National Centers for Environmental Prediction

1996 UCAR Review Team Report on the Environmental Modeling Center

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Executive Summary

This document constitutes the 1996 University Corporation for Atmospheric Research (UCAR) Review Team Report on the National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC). This community-based review was conducted by a team of seven individuals appointed by UCAR President Dr. Richard A. Anthes and was governed by the review policies and procedures of the UCAR Advisory Panel to NCEP. The review was based on a two-day site visit to EMC in Camp Springs, MD on April 17 and 18, 1996 with extensive documentation provided by EMC to each team member in advance of the site visit, and on the particular expertise of the assembled team.

The Review Team reports that EMC is world class in terms of its scientific productivity, the quality of its operational products, and in the relevance of its research to the service function and mission of the Center. Significant progress has been made since EMC's last formal review in 1992. The organization is healthy and well managed.

EMC is making good progress in adapting the new data streams made available through the Modernization and Restructuring of the National Weather Service to operational models and analyses, and keenly recognizes that its role is central to the success of the Modernization as well as to the newly created NCEP.

Outstanding accomplishments of EMC include:

- The leveraging of limited resources, through cooperative ventures with an array of university, government, and international organizations on projects relevant to EMC's research and operational mission, is a marked achievement (e.g., the hurricane model from GFDL, the RUC model from FSL, and the Princeton Ocean Model in the COFS);

- The creation of the Climate Modeling Branch will benefit all of EMC and especially the Ocean Modeling Branch;

- The 40-year reanalysis by EMC/NCAR is to be applauded;

- The commitment of a high-resolution forecasting effort in support of the Atlanta Olympics, employing the Cray Research, Inc. offer, will advance the state-of-the-art;

- The success of the direct assimilation of radiances;

- The increase in number and quality of both refereed journal articles and non-refereed publications since the last formal review; and

- The responsiveness of EMC to the field forecasters and selected commercial weather companies in correcting NGM and Eta model bias and improving forecast products.

During the course of the review, it became apparent to the Review Team that EMC should strive for international preeminence, i.e., rank above all others. We do not make this suggestion without a keen sense of the effort required by each EMC employee, of the support required by NCEP and NWS, and of the national commitment to mitigate the destructive forces of nature. We believe this is achievable through vision, careful planning, focusing the scientific enterprise and improving collaboration, communication and commitment to the operational and user communities. The recommendations which follow are designed toward that end.

- EMC must craft a realistic shared vision and strategic plan to encourage better teamwork, improve cross-branch collaboration, reduce unnecessary duplication of effort and improve management follow-through on important issues. The plan should delineate a path to preeminence and realistically address resources required.

- EMC should restructure toward a matrix form of organization to improve cross-branch interactions in data assimilation, parameterization and numerics.

- The present partitioning of EMC's budget into base (51%) and soft (49%) support has negative consequences on staff time and on the organization's attractiveness to present and future employees. On the other hand, competition for soft funds can serve as an incentive to produce better science in a more efficient manner. If preeminence is the goal, EMC should be a high priority for new and redirected base funding within NWS/NCEP.

- EMC with the assistance of NCEP and the NWS must find a way to distribute full resolution Eta model output to local forecast offices and other users of EMC products, including the commercial sector.

- EMC must be able to procure high-end computing systems on the world market best suited to its needs, as requirements for upgrades are justified.

- EMC must develop mechanisms for assessing user satisfaction, including quality factors, with its products and services. The annual NWS Users Meeting is a good first step. However, other federal agencies, state and

local governments, and a wide range of commercial enterprises make extensive use of EMC products and services, and their derivatives. They should be assessed on a regular, formal basis.

Further information and discussion of these major findings and recommendations are contained in the main body of the our report.

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I. Introduction

The Review Team met at the National Centers for Environmental Prediction (NCEP) (Camp Springs, MD) from mid-day April 17 to late afternoon April 18, 1996. Three members of the Team are also members of the NCEP Advisory Panel (J. Kimpel, R. Elsberry & P. Malanotte-Rizzoli). Two of the Team members (M. Fritsch & D. Williamson) served on a review panel in 1992 for the former NMC Development Division.

Prior to their meeting, the Review Team was supplied with a variety of material consisting of the following:

1. NCEP Center Review Purpose and Procedures
2. List of Personnel including contract personnel and UCAR visitors
3. Organizational Chart
4. Mission Statements for each Branch
5. Proposed FY 96 EMC Spending Plan
6. FY 96 Sources of Funding
7. Publication Lists (1993, 1994, and 1995)
8. Annual Numerical Model Research Reports (May 1995 & March 1996)
9. Copies of selected publications
10. 1992 Review Panel Report of the Development Division

The Review Team met for an executive session luncheon on Wednesday, April 17 to discuss their review approach. Following the luncheon meeting, the Team met in plenary with the Director of NCEP, Dr. Ronald D. McPherson, and the Environmental Modeling Center (EMC) Division Chief, Dr. Eugenia Kalnay, for an overview of the key issues, followed by presentations on scientific work and plans by six division scientists. Team members spent the remainder of the afternoon visiting the four main branches of EMC. Members had been pre-assigned branches that they would meet with and contribute that portion of the final report (Refer to the Table of Contents for the Branch assignments). The Review Team met for an executive session dinner on Wednesday evening and then reconvened later that night at the hotel for further discussions.

The following day, the Review Team continued individual Branch meetings and reconvened in executive session to consolidate issues and outline writing assignments. Late morning, the Review Team briefed Drs. McPherson and Kalnay of the primary issues that would be contained in the report. Based upon preliminary feedback, the Team reconvened in executive session for two hours to expand upon the issues. The Team met in plenary late that afternoon with R. McPherson and E. Kalnay as well as the Branch chiefs to expand upon the issues and brief them on the expected content of the report.

During its review, the Team recognized that EMC is a healthy and well managed organization. Specifically, the Review Team is convinced that a large volume of high quality research and development is being accomplished. The Team now encourages EMC to strive for preeminence, i.e., rank above all others. We believe this is achievable through vision, careful planning, focusing the scientific enterprise, and improving collaboration, communication, and commitment to the operational and user communities. This overarching principal is the primary focus of the review that follows.

II. Centerwide

Since the 1992 review of the old National Meteorological Center (NMC) Development Division, a major reorganization has occurred. The new National Centers for Environmental Prediction (NCEP) has EMC at its core (Figure 1). The EMC retains much of the structure and function of the old NMC Development Division and has expanded to include a Climate Modeling Branch and a Test Facility. The Test Facility is not as yet operational because of lack of funding. While it is too early for the Review Team to assess the impact of the reorganization, the sense is that the creation of NCEP is very positive and strategically positions the NWS and NOAA to play a key role nationally in disaster reduction, public policy issues, and in providing an economic advantage to business through improved products and services. The success of NCEP, and therefore of EMC, will partially depend on the quantity and quality of interaction among the NCEP Centers. The Review Team encourages NCEP and EMC management to foster this interaction as one of its top priorities.

Also since 1992, the National Weather Service (NWS) Modernization has made considerable progress. The Review Team is pleased with the progress EMC has made in adapting the new data streams to the models. The NCEP/EMC plan for model evolution over the next five years (Figure 2) seems appropriate and will present a challenge if funding remains flat or diminishes during the period of the plan.

The Review Team is pleased to note that many of the recommendations contained in the 1992 review have been acted on. The assignment of Jordan Alpert to EMC Computing, new expertise in parameterization, and the strengthening of the Global Modeling Branch are particularly acknowledged. However, problems persist in the lack of a center-wide, long-range strategic plan and short-range goals; Cross-branch collaboration, although much improved, needs further attention. These later issues are addressed elsewhere in this report.

Figure 1

NATIONAL CENTERS for ENVIRONMENTAL PREDICTION

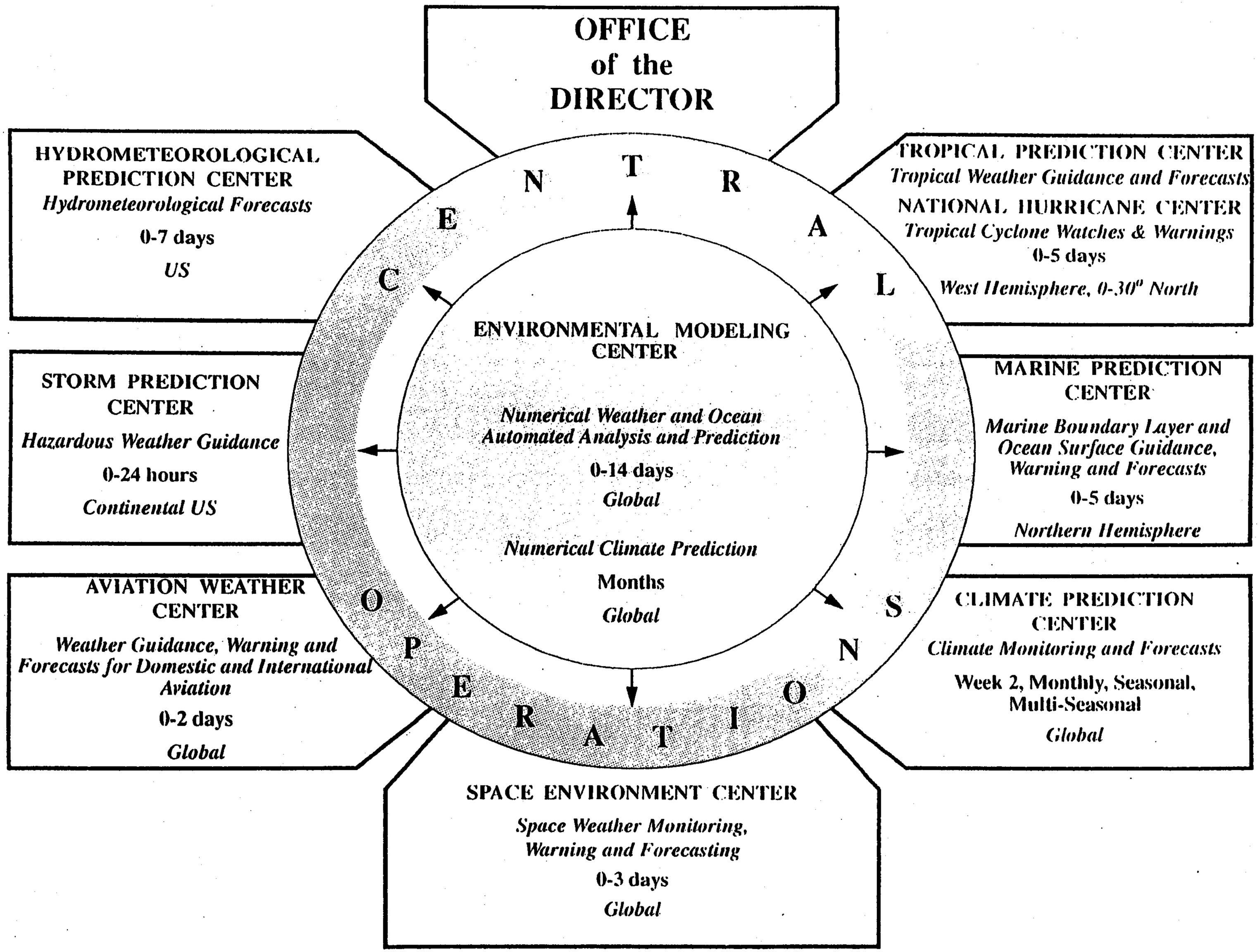
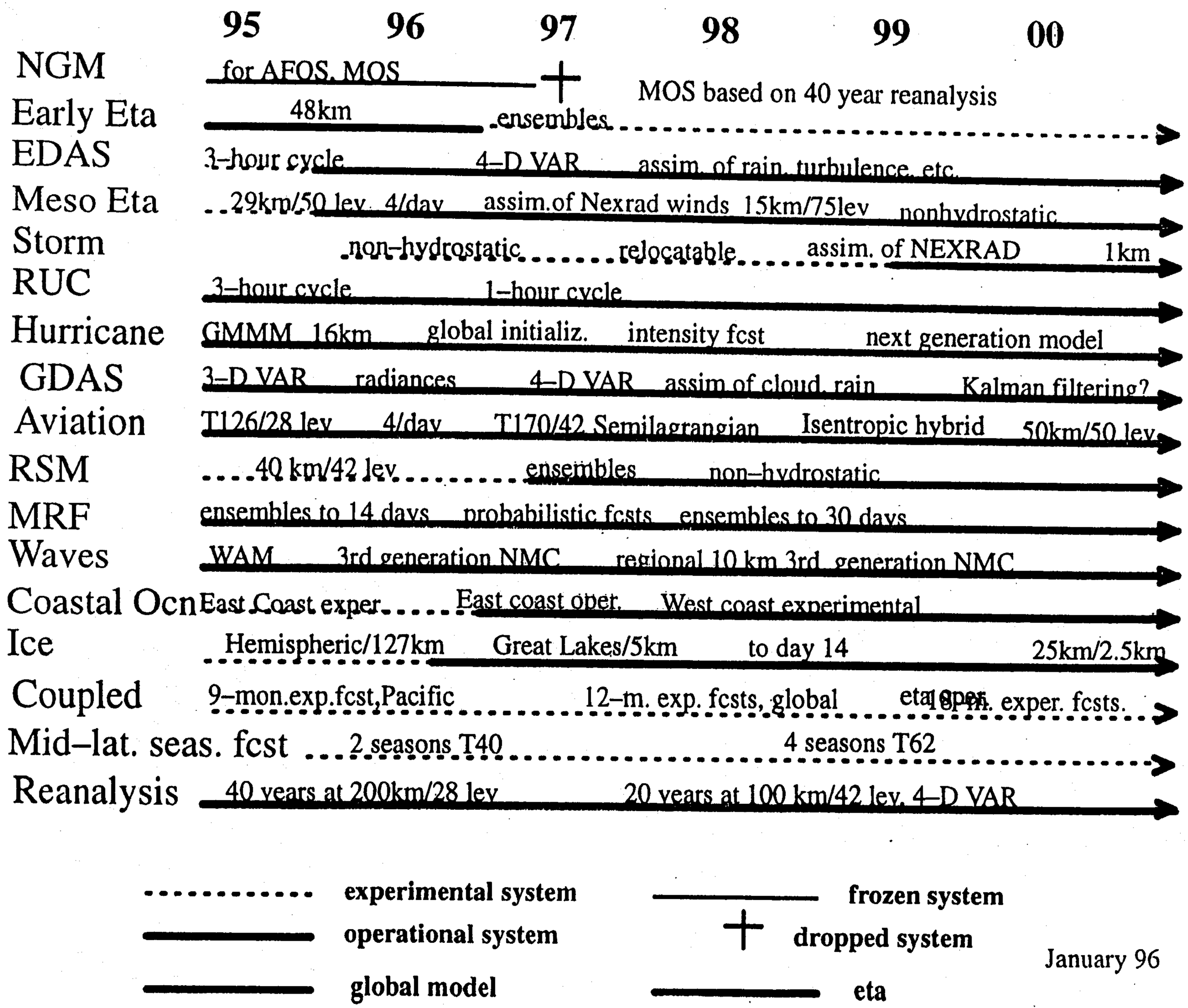


Figure 2

NCEP Model Evolution Plans, 1995 – 2000



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1. Scientific Productivity / Quality

Measures of the scientific productivity of the EMC should not be judged solely in terms of journal articles, conference preprints, and technical reports. Additional measures should include contributions to the operational system, and specifically the improvements in the quality of the analysis and forecast guidance that result from the implementation of a new system or an upgrade of an existing system. Such an evaluation is difficult because such contributions are the result of team efforts over a period of months or even years and improvements continue as new problems arise in the operational environment.

Publication counts were made from journal articles, conference preprints, and technical report summaries provided to the Review Team. It is important that EMC personnel publish in the refereed literature and conference preprints to document scientifically the improvements to and the performance of EMC products. It is primarily via these media that the wider science and forecasting community learns of EMC's accomplishments and progress. Although NOAA frequently experiences shortages in travel funds, every effort should be made to have EMC personnel attend appropriate scientific conferences and workshops to inform the community, exchange ideas, and to learn the challenges and problems confronting the operational community. These comments apply also to EMC's visiting scientists.

Based on the publication lists provided, EMC personnel published 68 refereed journal articles during 1993-1995. According to the previous review in 1992, 37 journal articles were published during 1989-1991. At the time of the previous review, the Development Division had fewer employees, but a greater proportion were fully funded civil servants rather than visiting scientists or contract employees. The Review Team does not have a good standard by which to judge journal article production for a specialized operational modeling center like EMC. For the Meso- and Microscale Meteorology Division at NCAR, the productivity rate is about one refereed article per year (i.e., per scientist, per staff member including support scientists and programmers, etc.). Meteorology faculty at the University of Oklahoma average about two articles per year. By comparison, EMC scientists are producing about one article every two years. This seems to be a reasonable achievement considering the operational focus of EMC's research and development mission. The upward trend in the number of refereed articles is viewed as a very favorable sign.

A count of non-refereed publications (preprints, proceedings, technical reports, etc.) was also made over a multiple year period since technical conferences such as Numerical Weather Prediction and Weather Analysis and Forecasting are scheduled biennially. The EMC was particularly well

represented at the Numerical Weather Prediction Conference in Portland, Oregon in 1994. Several EMC personnel gave keynote addresses, and Dr. Eugenia Kalnay was given a full hour plenary session to describe EMC analysis and prediction products. The Review Team regards these as independent measures of the scientific value and importance of EMC. During 1993-1995, EMC personnel list 143 non-refereed publications which compare with 78 during 1989-1991. Again, the trend is upward and partially reflects the number of new products brought on-line, which the panel views as a positive sign.

Thus, the Review Team is quite pleased with the overall scientific productivity of EMC as evidenced by trends in publications. The majority of the refereed articles published by EMC personnel over the last several years have appeared in AMS and other first-tier journals. Given this and individual Team members knowledge of specific papers, the Review Team determined the quality of EMC's published works to be quite high. The quality of EMC's science is reflected also in the quality of its operational products. This point is discussed in Section II. 2 immediately following.

2. Quality of the Operational Products of the Center

The ultimate judge of the scientific quality is the user of an EMC analysis or prediction model. That user may be another center in the NCEP galaxy (Figure 1). In many cases, other NCEP centers take EMC products and "add value" before passing it on to the 120 NWS Weather Service Forecast Offices (WFOs), to private industry, federal, state and local governmental agencies, or directly to the public. Thus, it is often difficult to identify the specific contribution EMC personnel have made to the final product. Nevertheless, the Review Team has attempted to identify those NCEP centers and a few private and public sector users of EMC analysis and prediction models for a "quick look" analysis. Results are reported in Section IV. 4. of this report. It was not possible for the Review Team to undertake a more comprehensive survey of user satisfaction with the quality of EMC's products. However, this issue is an important one and requires EMC and NCEP attention. Therefore, the Review Team recommends that, prior to the next external review slated for 1999, EMC/NCEP develop a mechanism for assessing user satisfaction, including quality factors, with EMC products and services. This is to be in addition to the annual NWS Users Meeting. We believe that the benefits of such a mechanism in these uncertain times will far outweigh the time and effort spent. Perhaps the NCEP Advisory Panel could be asked for guidance.

A more detailed review of the operational products of EMC is contained in the branch reports (Section III). Taken in aggregate, the Review Team is impressed with recent improvements and additions to EMC's suite of products and services.

3. Relevance and Impact of the Research to the Service Function and Mission of the Center

The Review Team found the research being conducted within EMC to be in keeping with the mission-oriented, operationally driven nature of NCEP. We did not find evidence of individuals "doing their own thing" outside the mission of EMC. For example, an examination of EMC 1995 publications (refereed and conference preprints) indicate contributions to both science and operational modeling. The balance is heavily skewed in favor of modeling / operational initiatives (58 of 60) , which the Review Team considers appropriate. At the same time, many of these publications are a blend of theory, modeling, and observations and make real contributions to the advancement of knowledge. Thus, we consider the research being conducted at EMC to be completely relevant to the mission and service function of the center.

The question of impact is more difficult to access. Impact implies a transfer of knowledge gained in research to the modelers and thence to the operational product. Given the nature of the team approach within working groups and the breadth of many EMC scientists, this linear path of transfer is obscure. Suffice it to say the Review Team believes that the research conducted at EMC has a large, positive impact on the service and operational mission of the center. The research / operations mix at EMC is similar to the numerical model employed at ECMWF, UKMO, and the basis for the NWS initiative to co-locate WFOs at universities with viable atmospheric science programs. Further information on this topic is incorporated into the Branch reviews (Section III).

4. Plans for Program Institutions, Continuations and Terminations, and Specifically its Plans for Future Research

The 1992 external review stressed the necessity for both long-range strategic planning and the establishment of shorter range specific goals. It is the opinion of the Review Team that planning is a weakness within EMC, and that EMC personnel, management and external constituencies, including the annual budget process, are hampered as a consequence. The Review Team received a one-page bar graph entitled "NCEP Model Evolution Plans. 1995-2000" (Figure 2) and a four-page draft document that defines the "NCEP Work Breakdown Structure relative to Stage 2 of the NWS modernization program". Neither document is strategic and both are essentially lists of objectives with timetables. While the Model Evolution Plans document proposed work on six new operational models while terminating two existing models, we do not have an overview of the personnel, computing, telecommunications, and financial resources required to ensure reasonable success. Thus, the Review Team does not feel it had the information necessary to evaluate properly and comment on EMC's program plans. In

some cases, Branch internal plans were reviewed in Section III. The Review Team recommendation on planning is contained in Section II. 7. B. i.

5. Optimal Use of Resources

Optimizing resources to ensure a reasonable balance between research and development initiatives and operational responsibilities involves both financial and human components. In the case of EMC, these two components are inseparable because of the high proportion of personnel cost in EMC's $7.5 million annual budget.

Fully 92% of the budget under the control of the EMC Director is in personnel. Presumably, space and other infrastructure costs are budgeted elsewhere. There has been some growth in personnel in the ten-year period 1986-1996 (62 to 89) but much of this can be attributed to the addition of the Climate Modeling Branch in 1995. When this reorganization is taken into account, EMC has been essentially "flat" in terms of personnel over the past five years. The Review Team is satisfied with the current allocation of resources between research and development and operations because research and development is the major mission of EMC, whereas other NCEP Centers have stronger operational commitments.

Other than the bottom line, the chief budget issue within EMC has been the dramatic change in the partitioning of the EMC budget between base support and support via grants and contracts. "Soft" support has grown from a small percentage in 1986 to 49% of the $7.5 million in fiscal year 1995. Of this 49%, 38% is from other parts of NOAA and 11% is from other federal agencies. In the present federal fiscal climate, both base and soft funds are at risk, with soft funds in greater jeopardy. The impact of this situation on personnel is enormous. Year-to-year grant and contract funding is a real detriment to recruiting top flight scientific and technical support staff. Anxiety levels increase in employees who are soft funded and stress is placed on EMC and Branch leaders. Because of the importance of this issue, the Review Team considered it as a separate, cross-cutting issue and reports its findings in Section IV.

6. Joint Efforts

EMC participates in a wide variety of joint efforts with groups and individuals from universities and other organizations. Documentation provided to the Review Team lists collaborative projects with nine universities, NCAR, NOAA Environmental Research Laboratories (ERL), other NCEP Centers, NWS Headquarters and WFOs, NESDIS, USWRP, NASA, DOD, DOE, Scripps, Lamont-Doherty, and several international organizations (ECMWF, five foreign national modeling / forecast centers). Such collaboration is vital to the success of EMC in obtaining access to

research results from top researchers in a timely manner and thus maintaining EMC's world-class status. Collaboration keeps external constituencies appraised of challenges, opportunities, and problems from an EMC perspective and can help shape the research agendas of others. Also, these joint efforts are necessary to maintain and enhance the portion of EMC's operating budget funded via soft money.

Three collaborative efforts with the NOAA ERL and the university oceanography community are particularly noteworthy. The first EMC collaboration effort is the transition of the Geophysical Fluid Dynamics Laboratory (GFDL) Hurricane model to an operational status. Approximately 15 years of basic research effort at GFDL were required to develop this high-resolution numerical model with sophisticated physical process representations appropriate for tropical cyclones. An excellent collaboration between EMC and GFDL personnel quickly accomplished the conversion of the GFDL model to an operational model that is robust (capable of being initiated and integrated in a wide variety of real conditions), efficient, and timely (forecast products arrive at WFOs as early as possible). A vivid demonstration of the benefits from this effort occurred during the 1995 Atlantic hurricane season, which was the second-most active in history. The GFDL model provided track forecast guidance that contributed in large measure to the excellent 48- and 72-hour track predictions by the National Hurricane Center (R. Burpee, Director, personal communication). Even though this is a significant achievement, few people know of the essential role played by EMC personnel.

The Forecast Systems Laboratory of ERL created, with basic research funding, the Mesoscale Analysis and Prediction System (MAPS) over a number of years. This MAPS addresses the need for three hourly (perhaps even hourly) analyses and forecasts of the atmospheric circulations on the mesoscale (say 2-200 km horizontal scales and 100-200 m vertical resolution). Such analyses and short-term (3-12 h) predictions are useful for aviation flight planning and warnings, and for warnings associated with rapidly developing mesoscale convective systems that create high winds, severe local storms, hail, etc. Thus, such products would directly support the Aviation Weather Center (plus commercial and general aviation users), and the new Storm Prediction Center that is responsible for hazardous weather warnings on time scales of 0-24 h (Figure 1). Although the longer range analyses and forecast systems also use the observations, the renamed Rapid Update Cycle (RUC) System at NCEP may be viewed as the most challenging exploitation of the Nation's investment in new weather-related technology: (i) the Radar Wind Profiler Demonstration Network; (ii) the WSR-88D Doppler radar deployments; (iii) the new geostationary satellites such as GOES-8 and -9; and (iv) the Automated Surface Observing System.

Again, the challenge for the EMC personnel was to take the MAPS and convert this basic research system into an operational analysis and forecast model called RUC that is robust, efficient, and timely. The timely aspect is absolutely critical when dealing with mesoscale phenomena that often are generated, achieve maturity, and die on the 12-24 h time scale of prior numerical weather prediction products. The challenge is to receive raw observations continuously (versus every 12 h as in the past), perform a quality control, assimilate various types of observations of varying accuracy and spatial distributions into an analysis, and then integrate a numerical forecast model for 12 h every 3 h of each day. Furthermore, this entire procedure must be completed in about an hour, and rapidly communicated to the user because the forecast product is only useful for a few hours until it becomes a historical record. The accomplishment of the MAPS-to-RUC transition is very significant, but the role of EMC in creating these products will be little recognized by the users.

The third example of EMC collaboration is the Coastal Ocean Forecast System (COFS). Although COFS is not a fully operational model, it is being made available via an Internet home page as sea-surface temperatures, near-surface ocean currents, and the near-surface air temperature and winds derived from the mesoscale Eta model, which are used to force the ocean model. Now that the tides have been entered, the ocean surface elevation prediction should become a useful product, especially when winter storm surges are possible.

The COFS collaboration is a multiple interaction effort. The basic ocean model is the Princeton Ocean Model, which has been tested extensively and has a large academic user group that will be continually doing research and improving the model at no expense to EMC. Secondly, EMC is collaborating with the Navy, which is developing a similar version of the Princeton Ocean Model as the operational model for the west coast of the U.S. Thus, EMC will benefit from the Navy's experiences in developing operational ocean models. As an example of this collaboration, the Navy is now providing the EMC Ocean Modeling Branch (OMB) the TOPEX ocean surface elevations that will be assimilated into the COFS.

The GFDL hurricane model implementation, RUC model implementation, and COFS collaboration effort are considered by the Review Team to be excellent examples in which EMC is able to provide useful forecast products to their customers in a more timely and cost-effective way than if they had developed the analysis and forecast models as a fully internal effort. The latter approach had been the "culture" of the Development Division in the past where each new product was internally developed, often with multiple versions that were intercompared to result in an operational product. Whereas this did result in some excellent models, it took a lot of time and internal effort. These development efforts frequently did not use much of the possible contributions from academe, research laboratories, or other

operational agencies, in part because this was not the culture of the era. In the present era, the universities and ERL are being more strongly encouraged to demonstrate that their research has a practical application to societal needs.

The Review Team believes that the EMC should consider such collaborations are an optional and favorable mode of developing new models in those areas in which universities and the ERL are producing advances. One area in which it is not likely that such collaborations with universities will be fruitful is in data assimilation, which university researchers have avoided since it is such an operational topic. Nevertheless, the EMC is encouraged to adopt a more open view in learning from and sharing with other operational centers to advance weather analysis and forecasting products for the common societal benefit. In the present financial era, EMC must be seen to be leveraging their research and development efforts and not internally developing new models where external expertise and supported model development can be exploited.

The Review Team is impressed with the number and breadth of EMC's collaborative efforts. We wish to congratulate EMC leadership and the individual scientists who have devoted time and energy to these joint projects. We consider these collaborative efforts to be one of EMC's outstanding strengths and help keep the organization looking outward for opportunity, rather than inward and stagnating. Specific collaborative efforts are usually related to a particular branch. Several of these are discussed in Section III.

7. Issues

As mentioned in Section I, the Review Team encourages EMC to strive for preeminence. We do not make this recommendation without a great deal of thought and the sense that it is achievable with a great deal of planning, effort, and a sustained commitment to marshaling necessary resources. This section attempts to provide EMC with a, albeit very brief, "road-map" on what the Review Team believes is a necessary beginning to move toward preeminence in the numerical weather and climate prediction arena. We consider this section of our report the heart of our review.

A. Ongoing Efforts

i. The creation of the Climate Modeling Branch is applauded with the acquisition of Dr. Ants Leetma and collaborators, who will be an asset to EMC. First, it will expand EMC activity to include the broad scientific and operational demands of the Climate System, which comprises and connects individual components such as the atmosphere and the ocean. Second, the additional expertise in ocean modeling and oceanographic data assimilation represents an excellent opportunity for a cross-branch link with the ocean modeling

component that was noted to be missing in the previous review. In particular, it will provide valuable guidance to the Ocean Modeling Branch for large-scale ocean circulation modeling issues.

ii. The 40-year reanalysis by EMC/NCAR effort is to be applauded, and the high visibility obtained through the BAMS article and widely distributed optical disk is a definite positive achievement.

iii. The Hurricane model from GFDL, the RUC model from FSL, and the Princeton Ocean Model in the COFS are excellent examples of transitions to real-time operational models that have had, or shortly will have, improved guidance to forecast centers.

iv. The commitment of a high-resolution mesoscale forecast effort to the Olympics is an excellent showpiece for EMC. It takes the offer by Cray Research, Inc. into an advantageous position for EMC and will yield a significant advancement in the state of the art.

v. EMC is to be congratulated on the success of the direct assimilation of radiances.

B. Center-wide Issues

i. The Review Team believes EMC must craft a realistic shared vision and strategic plan in the immediate future (see Section II.4.). The planning process and resulting document will assist in better teamwork and cross-branch interactions, reduce unnecessary duplications, and improve the follow-through by management on important issues. The plan should delineate a path to preeminence and realistically address resources required.

ii. Research and development of advanced data assimilation systems lie at the very heart of all of EMC's activities. Without a sophisticated assimilation system that demonstrably uses all available observations to best effect, the enormous national and international investments in observing systems will be under-exploited, and forecast quality will be less than optimal.

The development of such assimilation systems requires substantial and sustained investments of highly skilled manpower on a well-focused development program. The panel identified a large pool (about 11) of data assimilation experts at EMC. However, their efforts are spread across several assimilation systems, the global, regional Eta, coastal ocean, and tropical ocean models. EMC should be moving toward the development of a unified assimilation system that focuses their efforts and serves the needs of, at least, the two atmospheric models.

In addition, a variety of work is in progress at EMC on the interpretation of remotely sensed data (e.g., with neural nets) that is directed to the short-term goal of improving analyses for the bench forecaster. This work should be simultaneously directed to the longer term goal of improving the interpretation and assimilation of the data in a global variational (4DVAR) calculation, which would assess and interpret these remotely sensed data in the light of all other available data. Both the short-term and the long-term goals could be addressed simultaneously with an enduring piece of software for the forward and adjoint observation operators that would be configurable for a full variational calculation, or for a simplified (e.g., a 2DVAR), context for immediate needs. This is already being done with the neural network retrievals, which are being developed for use in the variational global analysis, including their forward, linear tangent and adjoint models.

As part of the planning process outlined in Issue 1, it is essential that EMC prepare a plan to develop an advanced four-dimensional variational assimilation system (4DVAR) that can be configured to serve the needs of the global and regional models, which has a comprehensive treatment of relevant physical parameterizations, and which has the ability to assimilate all available remotely sensed data at level 1.5 (e.g., engineering-calibrated and earth-located radiance or radar measurements). In such a system, the individual observation operators can be developed and tested in a stand-alone mode, which will facilitate interaction with the science teams responsible for new observing systems. Implementation of this initiative will take several years, but is all the more justified as we move into an era when operational global models will have resolutions of order 30-40 km and operational regional models will have resolutions of order 5-10 km or better.

If the efforts of EMC's assimilation and remote-sensing experts were focused on a unified assimilation system of the type described, then EMC would rapidly move ahead of the international competition in this area, because of the great wealth of new U.S. observation technologies and U.S. theoretical research available to EMC.

iii. The Center should continually identify and articulate the major systematic errors in the forecast-analysis system as a whole and in the individual components. These errors could be categorized according to whether there are ideas on how to reduce them, which are common to or different from those of other centers, and how other groups are dealing with or expect to deal with similar problems. Such a

categorization would aid management in focusing resources to provide early payoff in the operational system.

iv. Although operational guidance now provides model output with resolution far superior to that of only a few years ago, many local forecast needs require still higher resolution information. For example, it is well known that local physiographic effects can radically alter local weather conditions to the point that regional (zone) forecasts are far from representative of local conditions. In some instances, terrain-forced snowfall can vary by factors of two or three in only a few kilometers. Likewise, terrain can force the development of severe downslope windstorms on scales much smaller than those resolved by operational models. Furthermore, certain forecaster requirements, e.g., air quality, require special physics not now included in operational models. Moreover, a host of local temperature and wind forecast requirements exist for which no special guidance is now available. In short, a great and growing need exists for time-dependent local boundary conditions to drive local models.

Reasonably priced workstations are now available that are capable of running sophisticated numerical models in real time, and the number of university and research labs capable of running these models has greatly increased. Thus, it is no wonder that a growing demand exists for easy access to the NCEP data base necessary to run the models in real time. Furthermore, it is the Review Team's sense that this demand is increasingly surfacing at the NWS field offices. One can understand the frustration of field forecasters who are shown important detail in local research model integrations by the university, and which are never seen in the EMC forecasts available to the forecaster. An even greater source of frustration is that many field offices cannot even get the Eta model output at full resolution and in a timely fashion. This is because the National Weather Service's AWIPS data dissemination system uses fixed grids and data structures that are much coarser than the resolution of the Eta model. The Eta model output is therefore degraded to these coarser grids (a time-consuming process) before the output can be disseminated to the field offices (also a slow process). The end result is that some field offices never even see the high resolution detail that is available from the Eta model. Aviation forecasts are degraded in a similar fashion before transmission to customers.

To circumvent part of this problem in the NWS infrastructure, EMC has recently begun to make the full resolution Eta model predictions available on its World Wide Web home page. Some field offices are accessing the full-resolution data directly in this way. However, other

field offices are still accessing the 40 km data on the AWIPS grid, because they do not have display software for full resolution data.

If, in addition to accessing the full resolution Eta model output, local forecast offices and other entities want to run local forecast models at higher resolution, they will require the assimilated and forecast fields from a centralized system for both initial conditions and boundary conditions. If these are to be accessed in a timely fashion, then a fast telecom dissemination system is required.

v. The international market for high-end computing systems is very competitive. NCEP can use that fact to secure the best possible value for money when they next go to market. To maximize competition, NCEP's key operational codes (assimilation, model...) should be made parallel and portable so that they can be run, and be seen by the vendors to run, on the widest possible range of machines. This preparation will require some resources, but the pay-off will more than repay the investment.

vi. There are public relations opportunities that EMC can and should capitalize on to their advantage, e.g., contributions to improved hurricane track guidance during the 1995 season and the January 1996 storm predictions. This is a generic problem for NOAA and the entire meteorology community during this period of downsizing the federal government. Although severe weather is a major factor in commerce, transportation, public safety, and individual lives, the contributions and improvements being achieved by agencies such as NCEP/EMC are not being adequately publicized. Scientific agencies and individual scientists must be more public relations-conscious if science is to continue to be funded. The Review Team recommends EMC should work with NOAA to publicize their contributions at every opportunity.

vii. It is clear that there has been a significant change in NCEP funding over the past three to five years. Specifically, a large fraction of the NCEP budget is now "soft" money. At issue is whether or not it is better for NCEP and the nation to have its scientists funded out of base monies so that they are free to pursue in a "secure" manner those new scientific elements that will provide the most rapid rate of advancement in operational numerical forecasting, or is it better to "underfund" the scientific staff so that they must compete for additional monies within a limited (and dwindling) pool of resources. This, of course, is a very complex issue. On the one hand, it can be argued that proposal and report writing distracts from the time that scientists could be working on model development. On the other hand, when scientists actively participate in external programs, especially those that relate strongly to NCEP's basic mission, they are

more "in tune" with current research and therefore better qualified to make judicious decisions and selections regarding implementation of new technology and techniques. Further discussion on this issue and the Review Teams recommendation is deferred to Section IV. 1.

viii. The need is evident for a cross-branch matrix to provide team interactions and overall coordination of the scientific/operational efforts ongoing in each individual branch. This coordination will maximize the productivity of each group in each branch and insure the most efficient use of available manpower. The cross-branch matrix will also insure that the choice of specific directions/problems for Visiting Scientists or new personnel/contractors is not left to the individual's preference, but is the result of the cross-branch supervision and collective judgment. The importance of this issue cannot be overstressed and is incorporated into our overarching recommendation in SectionV.

C. <u>More Specific Issues</u>

i. Several numerical techniques offering increased accuracy and/or substantial economies are in a mature stage of development. Some have been in operational use for several years at forecast centers worldwide, but not at EMC. Examples of relevance to the MRF include the semi-Lagrangian time integration technique (in three-time-level and two-time-level versions), the use of a 'linear'grid, and the use of the reduced Gaussian grid. EMC has supported three efforts on semi-Lagrangian development for the MRF, but has yet to implement any of them. Perhaps EMC could have reaped the benefits of some of these mature technologies much sooner if they had a planning structure that optimized the output of the whole of EMC.

ii. Of the major developmental foci, physical parameterization seems to be under-staffed and could effectively use more resources. Center members are effective in keeping the parameterizations up-to-date. In addition, they are taking advantage of a unique opportunity available to them to capture relevant observational data sets over significant lengths of time specifically to examine parameterizations relating to identified forecast deficiencies. However, the Review Team believes that tighter coordination between branches would result in the benefits of individual developments being multiplied. A single parameterization suite common to all models (regional, global assimilation, global medium range, seasonal, climate) would benefit from experiences in each system. For example, preparation for the reanalysis system, with additional attention to climate-related variables, provided many improvements for the operational global system. Long runs to determine climatology are useful to uncover

problems not seen in the forecast mode. Similarly, experience in regional model applications becomes relevant as the global model moves to finer and finer resolution. Such a consolidation of physical parameterization efforts would allow existing resources to be used more effectively.

III. Branch Reviews

The Branch reviews are an important component of the external review process. Subcommittees of the Review Team examined each of the four Branches using criteria contained in the NCEP Center Review Purpose and Procedures document. Subcommittees were free to conduct and write their reviews as they chose.

1. Ocean Modeling Branch *(Paola Malanotte-Rizzoli and Russ Elsberry)*

The Ocean Modeling Branch (OMB) evolved from the previous Marine Prediction Branch. With respect to the 1992 review Report, the Review Team positively remarks on the strong improvement in OMB interactions with the other EMC Branches that has resulted in common teamwork projects. A strong recommendation is made to develop analogous interactions with the newly established Climate Modeling Branch, especially where the oceanographic modeling component of the OMB is concerned.

For those oceanographic phenomena that are surface-forced, the most important meteorological variable is the surface wind vector. A team in the OMB has invested considerable effort in improving the analyses and predictions of surface wind speed over the ocean. The new technology being exploited is two satellite-based remote sensing instruments: (i) Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I), which is a passive instrument; and (ii) European Space Agency Research Satellite (ERS)-1 scatterometer, which is an active radar. The OMB team has adopted the Neural Net approach to develop a nonlinear algorithm that relates the SSM/I brightness temperatures to surface wind speed estimates. For this situation in which a theoretical transfer function is not known because of the complexity of the relationship and the effects of the intervening atmospheric moisture content, it appears the Neural Net approach has advantages. At least for clear-sky conditions, the accuracy of the surface wind retrievals in a test sample is better than the multiple linear regression approach. A new SSM/I training set has been obtained from the Navy, and the Review Team encourages a timely update of the Neural Net algorithm to improve further the surface wind speed estimates over the ocean.

The ERS-1 scatterometer has the advantage of providing both wind speed and direction estimates, although the direction estimate has an ambiguity (may be

180° out). The EMC team has exploited an existing transfer function and the NCEP global model to process the scatterometer observations and remove the direction ambiguity. Data impact studies have been performed with the NCEP Global Data Assimilation System (GDAS). Although the overall global impact of the surface wind vectors is small, individual cases in which the ERS-1 winds define small synoptic disturbances missing from the operational analyses demonstrate the usefulness of these ERS-1 winds. The Review Team views this collaborative effort with the Global Modeling Branch as an improvement compared to the 1992 review, and encourages extension of the Neural Net to the ERS-1 scatterometer data, and preparations for rapid implementation of the NASA Scatterometer (NSCAT) wind estimates, which will have double swath coverage.

A small sea-ice analysis and prediction project in the OMB is the type of externally and internally interrelated activity that the Review Team encourages for EMC. The ties to external partners in ice analysis and modeling and to the National Ice Center are excellent. A long list of other users of the ice concentration fields was provided. Earlier sensitivity tests that demonstrate that changes in ice thickness and concentration may have remote effects on midlatitude cyclogenesis and storm tracks on medium-range time scales provide scientific justification for continuing the effort. Collaborative work with the Global Modeling and Climate Modeling Groups to develop an interactive ice-atmosphere model at NCEP is encouraged by the Team.

The major oceanographic effort of the OMB has been the development of the Coastal Ocean Forecast System (COFS), the collaborative effort previously discussed that is a very laudable example of transition from basic to operational research. Specific effort of the OMB in COFS is devoted to the Coastal Ocean Forecast. The Princeton Ocean Model (POM) developed at Princeton by Mellor and collaborators has been coupled to the NCEP Eta model. COFS works in a 24-hour analysis and forecast mode. The EMC goal is to provide operational forecasts within the next six months. A very important result of COFS has been an input to the meteorological component that resulted from the coupled model tests by the recognition of the deficiencies in the heat flux estimation by the Eta model. This has led to an improvement in the Eta boundary layer model. The COFS effort has a considerable number of interested customers, such as commercial fisheries, the Coast Guard, maritime commerce, and the Navy. The Review Team strongly supports the COFS effort and recommends its continuation.

Three other oceanographic projects were presented in the OMB review for which, however, some reservations are expressed. The first project is the development of the new NCEP wave model through a number of implementations made to the latest version of the WAM-4 wave model. These implementations involve changes in the physics of some model

processes, e.g., dissipation processes; improvement in the numerical scheme for swell propagation; changes in the time stepping for the forcing to allow for rapidly changing winds; and improvement in the numerical flexibility. Such implementations have led to the development of a wave model that has enough differences from the WAM-4 model to make an interesting alternative. This new wave model is essentially completed and parallel testing is planned to begin during Autumn 1996. While the new model development is certainly commendable, the Review Team also recommends to concentrate efforts in other factors affecting the quality of wave forecasts in a very sensitive manner, the most crucial of which is the wind quality.

The second project is based upon the development of a new parameterization of oceanic vertical mixing processes based upon a similarity approach. The Review Team remarks that the Mellor-Yamada 2.5 mixing scheme presently in use by the POM has not only been proved successful in the COFS effort, but has also been widely tested in a variety of oceanographic environments. The Mellor-Yamada scheme has recently been implemented in many ocean GCMs including the most-used GCM, the Geophysical Fluid Dynamics Laboratory (GFDL) model that is operationally used by the Climate Modeling Branch of EMC. The Panel observes that for operational purposes the Mellor-Yamada scheme is adequate. Moreover, its replacement would need extensive and time-consuming testing of the new scheme under a variety of different oceanographic configurations, comparable to the testing that has already been accomplished by other groups for the Mellor-Yamada. Thus, this project is a questionable use of EMC resources.

The third project involves the development of a new in-house global ocean model to be coupled to the atmospheric model and to provide boundary conditions to regional modeling efforts such as COFS. The development of a new ocean GCM requires years of thorough verifications and simulations with different model configurations, space resolutions, sub-grid scale process parameterizations, etc. before it can become operational. Such a task is much more demanding and time-consuming than numerical vectorization and parallelization. Such a process is the one the GFDL model has undergone during the last three decades, which has led to it being the mostly widely used GCM in the scientific oceanographic community. Telling examples are given by the adoption of the GFDL model as the oceanographic component in the coupled atmosphere-ocean modeling climate efforts ongoing at UCLA, NCAR and naturally GFDL. A strong recommendation is made to adapt the GFDL model, currently used by the Climate Branch, to become the global ocean for the OMB effort because it has already been very successfully tested in the scientific community. Such a choice will naturally strengthen the interactions of the OMB with the Climate Modeling Branch. It will also insure a much more efficient, and productive, use of EMC manpower and resources.

2. Mesoscale Modeling Branch *(Mike Fritsch and John Horel)*

The Mesoscale Branch is strong and accelerating. Over the past three years, Branch scientists have not only maintained the momentum noted in the previous three-year review but, through judicious leveraging of their personnel and computer resources, and through the stimulus of the special Cray offer for Olympics support, have accelerated development beyond their already ambitious schedule. As planned, the Branch has switched their "workhorse" operational model from the NGM to the Eta. With this switch, horizontal resolution has increased from 80 km to 29 km and vertical resolution from 16 to 50 levels. Concomitantly, model physics have also been improved with the addition of a soil moisture model, an explicit cloud scheme, and parameterized microphysics. Plans to provide Eta model Olympic coverage with 10 km horizontal resolution and 60 vertical levels are progressing solidly and, if successful, will signal a new era in operational forecasting guidance.

The Review Team was pleased to see that the model improvements over the past few years have produced significant improvements in all general measures of forecast skill. Of particular note is the substantial improvement in quantitative precipitation forecasts, one of the most difficult parameters to predict and one of the three parameters singled out for special attention in the most recent plans of the United States Weather Research Program. The increases in model resolution and improvements in model physics have also led to direct improvements in the services provided to local forecast offices and therefore to the public. For example, the Buffalo Office of the National Weather Service has used the output from the meso-Eta model to develop special tools to forecast lake-effect snowstorms. In particular, they have written software that uses hourly Eta-model output to identify the time and location of those special combinations of wind, moisture, and stability that are conducive to the formation of lake-effect snowbands. One can envision similar local applications of model output for forecasting other mesoscale phenomena such as severe downslope windstorms, mesoscale convective complexes, derechoes, etc.

Current plans in the Mesoscale Branch present a well-balanced mix of further improvements in model physics, model numerics, and data assimilation. For example, further enhancements in the cloud-radiation package and upgrades in the soil moisture model through the inclusion of observed precipitation are likely to produce additional improvements in model skill. Similarly, the panel anticipates that advances in four-dimensional variational data analysis such as the inclusion of the WSR-88D radar data and the introduction of targeted observations, two areas where NCEP scientists are at the forefront of current research, will also provide significant increases in forecast skill.

It is particularly noteworthy that some of the Branch scientists followed the suggestion of the previous review panel to turn to case studies as a vehicle to identify and correct certain model deficiencies and not to look exclusively to statistical measures of model performance to uncover model deficiencies. As mentioned in the 1992 review, this approach has benefits such as helping the investigating scientist focus on specific possible sources of error and eliminating the requirement of having to run a large sample of events to determine if the problem is corrected. It also forces the scientist to develop a greater understanding of the particular mesoscale phenomena and thereby more rigorously address the problem of incorporating the necessary model physics. This approach appears to have worked successfully in two ways. First, it enhanced communication between Branch scientists and forecasters at NWS field offices since it was the forecasters who drew the attention of Branch scientists to the model bias in which storm centers propagated out of the Great Basin and onto the Plains too soon, too far north, and too deeply. This communication resulted in the current effort to investigate how "form drag" might be utilized to ameliorate the problem and has undoubtedly given forecasters a morale boost in allowing them to be part of the process of improving the models and, therefore, their own forecast products. Along this same vein, we note that another model deficiency that sometimes results in large errors is the handling of snow cover. Branch scientists are encouraged to use the case study approach to identify and eliminate this problem.

The Review Team sees cloud-scale (delta-x less than 4 km) non-hydrostatic modeling as the next great challenge. To its credit, the Mesoscale Branch recognizes this challenge and has already developed a non-hydrostatic version of the Eta model. The Review Team notes that cloud-scale-resolution modeling has a long history of development in the research community and, as such, a wealth of knowledge and human resources is available to help Branch scientists rise to the challenge. We note that the implementation of the Rapid Update Cycle is a good example of how the Mesoscale Branch worked closely with the research community to take advantage of development work done outside of NCEP. Such efforts are strongly encouraged, especially in the development of the next generation of operational models.

3. Global Modeling Branch *(Dave Williamson)*

The scientific productivity and quality of the Global Modeling Branch continues to be outstanding. There has been significant research and development activity in both analysis and model formulation.

EMC has created a successful state-of-the-art 3DVAR global assimilation system. The move to grid-space statistical interpolation is making it more powerful by eliminating restrictive assumptions and allowing nonlinear

relationships. It will also allow application to regional models and provide a step toward unification. Scientists are making advances in the use of an adjoint and linear tangent model. EMC scientists are to be congratulated for having convinced senior NCEP and NESDIS management of the need to pursue their current approach of using radiance measurements that have suffered the minimum amount of pre-processing or blending with inaccurate information. The closer interaction with NESDIS that has been established is commendable. The assimilation now successfully includes SSM/I surface wind speed and precipitable water over oceans and ERS-1 near-surface winds. EMC has made big improvements in the Quality Control (QC) of sondes in recent years. They have added QC track-checking for aircraft observations. The Review Team encourages them to improve QC on other data sources in the future.

Model developments include both numerical approximations and physical parameterizations. Several numerical approximations have been studied that offer the promise of more efficiency and increased accuracy. The semi-Lagrangian approximations have been approached with three efforts. Either of the two reasonably well-proven techniques should lead to relatively near-term implementation. These are the gridpoint and spectral-based methods applied to latitude-longitude grids and involving back trajectories and point-wise conservation along the trajectories. The third, based on regular grids and possibly on novel more homogeneous global grids involves forward trajectories and volumetric conservation issues. This approach will take longer to come to fruition, but is likely to lead the field when it does. The regional spectral model development has continued as a complement to the global spectral model. It provides a tool to study the physical parameterizations of the global model at higher resolution and offers the potential, of providing a global model with resolution focused over a region. A vertical coordinate that transitions from traditional sigma at the surface to theta at higher levels is being considered. Such a system offers significant potential, especially as additional constituents such as ozone are included in the model. EMC scientists have also actively pursued application of the global spectral model to distributed memory computer systems (generally referred to as massively parallel processing systems). This work is essential to ensure EMC is in a position to adapt to a wide variety of computer systems, and open up future procurements to more vendors and increase the competitive nature of their bids.

Research has continued in many areas of physical parameterization and has lead to improvements in the operational models. In the land surface parameterization, the bucket model was replaced by a two-layer soil hydrology model and canopy transpiration was added. The Kuo convection was replaced with a simplified Arakawa-Schubert scheme with a simple downdraft. Work has proceeded to add further improvements to the relaxed Arakawa-Schubert parameterization. The diagnostic cloud scheme was updated based on satellite

observed clouds and generalized to be multilayer instead of the three low-mid-high categories. Research is ongoing on inclusion of predicted cloud water rather than diagnosed clouds. The planetary boundary layer parameterization was upgraded to include surface layer similarity profile functions, and later replaced with a bulk-gradient diffusion scheme. The shortwave radiation and gravity wave drag parameterizations are also current topics of research. All these activities in numerical and physical aspects have led to and will continue to lead to improvements in the operational model.

The Branch is also committed to diagnostic evaluation of their products. This includes the 40-year reanalysis project as well as production and experimental systems. The diagnostic evaluation provides important feedback to the Branch scientists. It is adding significant value to the reanalysis by establishing the strengths and weaknesses of the reanalysis products. In addition, branch scientists are taking advantage of a unique opportunity to capture relevant observational data sets over significant lengths of time specifically to examine parameterizations relating to identified forecast deficiencies.

Branch members have continued to augment and improve the ensemble forecasting at NCEP. The ensemble size was increased to 17 with forecasts out to 17 days. They are providing experimental products of forecast uncertainty to the WFO forecasters and continue to interact with them and educate them on the possible applications of the experimental products.

The Branch invested tremendous effort in the reanalysis. This is an extremely successful project with the first phase coming to conclusion this fall, and continuing as the Climate Data Assimilation System (CDAS). The reanalysis will provide the data set defining the climatology of the atmosphere that will be used by researchers worldwide for years. Its value is increased significantly by the diagnostic evaluation being done by branch members and by its continuation into the CDAS. The development leading up to the reanalysis, with additional emphasis on climate aspects, has also led to significant improvements in the operational system.

Quality of operational products

The research in the Branch has continually lead to improvements in the operational analysis and forecast system. In addition to the improvements to the basic components resulting directly from the research described above, the overall system has been augmented and expanded. A three-dimensional ozone analysis and forecast was added to global system, the vertical resolution was increased by a third to 28 layers, the frequency of longwave radiative flux calculation was increased to 3 hourly and the shortwave to hourly, the frequency of the aviation forecasts was increased to four times daily, and both the size and length of the ensemble forecasts were increased. The overall

system has been improved by becoming more physically based. In addition to this qualitative measure of improvement, the improvement to the operational system is also quantified by the gain in objective skill scores, both those of long-standing tradition such as the root-mean square and newer, more discriminating precipitation-based scores.

Relevance and impact of research

The research and development undertaken by the Branch is directly related to the service function and mission of the Center. Branch scientists are fully aware of their mission, are personally interested in contributing to it, and take pride in their accomplishments. Much of the documented increase in forecast skill is attributable to improvements in the forecast-analysis system developed and implemented by Branch scientists. The data sets created by the reanalysis will have a tremendous impact on the worldwide climate research community for at least the next 5 to 10 years.

Evaluation of Branch plans

The Review Team was disappointed by the apparent lack of a long-range (4-5 year) strategic plan. Presumably one was produced following the last review, but it appears not to have been revisited or updated since then. A projected implementation plan was provided for FY96 that details the anticipated implementation schedule of research and development efforts of researchers coming to fruition this year. Individual researchers, of course, have a good idea of their individual near-term research topics. Other than the basic objectives of improving model numerics and physics, and improving the analysis system, no coherent statement exists of major model and analysis deficiencies and few explicit goals that provide a source of focus and motivation for the Branch as a whole. A continually updated summary of system deficiencies would provide a basis for priority setting.

Success in optimizing resources, balance between research and development and operational responsibilities

The developments in the global forecast-analysis system are clearly first class. The Branch can be justifiably proud of its contribution to EMC operations and the research community. The Branch consists of many top-notch scientists working to improve the system. However, the Branch is over-stretched given that it has overall responsibility for developing the global forecast system for short, medium, and seasonal forecasting, climate simulation, and for the reanalysis. Although the current reanalysis will be winding down, the seasonal prediction and climate simulation activities will be expanding. It is very reasonable for the Branch to be involved with and to provide the model and analysis infrastructure for all these efforts, as they are all interrelated, and all gain from improvements and knowledge gained from any one of them.

The work is so all-encompassing and manpower so limited that management should strive for more coordinated development, both within the Branch and across Branches, in the three areas of numerical approximations, physical parameterization, and analysis methods. The Review Team questions if the balance between long-term research and short-term development, which feeds directly into operations, is optimal. The Branch should be on the lookout for proven technologies that might be implemented on a fast track and lead to gains in either efficiency or accuracy. For example, faster implementation of a semi-Lagrangian model or reduced grid would have freed up computing resources for research or increased operational resolution.

4. Climate Modeling Branch *(Tony Hollingsworth)*

Scientific productivity and Impact

The Branch continues to be the world leader in the fields of near-real-time ocean data assimilation and of seasonal forecasting with coupled atmosphere and ocean GCMs. The work of the group on near-real-time ocean data assimilation was a key contribution to the TOGA experiment. The success of TOGA played a central role in motivating the creation of the IRI (International Research Institute) that was launched at a White House sponsored meeting in late 1995. The success of TOGA and the example of the Branch triggered the initiation in 1995 of a major European initiative in experimental seasonal and interannual forecasting, as well as a seasonal and interannual forecasting initiative to be launched in Japan in 1996, with funding for modeling and for extensions of the TOGA observational network.

If the success in a scientific endeavor is assessed by its impact on the ideas and plans of other national and international scientific groups, then the Branch has been an unqualified success. If success is measured by other means such as the number of publications in high-quality journals, or by the number of citations, then by these measures also the group is an unqualified success.

Main foci of Branch work

In the course of the TOGA experiment, the Branch developed close ties with the observational, theoretical, and ocean modeling communities. The Branch focused its main efforts on two issues: data assimilation, and methods for coupling ocean models to atmosphere forcing. These key foci were absolutely appropriate given the status and needs of the science, and the scientific and technical resources uniquely available at NCEP. In particular, this Branch has benefited from GFDL's and NCEP's expertise on atmospheric data assimilation.

Support for the ocean model

The Branch has a well-defined external support network for ocean model development, including GFDL (the parent institute for the ocean model), the teams forming the new IRI (Lamont-Doherty and Scripps), and the ocean modeling groups at NCAR and NASA-Goddard. A very effective exchange of information and experience on ocean modeling occurs within this network, and this has been of great value to the Climate Modeling Branch.

Support for the atmospheric model

Several different modeling Centres (e.g., UKMO, Meteo-France, ECMWF) have found that the current generation of parameterization schemes can be used effectively over a wide range of model resolutions. Thus, the same schemes can be used for short-range regional forecasting, medium range global forecasting, and short-term (seasonal to inter-annual) climate prediction. This well-established result implies that an improved parameterization in one of these applications is readily transferable to the other applications. In these European institutes the local physics package is maintained and developed by a single physics team which 'owns' its physics package, i.e., the team is committed to improving its physics performance across the full range of time space scales. The substantial scientific, technical and economic benefits of this structure explain why these institutes adopted a single in-house parameterization.

The situation is quite different at EMC. The ETA model has one physics package, the MRF has another physics package, and the climate prediction model has still another. None of these packages can be used in the other models. Each separate physics package needs the full attention of a dedicated physics team, but EMC does not have the resources to maintain and develop all three physics packages. In fact, most resources for physics development have been devoted to development of the climate model.

EMC should form a single physics team as soon as practicable, i.e., a team charged with the maintenance and development of one physics package to be used across EMC's range of operational models. This will be especially important for the climate modeling branch, and doubly important for EMC's future progress, given the efficiencies that will flow from the change, and given also the growing role of physical parameterizations in advanced data assimilation methods.

Coupling of the atmospheric and ocean models

Partly because of the limitations of the atmospheric model described above, the EMC group has been forced to use a variety of expedients to improve or constrain the atmospheric forcing fields they use in their work. A number of

other groups have improved the performance of their atmospheric models on seasonal and interannual time scales, and are moving to a position where they can use much simpler coupling mechanisms to drive their ocean model in coupled integrations. The EMC group will have to do likewise.

Pre-operational assessment of skill

The use of coupled models for seasonal and interannual forecasting is still an experimental field with many new developments in progress (e.g., the coupled modeling group's new results on the assimilation of altimeter data as well as TOGA-TAO and XBT data). However, the field is sufficiently mature that many potential users inside NWS (e.g., CPC), and outside NWS, are anxious to have access to real-time results.

It is essential that potential users are provided with the best possible pre-operational assessment of the level of skill they can expect from the products. The Coupled Modeling team should meet this requirement by producing a comprehensive set of forecasts for the period of useful instrumental record (1982-date). In this way, CPC and other users can have a quantitative feel for the skill of the system. The validation should be repeated whenever there is a major system upgrade.

It should be noted that such an exercise could take advantage of the reanalysis soil moisture fields as an additional source of memory for the first one or two seasons.

IV. Cross-Cuts

The following issues cross all branches and were initiated either by EMC / NCEP management or through Review Team discussion. They are presented here because they fall outside the formal charge given to the Review Team.

A. Resources

In a shrinking resource environment, budgetary issues can and will take on many forms. Careful, integrated strategic planning at the EMC, NCEP, and NWS levels can reduce, but not eliminate, anxieties for individuals or for work units. At the National Weather Service level care must be exercised to not let internal lobbying for resources mask and eventually overwhelm programmatic and planning initiatives. In the case of EMC and NCEP, the real competition as well as opportunity is external. The Review Team notes that the lack of formal strategic planning documents addressing the EMC and its relationship within NCEP contributes to uncertainty and attendant anxiety.

Of particular concern is the amount of "soft money" (49%) in the EMC annual budget, especially since more than 90% of the total budget goes toward salaries and benefits. EMC is a mix of permanent, contract, and temporary employees. To put this in perspective, the fraction of soft support in EMC is higher than that at NCAR, as a whole, comparable to that of the Climate and Global Dynamics Division of NCAR, and less than that at most university-based atmospheric science departments. The administrative burden of dealing with more than 30 grants and contracts, including project monitoring, proposal and report writing, accounting, and sponsor cultivation is quite large. The Review Team recognizes that this burden has a major impact on the time commitments of the EMC Director, Deputy Director, and Branch Chiefs. It is time away from science, operations, and nurturing new and existing projects and talent. The Review Team recognizes also the NCEP management may not be able to identify reprogrammed base funds in the near future to reduce EMC's dependence of soft support. Given the reality that soft funding is better than no funding, and that in many instances soft funds serve as an incentive to produce better science in a more efficient manner, the Review Team recommends that:

- EMC remain a high priority for new and redirected base funding; and

- A proportion of the total soft funds be used to hire an experienced technical projects manager to relieve the administrative burden on EMC leadership. Such individuals exist in industry, DOE and DOD laboratories, NASA, and universities.

B. Local and Central Modeling

The issue of local and central modeling is difficult to dissect from the resource issue. Intellectually, the idea of field forecasters collaborating with university scientists in the testing of mesoscale analysis and forecast models is delightful and a positive by-product of NWS Modernization. In reality, neither the NWS or the universities have the resources to fully support operational mesoscale models in each field office. A centralized effort at EMC has been discussed as one of several options and would require telecommunication bandwidth in excess of current and planned capability. While it is beyond the purview of this EMC Review Team to solve this issue, we offer the following thoughts and recommendations.

Local models (i.e., horizontal resolution of about 5 km over a domain of perhaps 500 km^2) are still years away from being fully operational. Given the present rate of technology transfer from testing early prototypes to full operation, it is probably too soon to make major policy decisions on this issue. Instead, field testing should be encouraged and the situation carefully monitored. Immediate planning should begin to increase the

telecommunication bandwidth between each field office and EMC. Full resolution output on a regional basis from the Eta model should be available to each field office. Local data sets and WSR-88D data should be available to the EMC.

The NWS, NCEP, and EMC must come to grips with the possibility that federal downsizing will severely inhibit NWS's ability to deliver the full value of its Modernization directly to society. Value-added research, development, and user products and services will come through other federal agencies, local governments, universities, and the commercial sectors. Local models are likely to be an important component in this value-to-society argument. The question then becomes what can EMC do to foster the development of mesoscale models in this larger arena? The Review Team believes that EMC is strategically positioned to offer its world-class abilities and products in 4-D data assimilation and model output to the above mentioned, external communities for specification of a background analysis and boundary conditions for operational local models. (The Review Team notes that EMC is unique as the only U.S. national institute with such a capability.)

Thus, the Review Team's recommendation on the local and central modeling issue is to:

- Encourage experimentation with prototype local scale models at universities or laboratories co-located with NWS field offices;
- Initiate immediate plans to upgrade the telecommunication bandwidth between local field offices and EMC;
- Defer making major policy decisions until the scientific, technical and resource pictures improve; and
- Develop a strategy to position EMC at the forefront in serving the national needs for operational mesoscale model support.

C. Computing Support

During the site visit, the Review Team Chair interviewed both the Director of NCEP Central Operations and the Senior Meteorologist in the EMC System Development Group to gain first-hand information on the adequacy of computer and network support for EMC's research and operations. At the present time, computing support is becoming marginal considering that the Crays are saturated and some scientists would benefit from upgraded workstations. There did not appear to be concerns with the adequacy of the local area network nor with connections to the outside world. The Review

Team interprets this as EMC/NCEP achieving a reasonable balance of resources devoted to science and operations, and technical support infrastructure. The disparity of the present computational resources between NCEP (with a saturated Cray C-90) and ECMWF (with a Fujitsu five times more powerful and scheduled for a factor of five upgrade in 1998) will inevitably lead to an increase in the skill gap which has been significantly reduced during the last decade. Major technical issues in the near-term include the ingest of WSR-88D data and upgrading the Crays.

D. External Survey

At the request of the NCEP Director, a "quick look," informal poll was conducted by several Review Team members of user satisfaction with EMC products and services. In all about 20 individuals were contacted from a cross-section of the user community. NWS Headquarters, other NCEP Centers, NWS field offices, private industry and commercial weather services are represented. Since the poll was conducted with the promise of anonymity, user comments are presented below in no particular order.

- The comparisons of the EMC's forecast skill with other international centers (ECMWF, UKMO) are well known and quite impressive. Where is the measure of EMC's success with respect to the satisfaction of its customers? EMC should spend some of its time and resources to develop such an information base.

- EMC should take greater care in notifying its customers well in advance of changes in its models and especially of changes in formats of model output. Some customers ingest EMC information electronically and are caught off guard when changes occur. Lead times of up to a year were indicated as being desirable by users.

- Field forecasters welcome interaction with EMC. Several believed that they had significant input to the improvement of NGM and early Eta models on their tendency to bring lows out of the Rockies too far north and with too great an intensity. In response, EMC introduced changes to the form drag (a predominately mountain effect) that helped to correct the problem. They feel EMC is very responsive to their needs and suggestions.

- Forecasters at other NCEP Centers appreciate being asked to participate in model development and performance evaluations.

Co-developed conference papers describing the use of model output in forecasting have resulted from this interaction.

- Concern was raised in one NCEP Center that going to a single communication line between EMC, NCEP Centers, and all WFOs would essentially result in new model features becoming operational before they were fully evaluated.

- Several large commercial weather companies believe that things are moving in the right direction at EMC. They note the increase in speed to 56K in the transmission rate of NOAA's Family of Services. This has been a big help to corporate scheduling and the performance of private weather services.

  One company received a very positive response when it contacted EMC and suggested improvements to the way "spaghetti" plots are displayed. Their suggestion was implemented quickly and facilitated the operational use of the ensemble product.

- Several private sector users stressed the importance of EMC numerical model output in creating their forecast products. They indicated that the availability of the full array of model data and derived products is crucial to their operations and look forward to accessing new products, such as ensemble forecasts, on the Family of Services.

- The private sector believes any product created by a federal agency should be available to the entire public and that limited products that service specific private users should not be created or disseminated.

- Several commercial weather companies are aware the EMC encourages visits with the academic community, and other federal agencies and laboratories. There should be similar interactions with the private sector. Such interactions would go far in helping define what types of new products, made available to all, would best serve the nation.

V. Overarching Recommendation

It became apparent to the Review Team that cross-branch interactions could be stronger in areas such as data assimilation, parameterization, numerics, etc. Scientific methods and the resulting software are sometimes developed in one Branch that is independent of the effort in another Branch. Given the prospects for resources in the future, duplication and even triplication of

effort is inefficient and diverts precious resources from other higher priority initiatives. The sense that this is a real concern is evident in Sections II.7.B.i, ii, and ix; II.7.C.ii; and III.1,3, and 4 of this report.

Similar problems faced ECMWF, UKMO, and Meteo France and were addressed by moving toward common infrastructure for all modeling efforts. The Review Team recommends that EMC / NCEP management address this issue head-on by restructuring EMC into a matrix form of organization. Cross-branch teams, with identified leadership and group plans would interact on a regular basis to promote commonality and interchangability in EMC's suite of models. There would be some up-front costs during the transition, but considerable savings downstream. As a starting point, we recommend that EMC leadership assess the benefits / costs of the transformations undertaken by UKMO and Meteo France to achieve such a structure.