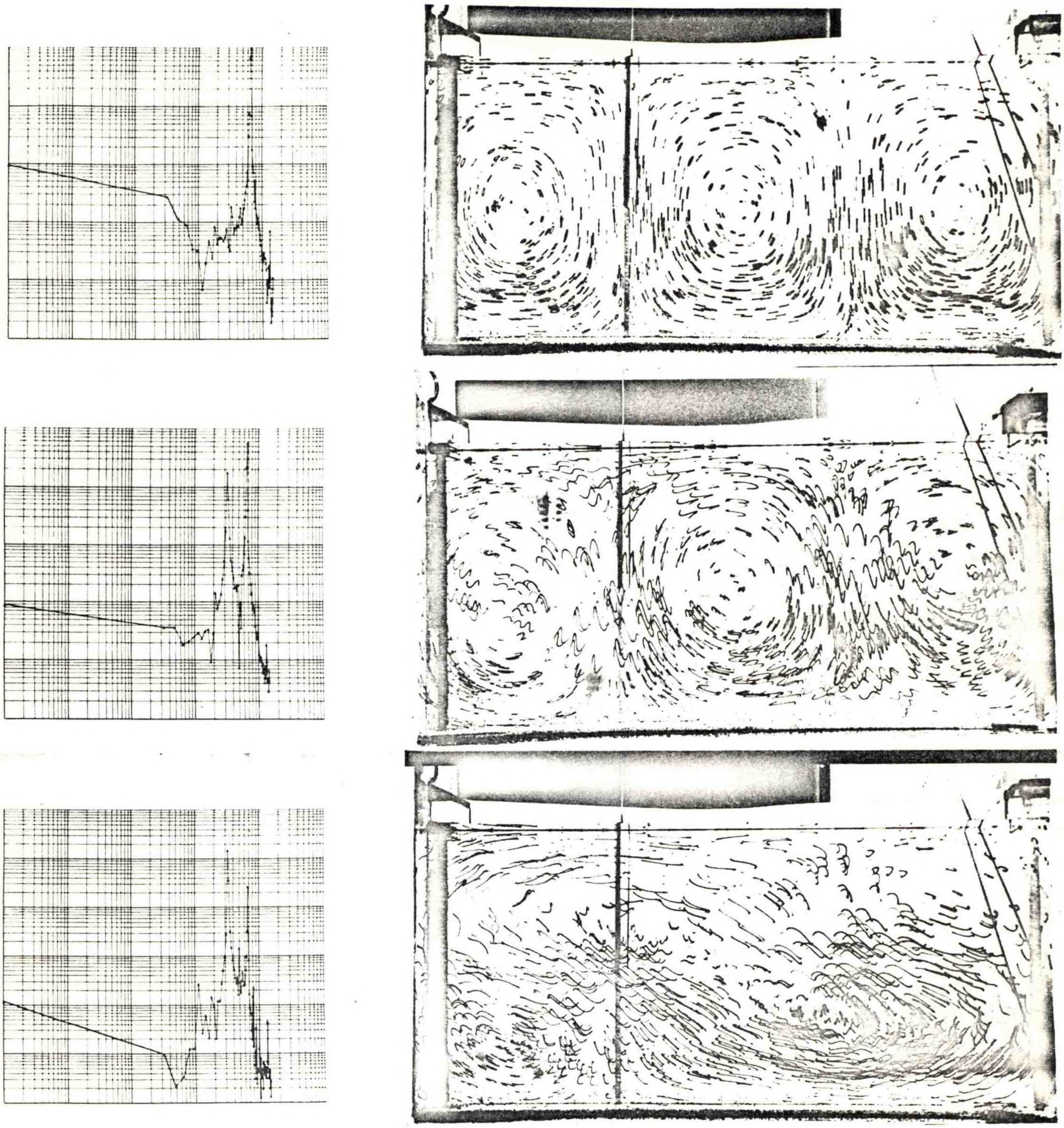

Figure 8.2. Left side shows spectra for density fluctuations at mid-depth near tank end wall, while right side shows streak photographs. Upper figures show ω_{31} mode, and the middle figures correspond to a time shortly after a perturbation at frequency $0.5\omega_{31}$ was introduced. Bottom figures show system at later time, when perturbation components dominate the flow field.

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 FY77

Improvements in the existing three-dimensional numerical model of deep moist convection included a simplification of the subgrid-scale turbulence parameterization and a more accurate calculation of the condensation rate, C_d. Present computations indicate that an accurate determination of C_d is extremely important in the early stages of cloud growth.

Calculations of cloud and rain development have been carried out for a domain 10 km deep and 12 km by 12 km in the horizontal. For a case with no mean wind present, the cloud reached a maximum height of 7.6 km and had a maximum vertical velocity $w_{max} = 22^m/sec$ and a maximum perturbation potential temperature $(\theta')_{max} = 3.1°C$. The maximum rainfall rate occurred 31 minutes after the cloud formed and was accompanied by a downdraft of 5.1 /sec and a 1.7°C cooling at the surface. The total rain reaching the ground at the center of the shower was 3.3 cm.

Positive features of the above simulation included the downdraft and surface cooling at the time of maximum rainfall rate. Also, the maximum values of C_d are nearly proportional to the vertical velocity and agree well with analytical calculations. The total time of cloud and rain development is reasonable. A less desirable result is that the mean cloud radius is smaller than observed. In addition, the values $w_{max} = 22^m/sec$ and $(\theta')_{max} = 3.1°C$ appear too large for a cloud penetrating to only 7.6 km. However, observational data are scarce.

One paper (264) concerning the DuFort-Frankel finite difference scheme has been published and another paper (q) involving the numerical simulation of shallow moist convection will be published shortly.

PLANS FY78

Present model results indicate that a further examination of numerical truncation errors and of the subgrid-scale turbulence parameterization is necessary. Thus, a first priority in FY78 will be to study these model deficiencies. A series of two-dimensional computations will be carried out in order to determine the resolution required for an accurate simulation of deep moist convection.

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. The Turbulence Closure Model

Development of a second moment closure model (185) has continued. Of greatest significance is the fact that the theory has been developed so that the model can include condensation processes (261). These processes intimately couple with the turbulence dynamics. Quantities such as cloud formation, mean liquid water and liquid water variance can be predicted.

9.2.2. Planetary Boundary Layer Simulations

Work has proceeded on simulating BOMEX data as a first test of the P.B.L. model including condensation physics. Initial results are encouraging, but it may be some time before a convincing comparison between numerical simulations and observations is available.

9.2.3. Laboratory Experiment

Work was completed on the laboratory study of homogeneously decaying turbulence in constant density water and salinity-stratified water. Behavior of the turbulence was, of course, dramatically different. The quantitative results will be useful in extending our turbulence closure model so that it may properly account for turbulence generated internal waves.

PLANS FY78

Papers will be prepared to describe the updated Planetary Boundary Layer (PBL) with condensation physics and the BOMEX simulations. Papers will be prepared to report on the laboratory data and analysis.

Research on the proper inclusion of internal wave dynamics into the turbulence closure model will continue.

9.3. ATLANTIC OCEAN COASTAL DYNAMICS MODEL

ACTIVITIES FY77

The construction of an advanced three-dimensional hydro-numerical model which will accurately predict the dynamic and thermodynamic properties of Atlantic coastal waters continues. This ocean model uses a modified "sigma" coordinate system and incorporates a second moment turbulence closure scheme. Tidal, surface wind, heat and salinity forcing are included. In order to test the model, a data bank containing the climatological oceanographic properties of the Middle Atlantic Bight (MAB) has been prepared, (270) using all historical temperature and salinity data on file at NODC. Concurrently, the tidal portion of the model is being used (254) to predict the observed tides in the MAB for the year 1975.

PLANS FY78

As soon as the 3-D model is fully operational, it will be applied to the MAB. The data bank will provide for boundary conditions and for the verification of a year-long climatological simulation. The tidal model will be used to carry out pollutant dispersion simulations for the MAB using both a Lagrangian tracer technique and the solutions of the Eulerian transport equations with no turbulent diffusion.

APPENDIX A

GFDL Staff Members

and

Affiliated Personnel

during

Fiscal Year 1977

* Affiliation Terminated Prior to September 30, 1977

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

Computer Support

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

CLIMATE DYNAMICS

Manabe, Syukuro	Sr. Res. Scientist	FTP
Fels, Stephen	Research Scientist	FTP
Hamilton, Kevin	Student	PU
Schwarzkopf, M. Daniel	Research Associate	FTP
Hahn, Douglas	Sr. Res. Associate	FTP
Daniel, Donahue	Research Associate	FTP
Dimmick, Lanny	Senior Technician	FTP
Green, Edwin	Research Associate	FTP
Hayashi, Yoshikazu	Res. Scientist	FTP
Golder, Donald	Research Associate	FTP
Holloway, J. Leith, Jr.	Sr. Res. Associate	FTP
Thompson, Edna	Secretary	FTP
Shukla, J.	Visiting Scientist	PU *
Spelman, Michael	Sr. Res. Associate	FTP
Stouffer, Ronald	Research Associate	FTP
Wetherald, Richard	Sr. Research Assoc.	FTP

MIDDLE ATMOSPHERE DYNAMICS AND CHEMISTRY

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

EXPERIMENTAL PREDICTION

Miyakoda, Kikuro	Sr. Res. Scientist	FTP
Belle, Kenneth	Student	PU
Bourke, William	Visiting Scientist	PU
Gordon, Charles	Research Scientist	FTP
Coleman, Craig	Junior Fellow	PTT
Stern, William	Research Associate	FTP
Hembree, Daniel	Sr. Res. Associate	FTP
Lusen Ronald	Research Associate	FTP*
Mesinger, Fedor	Visiting Scientist	PU
Rosati, Anthony	Research Associate	FTP
Simmonds, Ian	Visiting Scientist	PU
Sirutis, Joseph	Research Associate	FTP
Strickler, Robert	Sr. Res. Associate	FTP
Chludzinski, Julius	Research Associate	FTP
Terpstra, Theodore	Research Associate	FTP
Jobson, C. T.	Research Associate	FTP
White, Robert	Jr. Technician	FTP
Umscheid, Ludwig	Sr. Res. Associate	FTP
Caverly, Richard	Research Associate	FTP
Davis, William	Research Associate	FTP
Hovanec, Russell	Research Associate	FTP
Orzol, Raymond	Jr. Technician	FTP

OCEANIC CIRCULATION

Bryan, Kirk	Sr. Res. Scientist	FTP
Anderson, David	Visiting Scientist	PU
Cox, Michael	Sr. Res. Associate	FTP
Kepics, Cynthia	Junior Fellow	PTT
McGuirk, David	Research Associate	FTP
Hellerman, Solomon	Research Associate	FTP
Hibler, William	Visiting Scientist	PU
Jackson, Martha	Senior Technician	FTP
Philander, Samuel	Visiting Scientist	PU
Carton, James	Student	PU *
Pacanowski, Ronald	Research Associate	FTP
Strub, P. T.	Student	PU
Willebrand, Juergen	Visiting Scientist	PU
Schopf, Paul	Student	PU *
Ripa, Pedro	Visiting Scientist	PU *

PLANETARY CIRCULATIONS

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

OBSERVATIONAL STUDIES

Oort, Abraham	Sr. Research Sci.	FTP
Chan, Paul	Student	PU *
Levitus, Sydney	Research Associate	FTP
Rosenstein, Melvin	Senior Technician	FTP
Stefanick, Michael	Student	PU
Cilino, Laura	Junior Fellow	PTT

HURRICANE DYNAMICS

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

MESOSCALE DYNAMICS

Orlanski, Isidoro	Sr. Research Sci.	FTP
Cerasoli, Carmen	Visiting Scientist	PU
Garraffo, Zulema	Student	PU
Mechoso, Carlos	Student	PU
Polinsky, Larry	Research Associate	FTP
Ross, Bruce	Sr. Res. 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
Dickey, Tommy	Student	PU *

GFD PROGRAM

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

PERSONNEL SUMMARY
(9/30/77)

FTP - Full Time Permanent (GFDL)	91
Vacancies for FTP Positions (GFDL)	4
PTP - Part Time Permanent (GFDL)	1
Junior Fellows (GFDL)	4
Visiting Scientist (PU)	10
Students (PU)	8
Professors (PU)	2
Secretaries (PU)	2
TOTAL	122

APPENDIX B

GFDL
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DELISI, Donald P.	(193-A), (201), (202)
DELSOL, Frederick	(107)
DICKEY, Thomas	(273)
FELS, Stephen B.	(163-A), (170), (196), (204), (262), (t)
FRIEDRICH, Hans J.	(102)
GALL, Robert	(221), (222)
GILL, Adrian E.	(113), (154-A), (dd)
GOLDER, Donald G.	(260)
GORDON, Charles T.	(132), (180-A)
GRAHAM, R. D.	(56)

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MATSUNO, Taroh	(117)
MELLOR, George L.	(159-A), (185), (203), (209), (217), (261)
MIYAKODA, Kikuro	(20), (60), (72), (85), (89), (91), (107), (109), (119), (120), (122), (132), (139), (154), (158), (166), (180), (181), (220), (227), (m), (o), (r)
MOLLER, Fritz	(10), (11), (13), (14)
MOXIM, W. J.	(239)
MOYER, R. W.	(60), (122)
NAPPO, C. J.	(109)
OORT, Abraham H.	(73), (77), (83), (90), (95), (106), (115), (118), (126), (145), (148), (168), (169), (171), (174), (175), (188), (197), (232), (245), (h), (k), (u), (w), (bb)
ORLANSKI, Isidoro	(61), (82), (84), (114), (130), (146), (159), (160), (173), (188-A), (200), (201), (224), (225), (249), (f), (i)
PACANOWSKI, Ronald C.	(191), (dd)
PHILANDER, S. G. H.	(144), (157), (235), (255), (270), (h)
PIACSEK, Steve A.	(101)
POLINSKY, L. J.	(173), (188-A), (i)
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RASMUSSON, Eugene M.	(40), (52), (57), (66), (90), (104), (140)
RINTEL, Lionel	(48), (59),
RIPA, Pedro	(j), (s)
ROBINSON, John B.	(152), (184)
ROSATI, Anthony	(o)
ROSS, Bruce B.	(160), (173), (188-A), (f), (z)

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SCHWARZKOPF, M. Daniel	(204)
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SHULMAN, Irving	(139)
SIMMONDS, Ian	(233), (251), (y)
SINCLAIR, Russell W.	(263)
SIRUTIS, J.	(227), (r)
SMAGORINSKY, Joseph	(1), (2), (5), (8), (9), (17), (22), (23), (25), (32), (33), (42), (43), (44), (49), (58), (72), (74), (87), (91), (99), (112), (138), (183), (272), (a), (aa)
SOMERVILLE, Richard	(105), (111), (151)
SPELMAN, Michael J.	(143), (190)
STAMBLER, H.	(122)
STEGEN, Gilbert R.	(178), (186), (193-A), (202), (207)
STERN, Bill	(180-A)
STONE, Hugh M.	(67), (87), (92)
STRICKLER, Robert F.	(26), (33), (58), (72), (85), (91), (109), (122), (131), (139), (m)
SUAREZ, Max J.	(161-A), (242), (243)
TALAGRAND, Oliver	(119), (120)
TANG, D. H. Edward	(225-A)
TERPSTRA, Theodore B.	(162)

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APPENDIX C

Computational Support

APPENDIX C

The computational resources available to GFDL during FY7T (the transitional quarter from July 1976 through September 1976), and for FY77 consisted of the Texas Instruments, Inc. X4ASC and the Datagraphix 4020. The table below provides a summary of actual X4ASC central processor unit (CPU) hours realized during each of the fifteen months, and the number of frames of microfilm (either 16mm or 35mm) produced.

The Laboratory's scientific program requirements for computer power are of at least an order magnitude greater than can be supplied by the X4ASC. Two separate efforts to increase computer power were undertaken during the past year.

First, in cooperation with Texas Instruments, Inc., a concerted effort was made to improve the reliability of the X4ASC hardware and to improve the efficiency of the operating system and the FORTRAN compiler. During the period from July 1976 through June 1977, GFDL was able to realize in excess of seventeen CPU hours per day, which was approximately an hour per day more than the previous year, but short of the long term goal of nineteen hours per day. During the last three months of FY77 the hardware reliability of the X4ASC decreased significantly as the result of the manner in which the system reacts to external electrical power problems. It appears that the most reasonable expectation for the X4ASC is hardware/software reliability which permits not more than eighteen CPU hours per day.

The second effort to increase the computational power available to GFDL involved the initial planning needed to provide for the orderly replacement of the X4ASC when its eight year life ends in September 1982. Based on information obtained from the computer industry, it is believed that systems up to ten times as powerful as the X4ASC will become available by 1980 if multi-processor systems are acceptable to the Laboratory. While such systems preclude the execution of a single extremely large problem on the full system, it is believed that the scientific program can accommodate this constraint and make effective use of the increased power. A feasibility study documenting scientific program requirements and providing implementation schedules was completed in May 1977 and was under review in higher headquarters at the end of FY77.

It has been planned for some time to replace the Datagraphix 4200, which was built in 1963. A feasibility study for replacement was completed by GFDL, and reviewed and approved by higher headquarters. At the end of the fiscal year, the Request for Proposal prepared by GFDL was in the final review stage. It is anticipated that a new graphical output system will be installed at GFDL late in FY78.

TABLE: MONTHLY USAGE

Month	Actual ASC CPU Hours Realized	SD-4020 Frames Produced
July 1976	558	47,672
August 1976	560	50,131
September 1976	523	44,885
October 1976	543	45,549
November 1976	517	40,208
December 1976	527	43,670
January 1977	539	39,952
February 1977	479	37,227
March 1977	579	51,378
April 1977	529	46,753
May 1977	578	49,336
June 1977	543	47,079
Jul6 1977	506	37,824
August 1977	498	34,663
September 1977	432	32,908

APPENDIX D

Seminars Given at GFDL
During Fiscal Year 1977

June 9, 1976	"Recent Observational Studies on the Tropical Monsoons" by Dr. K. R. Saha, Indian Institute of Tropical Meteorology, Poona, India
June 15, 1976	"Recent Research Developments at the Australian Numerical Meteorology Research Centre" by Dr. D. J. Gauntlett, Australian Numerical Meteorology Research Centre, Melbourne, Australia
June 17, 1976	"A Monte Carlo Model of a Stratified Fluid" by Ms. Sylvia Worthem, Atlantic Oceanographic & Meteorological Laboratories, Miami, Florida
June 23, 1976	"Recent Results from Venera 9 and 10 on Atmosphere of Venus" by Dr. William B. Rossow, GFD Program, Princeton, NJ
June 28, 1976	"Instability of an Antarctic Circumpolar Current" by Dr. Peter Kilworth, Cambridge University, England
July 22, 1976	"A Finite Element Weather Forecasting Model" by Mr. Michael Cullen, British Meteorological Office, Bracknell, England
July 26, 1976	"Photochemistry of the Upper Atmosphere" by Dr. Hiram Levy II, GFDL, Princeton, New Jersey
July 28, 1976	"What Meteorological Measurements do Oceanographers Need?" by Dr. S. G. H. Philander, GFDL, Princeton, New Jersey
August 10, 1976	"Upstream Influence of Stratified Flow Over a Bump" by Dr. Peter Baines, C.S.I.R.O., Mordialloc, Victoria, Australia
August 11, 1976	"Sequences of Visible and Infrared Imagery of Hurricane Fifi (September 1974) as Viewed from the Synchronous Meteorological Satellite (SMS-1)" - Film by Mr. Ronald Lusen, GFDL, Princeton, New Jersey
August 16, 1976	"Simulation of the Wisconsin Ice Age" by Mr. Douglas G. Hahn, GFDL, Princeton, New Jersey
August 27, 1976	"A Simple Hemispheric Temperature Model" by Professor Reid A. Bryson, Institute for Environmental Studies, University of Wisconsin, Madison, Wisconsin
September 24, 1976	"Variational Methods in Numerical Weather Prediction" by Professor Yoshi K. Sasaki, University of Oklahoma, Norman, Oklahoma
October 1, 1976	"A Numerical Method to Solve Unstable Boundary Problems" by Professor Eugenia Kalnay-Rivas, Massachusetts Institute of Technology, Cambridge, Massachusetts

October 13, 1976	"The Canonical Formulation of Quasi-Geostrophic Dynamics Applied to a Model of Gulf Stream Rings" by Dr. M. A. Virasoro, Institute for Advanced Study, Princeton, NJ
October 22, 1976	"Open Questions about Upper Ocean Internal Waves" by Dr. Melbourne G. Briscoe, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
October 26, 1976	"An Examination of Simple Climate Models" by Professor Richard S. Lindzen, Division of Engineering and Applied Physics, Harvard University, Cambridge, Massachusetts
October 27, 1976	"Modelling of Sea Ice Drift and Deformation" by Dr. William D. Hibler III, GFD Program, Princeton, New Jersey
November 3, 1976	"Deep Ocean Internal Waves" by Dr. Jüergen Willebrand, GFDL, Princeton, New Jersey
November 5, 1976	"Parameterization of Clear Air Turbulence" by Professor Hans A. Panofsky, Pennsylvania State University, University Park, Pennsylvania
November 5, 1976	"Mean Meridional Circulation in the Earth's Thermosphere" by Dr. Robert Dickinson, National Center for Atmospheric Research, Boulder, Colorado
November 10, 1976	"The Ocean Heat Transport - The Barotropic Circulation" by Mr. Paul Schopf, GFD Program, Princeton, New Jersey
November 11, 1976	"The Stability of Planetary Waves in the Atmosphere" by Dr. John H. E. Clark, Department of Meteorology, Pennsylvania State University, University Park, Pennsylvania
November 16, 1976	"Recent Upper Ocean Current Measurements in the Equatorial and Tropical Pacific" by Mr. David Halpern, Pacific Marine Environmental Laboratory/NOAA, Seattle, Washington
November 19, 1976	"Martian Meteorology" by Dr. James B. Pollack, National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California
November 26, 1976	"Operational Prediction with the NMC Movable Fine-Mesh Model (MFM)" by Dr. John B. Hovermale, National Meteorological Center, Washington, DC
December 2, 1976	Weather Systems Viewed from SMS-1" and "GATE to World Weather" - Films by Mr. Ronald Lusen, GFDL, Princeton, NJ
December 3, 1976	"A Statistical-Dynamic Model of the Annual Water Balance" by Professor Peter S. Eagleson, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts

December 8, 1976	"Preliminary Results from the Global Air-Sea Climate Model with Seasonal Variation" by Mr. Michael Spelman, GFDL, Princeton, New Jersey
December 10, 1976	"Numerical Experiments on the Sensitivity of the Atmospheric Hydrologic Cycle to the Equilibrium Temperature" by Dr. John Roads, Department of Meteorology, Massachusetts Institute of Technology, Cambridge, Massachusetts
December 13, 1976	"An Observational Study of the Northern Hemisphere Winter Time Circulation" by Dr. John M. Wallace, Department of Meteorology, University of Washington, Seattle, Washington
December 15, 1976	"Simulation of an Ice-Age Climate" by Mr. Douglas Hahn, GFDL, Princeton, New Jersey
December 16, 1976	"Experimental Explanations of Sharp Tropopauses Based on Radar Observations" by Dr. Pierre Schereschewsky, New York, NY
December 22, 1976	"Viking 1 and 2 Photos" by Dr. William B. Rossow, GFD Program, Princeton, New Jersey
January 3, 1977	"Statistical Corrections to Numerical Prediction Equations" by Dr. Charles E. Schemm, University of Maryland, College Park, Maryland
January 7, 1977	"Some Recent Scientific Results from TWERLE" by Dr. Paul R. Julian, National Center for Atmospheric Research, Boulder, CO
January 18, 1977	"On the Energy Balance of Internal Waves" by Dr. Peter Müller, Institut für Geophysik, Universitat Hamburg, Hamburg, Germany
January 21, 1977	"Summer Circulation of Lake Ontario" by Professor John Bennett, Massachusetts Institute of Technology, Cambridge, Massachusetts
January 26, 1977	"Space-Time Maximum Entropy Power Spectra" by Dr. Yoshikazu Hayashi, GFDL, Princeton, New Jersey
February 2, 1977	"Report on DPS Meeting" by Drs. William B. Rossow and Stephen B. Fels, GFD Program and GFDL, Princeton, New Jersey
February 2, 1977	"Changes in the Deep Circulation of the North Atlantic Ocean as Determined by Changes in Benthic Foramifera Over the Past 120,000 Years" by Dr. Steven Streeter, Lamont-Doherty Geological Observatory, Palisades, New York
February 9, 1977	"Nested Grid" by Mr. Tony Rosati, GFDL, Princeton, New Jersey
February 10, 1977	"Atmospheric Tides and the Rotation of Venus" by Professor Andrew Ingersoll, California Institute of Technology, Pasadena, California

February 16, 1977	"Data Assimilation with Multi-Level Spectral Model" by Dr. Ian Simmonds, GFD Program, Princeton, New Jersey
February 16, 1977	"Some Recent Developments with SOFAR Floats" by Professor Thomas Rossby, University of Rhode Island, Kingston, RI
February 18, 1977	"Some Langrangian Aspects of Ocean Eddies and Mean Circulation" by Dr. Peter B. Rhines, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
February 24, 1977	"Application of Hough Harmonics for Diagnosis and Prognosis of Large-Scale Motions in the Atmosphere" by Dr. Akira Kasahara, National Center for Atmospheric Research, Boulder, CO
March 4, 1977	"Moist Available Potential Energy" by Professor Edward N. Lorenz, Massachusetts Institute of Technology, Cambridge, MA
March 10, 1977	"Poleward Heat Flux in the Southern Ocean" by Dr. Andrew Bennett, Mathematics Department, Monash University, Melbourne, Australia
March 16, 1977	"Mixed Layer" by Mr. Tony Rosati, GFDL, Princeton, New Jersey
March 18, 1977	"Sea Water Cycling Through Mid-Ocean Ridges and the Chemistry of the Oceans" by Professor Heinrich D. Holland, Department of Geological Sciences, Harvard University, Cambridge, MA
March 25, 1977	"Results of Three-Dimensional Numerical Simulation Experiments of Cumulus Convection in Shear Flow" by Professor William R. Cotton, Colorado State University, Fort Collins, Colorado
March 31, 1977	"A Comparison of the Climatologies of General Circulation Models with Observations" by Dr. Maurice L. Blackmon, National Center for Atmospheric Research, Boulder, Colorado
April 21, 1977	"The Use of Ra_{222} and Ra_{228} to Study Mixing in the Deep Sea" by Dr. Jorge Sarmiento, Columbia University, New York, NY
April 28, 1977	"Oceanic Variability Induced by Random Atmospheric Forcing in Mid-Latitudes" by Dr. Claude Frankignoul, Massachusetts Institute of Technology, Cambridge, Massachusetts
April 29, 1977	"Zonal Flows as an Analogue to Open Channel Flows" by Dr. Lawrence Armi, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
May 5, 1977	"Coastal Trapped Waves" by Professor Lawrence A. Mysak, National Center for Atmospheric Research, Boulder, Colorado
May 11, 1977	"N_2O: No Laughing Matter?" by Drs. Hiram Levy and Jerry Mahlman and Mr. Walter J. Moxim, GFDL, Princeton, New Jersey

May 13, 1977	"The Efficient Solution of Poisson's Equation in Two Dimensions via Chebyshev Approximation" by Dr. Dale B. Haidvogel, Center for Earth and Planetary Physics, Harvard University, Cambridge, Massachusetts
May 13, 1977	"The Stability of Ocean Currents in Eddy-Resolving General Circulation Models" by Dr. Dale B. Haidvogel, Center for Earth and Planetary Sciences, Harvard University, Cambridge, MA
May 18, 1977	"N_2O: No Laughing Matter? Part II" by Drs. Hiram Levy and Jerry Mahlman and Mr. Walter J. Moxim, GFDL, Princeton, NJ
May 27, 1977	"Cooperative Submarine and Aircraft Profiling of Arctic Sea Ice" by Dr. Peter Wadhams, Scott Polar Research Institute, Cambridge University, England
June 6, 1977	"A Simple Theory for the Location of the ITCZ" by Dr. Isaac Held, Harvard University, Cambridge, Massachusetts
June 7, 1977	"Tracers and Model Oceans" by Dr. John Shepherd, Fisheries Laboratory, Lowestoft, United Kingdom
June 8, 1977	"Circulation Associated with a Cold Front" by Drs. Bruce Ross and Isidoro Orlanski, GFDL, Princeton, New Jersey
June 13, 1977	"The Winter of '77" by Mr. Michael Matson and Mr. Alan Strong, National Environmental Satellite Service, Washington, DC
June 15, 1977	"Spectral General Circulation Model - Comparison with Grid Point Results" by Mr. J. Leith Holloway, Jr., GFDL, Princeton, New Jersey
June 17, 1977	"An Application Bifurcation Theory to the General Circulation of the Atmosphere" by Mr. Joseph Tribbia, University of Michigan, Ann Arbor, Michigan
June 22, 1977	"Short Wave Radiation Model" by Mr. M. Daniel Schwarzkopf, GFDL, Princeton, New Jersey
June 29, 1977	"Interacting Waves" by Dr. Pedro Ripa, GFD Program, Princeton, New Jersey
July 6, 1977	"Numerical Schemes of a Limited Area Model and Forecast of a Gulf of Genoa Cyclogenesis" by Dr. Fedor Mesinger, GFD Program, Princeton, New Jersey
July 20, 1977	"A Dynamic-Thermodynamic Sea Ice Model" by Dr. William Hibler III, GFD Program, Princeton, New Jersey
July 27, 1977	"The Utility of Satellite Retrieval Temperature" by Dr. Kikuro Miyakoda, GFDL, Princeton, New Jersey

July 29, 1977	"Study of Mesoscale Eddies and its Implications in the Modeling of Joint Ocean-Atmosphere Systems" by Professor Yale Mintz, University of California, Los Angeles, California
August 14, 1977	"Experience in Developing a Limited Area Meteorological Forecast Model" by Dr. S. L. Csanady, Forecast Research Division, Environment Canada, Ontario, Canada
September 1, 1977	"Some Research at Reading University" by Dr. Brian Hoskins, University of Reading, Earley Gates, Whiteknights, Reading, England
September 2, 1977	"Prediction of Ultra-Long Waves in the Atmosphere" by Dr. Lennart Bengtsson, European Centre for Medium Range Weather Forecasts, Bracknell, England
September 14, 1977	"Numerical Modeling on the α, β and γ Mesoscales" by Dr. Richard Anthes, Naval Postgraduate School, Monterey, California
September 23, 1977	"The Radiative Effects of Clouds as a Climatic Feedback Process" by Dr. V. Ramanathan, National Center for Atmospheric Research, Boulder, Colorado
September 28, 1977	"Adequacy of the Rawinsonde Network for Global Studies" by Dr. A. H. Oort, GFDL, Princeton, New Jersey

APPENDIX E

TALKS, SEMINARS AND PAPERS PRESENTED OUTSIDE GFDL

DURING FISCAL YEAR 1977

TALKS, SEMINARS AND PAPERS PRESENTED OUTSIDE GFDL DURING FISCAL YEAR 1977

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
October 6, 1976	Dr. Yoshio Kurihara "Landfall of a Hurricane: Numerical Experiment" "Dynamic Initialization of a Boundary Layer of a Tropical Cyclone"	ERL Colloquium on Mesoscale Meteorology Boulder, Colorado
October 6, 1976	Dr. Frank Lipps "A Study of Turbulence Parameterization in a Cloud Model"	ERL Colloquium on Mesoscale Meteorology Boulder, Colorado
October 6, 1976	Dr. Kikuro Miyakoda "One-Way Nested Grid Models: The Interface Conditions and the Numerical Accuracy"	ERL Colloquium on Mesoscale Meteorology Boulder, Colorado
October 21, 1976	Mr. James G. Welsh "Status of ASC at GFDL"	NASA Langley Research Center Arlington, Virginia
October 29, 1976	Dr. Syukuro Manabe "Simulation of an Ice Age Climate with Mathematical Models of the Atmosphere"	Pennsylvania State University University Park, Pennsylvania
November 3, 1976	Dr. Syukuro Manabe "Relevance of Ice Age Numerical Experiment to the Study of Modern Climatic Variations"	Lamont-Doherty Geological Observatory Palisades, New York
November 4, 1976	Mr. Douglas G. Hahn "Sand Dunes and Princeton"	Lamont-Doherty Geological Observatory Palisades, New York
November 24, 1976	Dr. Syukuro Manabe "Climatic Effects of the Future Increase in the Atmospheric Content of Carbon Dioxide"	Massachusetts Institute of Technology Cambridge, Massachusetts

TALKS, SEMINARS AND PAPERS PRESENTED OUTSIDE GFDL
DURING FISCAL YEAR 1977

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
December 9, 1976	Dr. Kirk Bryan "Ocean Circulation"	Council Meeting of the American Geophysical Union San Francisco, California
December 15, 1976	Dr. Tony Gordon "The GFDL Spectral Model"	Courant Institute New York, New York
January 19, 1977	Dr. Stephen B. Fels "A Self-Consistant Model of the Venusian Stratospheric Circulation"	Division of Planetary Sciences (AAS) Honolulu, Hawaii
January 25, 1977	Dr. Stephen B. Fels "A Self-Consistant Model of the Venusian Stratospheric Circulation"	UCLA Los Angeles, California
March 6, 1977	Dr. Abraham H. Oort "On the Role of the Asian Monsoon in the Angular Momentum and Kinetic Energy Balances of the Tropics"	International Symposium on Monsoons New Delhi, India
March 7, 1977	Dr. Syukuro Manabe "The Response of Climate to Increased CO_2"	Workshop on Environmental Effects of Carbon Dioxide from Fossil Fuels Combustion Miami, Florida
March 21, 1977	Dr. Jerry D. Mahlman 1) "Stratospheric Models: Their Relationship to Trace Constituent Measurement and Analysis" 2) "Application of 3-D Model Output to the Problem of Sampling Means and Trends of Trace Constituents"	Representative of the U.S. Delegation t the "Meeting on Stratospheric Monitorin in Support of the U.S.-France-U.K. Tripartite Agreement" and speech at the "Scientific Seminar on Stratospheric Monitoring" at that meeting. Paris, France

TALKS, SEMINARS AND PAPERS PRESENTED OUTSIDE GFDL
DURING FISCAL YEAR 1977

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
March 26, 1977	Dr. Isidoro Orlanski "Strong and Weak Interaction in Modes"	Harvard University Cambridge, Massachusetts
April 5, 1977	Dr. Isidoro Orlanski "Open Boundary Conditions"	Harvard University Cambridge, Massachusetts
April 26, 1977	Mr. Ludwig Umscheid, Jr. "A Comparison of Three Global Grids Used in Numerical Prediction Models"	Third Conference on Numerical Weather Prediction Omaha, Nebraska
April 26, 1977	Mr. Robert Tuleya "A Numerical Simulation of the Landfall of Tropical Cyclones"	Third Conference on Numerical Weather Prediction Omaha, Nebraska
April 26, 1977	Mr. Anthony J. Rosati "One-way Nested Grid Models; the Interface Conditions and the Numerical Accuracy"	Third Conference on Numerical Weather Prediction Omaha, Nebraska
April 26, 1977	Dr. Isidoro Orlanski "Strong and Weak Interaction in Waves"	Miami Oceanographic Laboratory Miami, Florida
April 29, 1977	Dr. Isidoro Orlanski "Baroclonic Instabilities in the Ocean"	Florida State University Tallahassee, Florida
May 6, 1977	Dr. Kirk Bryan "A Mechanism for Low Frequency Variability of the California Current"	Department of Earth & Planetary Sciences Johns Hopkins University Baltimore, Maryland
May 23, 1977	Dr. Syukuro Manabe "Joint Ocean-Atmosphere Model - Possible Applications to Climate Sensitivity Study"	JOC/SCOR Joint Study Conference on Global Circulation Models of the Ocean and their Relation to Climate Helsinki, Finland

TALKS, SEMINARS AND PAPERS PRESENTED OUTSIDE GFDL DURING FISCAL YEAR 1977

APPENDIX E

DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
May 23, 1977	Dr. Kirk Bryan "Global Models of the Ocean Circulation"	JOC/SCOR Joint Study Conference on Global Circulation Models of the Ocean and their Relation to Climate Helsinki, Finland
June 6, 1977	Dr. Jerry D. Mahlman "A Three-Dimensional Numerical Simulation of N_2O: Some Preliminary Results"	EPA-NCAR Workshop on Climate Response to Stratospheric Change Boulder, Colorado
June 13, 1977	Dr. Abraham H. Oort "Structure of Atmospheric Variability on a Global Scale"	Symposium on the Structure of the Present Climate and its Variability Leningrad, USSR
June 23, 1977	Dr. Charles T. Gordon "Present Status of Numerical Weather Production Including a GFDL Spectral and Nested Grid Models"	International Symposium on Computational Methods for Partial Differential Equations Lehigh University Bethlehem, Pennsylvania
July 11, 1977	Dr. Yoshikazu Hayashi "Space-Time Spectral Analysis of Observed and Simulated Planetary Waves"	Stanstead Seminar Bishop's University Quebec, Canada
August 1, 1977	Dr. Kikuro Miyakoda "One Month Forecasts and the Parameterization of Cumulus Convection and Boundary Layer Processes"	U.S. Workshop on the GATE Central Program National Center for Atmospheric Research Boulder, Colorado
August 15, 1977	Mr. Richard T. Wetherald "Past and Recent Work on Climate Sensitivity"	Ecology-Meteorology Workshop University of Michigan Biological Station Pellston, Michigan

TALKS, SEMINARS AND PAPERS PRESENTED OUTSIDE GFDL
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DATE	SPEAKER AND TITLE OF PRESENTATION	OCCASION AND PLACE OF PRESENTATION
August 15, 1977	Dr. Hiram Levy II "Tropospheric Reactions and Global Cycles"	Gordon Conference on Environmental Chemistry - Air New Hampton, New Hampshire
August 19, 1977	Dr. Jerry D. Mahlman "Model Studies of Stratospheric Dynamics and Chemistry"	Ames Research Center Moffett Field, California
August 22, 1977	Dr. Jerry D. Mahlman "Application of General Circulation Models to the Stratospheric Transport Problem"	IAGA/IAMAP Joint Assembly Seattle, Washington
August 23, 1977	Dr. Kirk Bryan "Formation of AAIW in a World Ocean Model"	International Southern Ocean Studies Meeting Lamont-Doherty Geological Observatory Palisades, New York
August 24, 1977	Dr. Kikuro Miyakoda "Prediction Experiment with Refined Parameterization of Sub-Grid Scale Processes"	IAMAP Meeting Seattle, Washington
September 12, 1977	Mr. Douglas G. Hahn "Influence of the Lower Boundary Conditions (snow and sea surface temperature) on the Monsoon Circulation"	Informal working meeting on the Summer Phases of the Monsoon Experiment (MONEX) National Center for Atmospheric Research Boulder, Colorado
September 22, 1977	Dr. Abraham H. Oort "The Global Climate System"	Department of Physics Catholic University of America Washington, DC