

## NMC Overview: Recent Progress and Future Plans

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(Manuscript received 3 March 1989, in final form 22 March 1989)

### ABSTRACT

This article describes the mission and organization of the National Meteorological Center (NMC), summarizes progress since the introduction of the CYBER 205 computers in 1983, and describes plans for NMC numerical prediction systems in the 1990s. Plans include the introduction of a new mesoscale "storm" model on next generation computers, continued improvements in the resolution and physics of the NMC global model, and extension of daily forecasts from 5 to 7 days with a "week-two" forecast of average weather conditions.

### 1. Introduction

This overview paper describes the general mission and organization of the National Meteorological Center (NMC), provides a description of progress in recent years and indicates directions for the future. The mission of NMC and its current organization are described in section 2. This mission is extremely broad. Papers in this issue, including this paper, focus on the forecast guidance operations located at NMC. Articles describing the operations of other national centers that are part of NMC—the Climate Analysis Center (CAC), National Severe Storms Forecast Center (NSSFC), and National Hurricane Center (NHC) are planned for later issues of *Weather and Forecasting*. Section 3 describes the NMC numerical guidance system that existed in 1983, before the CYBER 205 computers were installed and the major changes to that system from 1983 to the present, and presents some statistics on improvements in forecast skill. Section 4 describes NMC plans for change in response to new observing systems, next generation computers, and changing National Weather Service priorities in the 1990s. Our intent in section 4 is not to pretend that we know exactly where the science of numerical weather prediction will lead us, but instead to give readers our best current estimate of the kinds of systems we will be running in the 1990s. Section 5 includes some remarks on the importance of numerical prediction research to NMC operations, the need for appropriate mechanisms for transfer of research into NMC operations, and the opportunities afforded by recent developments in interactive computer systems to look at numerical model output in new ways.

### 2. Mission and organization of the National Meteorological Center

As a component of the National Weather Service (NWS) and its parent organization, the National Oceanic and Atmospheric Administration (NOAA), the mission of NMC is a subset of NOAA and NWS missions in environmental information, warning, and forecast services. The National Meteorological Center was created (see article in this issue by Shuman 1989) to perform those weather analysis and forecast functions that can be done most efficiently in a central location. Its primary mission is to provide forecast guidance to Weather Service Forecast Offices (WSFOs) to aid in the preparation of local forecasts and warnings.

Core elements of the NWS information system are the national centers: WSFOs, Weather Service Offices (WSOs), and River Forecast Centers (RFCs). The primary information flow to users outside the National Weather Service is from WSFOs, RFCs, and WSOs. National prediction centers (NMC, NHC, NSSFC) provide the national and larger-scale information required by these offices. They also provide direct information to users that is beyond the scope or capabilities of local NWS offices.

This statement is much too simple, of course. Users of NMC include not only NWS personnel, but private meteorologists, Federal Aviation Administration (FAA) pilot briefers, Department of Defense forecasters, and university professors and students. By international agreements, NMC also makes products available to weather services of other countries, and to domestic and international air carriers.

The internal organization of NMC is shown in Fig. 1. Through most of the 1970s, NMC consisted of a Forecast Division, an Automation Division, and a Development Division. We have undergone many changes. In 1979 NOAA established a Climate Analysis Center from components of the National Environ-

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## NATIONAL METEOROLOGICAL CENTER

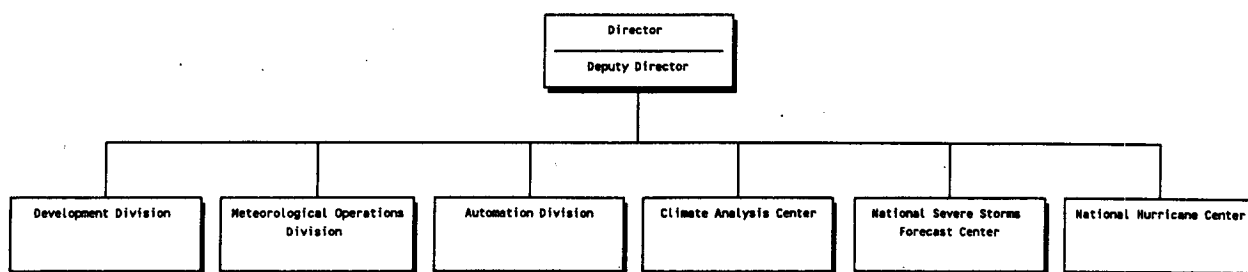


FIG. 1. Organization of the National Meteorological Center.

mental Satellite Data and Information Service (NESDIS), the Environmental Data and Information Service, and the Development and Forecast Divisions of NMC, and made the new center a part of NMC.

The National Meteorological Center assumed management responsibility for the NSSFC in 1984 and the NHC in 1985. An Ocean Products Center (OPC; see article in this issue by Rao 1989) was established by NOAA in 1985 to promote development efforts in marine weather and ocean prediction and to consolidate functions that had previously been performed by several components of NOAA. The OPC is a joint NOAA center, managed by the National Ocean Service (NOS), but is attached to NMC.

Through its Automation Division, NMC operates and manages the NOAA Central Computer Facility (CCF), providing mainframe computer support to NMC, NESDIS, NOS, and the NWS RFCs. To complete the picture, NOAA weather support units at NASA's Johnson Space Flight Center, and the FAA's Central Flow Facility are managed by the Meteorological Operations Division of NMC.

The mission of NMC involves both applied research and day-to-day operations. Scientists in the Development Division and the Climate Analysis Center interact with a broad community of numerical modelers and climate researchers in this country and abroad with the objective of translating scientific advances into improved NMC products. The Meteorological Operations Division, NHC, and NSSFC missions are heavily operational but each of these organizations has a small development unit responsible for improvements in operations based on new science or new technology such as interactive computer systems. A brief summary of the mission(s) of each center or division of NMC is given in Table 1.

### 3. Recent progress in numerical weather prediction at NMC

Progress in numerical prediction in the last 30 yr has been associated with improvements in the global

observing system, advances in numerical prediction research, and remarkable advances in the speed and memory of computers available for operational prediction and research.

Major improvements in the global observing system took place in the mid- to late-1970s with the introduction of temperature profiles over the oceans from polar orbiting satellites and cloud-tracked winds from geostationary satellites. The Global Weather Experiment in 1979 provided the necessary impetus and focus for international efforts in development of data assimilation systems to incorporate these new types of data into operational prediction systems (e.g., see Bengtsson 1984; Bonner 1986). Numerical prediction research published in the late 1960s and early 1970s had shown the potential for improved numerical forecasts from higher resolution models with more accurate representations of physical processes such as radiation and air-sea, air-ground interactions (see especially Miyakoda et al. 1972). It was not, however, until the introduction of modern supercomputers such as the Cray 1 at the European Center for Medium Range Weather Forecasts (ECMWF) in 1978, and the CYBER 205 at the U.K. Meteorological Office in 1982 and NMC in 1983, that it became possible to exploit the potential of the satellite observing systems and the results of recent NWP research to realize significant improvements in the skill of operational forecasts.

#### a. Recent changes in NMC analysis/forecast systems

Since the introduction of the CYBER 205 in late 1983, a number of improved or new analysis/forecast systems have been introduced into NMC operations. The current NMC system is described in an article in this issue by Petersen and Stackpole (1989).

In 1983, NMC numerical forecast systems were limited to the limited-area fine-mesh (LFM) model (Gerrity 1977) for short-range (12- to 48-h guidance); the spectral model (Sela 1980) for aviation wind forecasts and medium range (2- to 5-day forecast guidance); and the Global Data Assimilation System

TABLE 1. Units and primary responsibilities of NMC.

Center or division	Primary mission(s)
Meteorological Operations Division	Interpret numerical model forecasts and produce manual analyses and weather forecasts that improve upon computer-produced products. Generate national- and international-scale forecasts for aviation flight planning and safety. Issue heavy precipitation forecasts and forecasts of precipitation amounts. Monitor NMC operations; issue status reports. Supplement automated quality control systems with manual quality control of data.
Development Division	Develop and test improved numerical models for atmosphere and ocean surface prediction. Conduct diagnostic studies of model forecast error to aid in the interpretation of NMC model output and to isolate sources of error. Develop improved methods for quality control and assimilation of data; provide feedback to data producers on quality of data and their utility in NMC forecasts. Improve NMC analysis and forecast systems through research on critical problems of numerical weather prediction. Develop improved methods for display and interpretation of NMC model output.
Automation Division	Operate the NOAA Central Computer Facility. Implement new analysis and forecast systems developed and tested by the Development Division. Maintain the operational job stream. Provide the computer codes required to process observations, and communicate and display NMC products. Design and procure new computer systems in support of NMC operations. Develop NMC policy with regard to hardware and software standards.
Climate Analysis Center	Monitor short-term climate variations. Issue 6- to 10-day forecasts and monthly and seasonal outlooks. Disseminate information on United States and world-wide weather and climate anomalies. Improve climate monitoring and forecast systems through new technology and research.
National Hurricane Center	Track and predict the motion of tropical storms and hurricanes in the Atlantic, Caribbean, Gulf of Mexico, and eastern Pacific. Issue hurricane and tropical storm warnings. Issue tropical analyses and forecasts as a Regional Specialized Meteorological Center under the World Weather Watch Program of the World Meteorological Organization. Cooperate with federal, state, and local officials in hurricane preparedness planning.
National Severe Storms Forecast Center	Issue tornado and severe thunderstorm watches. Provide centralized expertise in mesoscale prediction for the conterminous United States. Issue convective outlooks and mesoscale convective forecasts. Issue hourly aviation bulletins on hazardous convective weather. Issue short-term forecasts of hazardous enroute weather for general and commercial aviation. Promote safety and severe weather awareness through interactions with the media, civic groups and state and local officials.

(GDAS, McPherson et al. 1979), which provided first-guess analysis fields for LFM and spectral model runs and a special movable fine-mesh (MFM) model for hurricane track prediction. The evolution of this system from 1983–88 is summarized in the chronology of major changes presented in Table 2.

Changes described in Table 2 are the major changes made in the CYBER 205 system. We will continue to make small improvements to current systems as computer resources permit. But efforts are now shifting towards development of improved systems for NMC operations in the 1990s on next generation computers. Initial plans for such systems are described in section 4.

*b. Recent progress in forecast skill*

Statistics that document the improvements in skill of individual parameters and NMC forecast systems are presented in a number of articles in this issue and

in summary articles in conference proceedings (e.g., Bonner 1986, 1988; Bonner et al. 1986). I will present only a few of the statistics that document especially the improvements in medium range (3- to 5-day) forecasts, and improvements in short-range aviation wind forecasts and forecasts of sea level pressure patterns.

1) MEDIUM RANGE FORECASTS

Figure 2 compares the current level of accuracy of NMC numerical medium range forecasts with that achieved nearly 20 yr ago with research general circulation models (Miyakoda et al. 1972). Such models could not have been run operationally. The experiments that Miyakoda describes were designed to test the limits of atmospheric predictability and to assess what might be possible operationally with more powerful computers. It is interesting to note that the model used in these experiments was hemispheric, with a grid resolution of 270 km, and required 12 h of computer

TABLE 2. Chronology of major changes in NMC numerical forecast system.

Date	Change
Oct. 1983	Increased horizontal resolution of spectral model forecasts from rhomboidal 30 (R30) to rhomboidal 40 (R40) for both 0000 and 1200 UTC forecasts.
Aug. 1984	Replaced Hough analysis (Flattery 1971) with multivariate optimum interpolation analysis (Bergman 1979) in 0000 and 1200 UTC spectral model runs.
Mar. 1985	Introduced new Regional Analysis Forecast System (RAFS) between LFM and spectral model runs (Hoke et al. 1989); advanced start time for LFM to 1 h 30 min (past 0000 and 1200 UTC).
Apr. 1985	Introduced new medium range forecast (MRF) model (rhomboidal truncation, 40 waves, 18 layers, GFDL-based physics) with late data cutoff (6 h), run once daily at 0000 UTC. The R40, 12-layer, limited physics version of the model (AVN) was run twice daily to 72 h at 3 h 30 min to satisfy aviation requirements.
Nov. 1985	Introduced dynamical model for global ocean wave prediction with NMC spectral model wind forecasts as input.
May 1986	Replaced R24, 12-layer, spectral model in GDAS with R40, 18-layer MRF model; improved physics in MRF model (shallow convection, vertical diffusion).
Jul. 1986	Introduced completely new physics package in nested grid model (NGM) component of RAFS [radiation, surface and precipitation physics; Tuccillo (1988)].
Nov. 1986	Replaced R40, 12-layer, limited physics version of the spectral model (AVN) run for aviation purposes with the R40, 18-layer, full physics MRF. All global systems (GDAS, MRF, AVN) now based on most advanced version of the spectral model.
Feb. 1987	Domain of NGM high-resolution C grid expanded and modifications made to surface stress formulation to improve forecasts of cyclogenesis in the eastern Pacific and western Atlantic.
Aug. 1987	Increased resolution of global forecast model (MRF, GDAS, and AVN systems) from rhomboidal 40 to triangular 80; introduced further improvements in global model physics [diurnal cycle in radiation, improved surface fluxes, vertical diffusion, gravity wave drag; Sela (1988), Alpert et al. (1988), Kalnay and Kanamitsu (1988)].
Aug. 1987	Changed initialization procedures in the RAFS [fewer vertical modes initialized to improve spinup of vertical motion and precipitation in the model; Carr et al. (1989)].
May 1988	Modified separately developed optimum interpolation schemes in regional and global analysis systems to incorporate best features of each. First step towards a single code, with variable parameters, for both regional and global analysis.
May 1988	Improved formulation of surface evaporation in the global model (AVN, GDAS, MRF).
June 1988	Replaced MFM with high-resolution, quasi-Lagrangian model for hurricane track prediction (Mathur 1983).
Aug. 1988	Introduced regional ocean wave model for Gulf of Mexico forecasts with NGM boundary-layer wind forecasts as input.
Nov. 1988	Replaced zonally averaged climatological clouds used in radiative flux calculation of the global model with diagnostic clouds computed from relative humidity and vertical motion predicted by the model.
Nov. 1988	Introduced new initialization method for the NGM as a first step towards regional assimilation of high-frequency observations (Parrish 1989).
Jan. 1989	Advanced start times of early global runs (AVN) from 0330 and 1530 UTC to 0245 and 1445 UTC to improve timeliness of aviation wind forecasts.

time for each 1-day forecast. The curve labeled Miyakoda et al. (1972) is based upon the average of 12 experimental forecasts from January days between 1964–69. The curve labeled NMC represents the average scores achieved in January 1989 by the NMC MRF model. The parameter verified is the 500 mb height anomaly (difference from climatology). The statistic is the correlation coefficient, computed for the Northern Hemisphere extratropics. Notice that the NMC operational 6-day forecasts in January 1989 were more skillful than 4-day forecasts with the databases, supercomputers, and research models of 20 yr ago. A similar comparison with operational forecasts produced by the ECMWF has been shown by Bengtsson (1984).

Figure 3 is a record of skill of the 84, 108, and 132 h numerical sea level pressure forecasts used by NMC forecasters in the production of 3-, 4-, and 5-day sea level prognostic charts. Scores are for the period from 1970–88. The verification score is a “standardized” anomaly correlation coefficient computed from forecast, observed and climatological sea level pressure at 130 grid points over North America. “Standardized” means that observed and forecast anomalies have been normalized by the climatological standard deviation

at each grid point. These scores are not numerically comparable to the anomaly correlation coefficients shown in Fig. 2. From 1970–76, scores were relatively constant. The sharp increase in 4- and 5-day skill from 1979–80 coincides with the change from a simple barotropic extension for 84- to 132-h forecasts to full integration of the NMC seven-layer primitive equation model. The general trend in skill since 1976 is strongly positive with some year-to-year variations from this trend. Forecast skill, by this particular measure, has increased at a nearly uniform rate for 84-, 108-, and 132-h forecasts. The 132-h forecasts have more than doubled in skill since 1979. They are now roughly as accurate as the 84-h forecasts made 10 yr ago.

## 2) AVIATION WIND FORECASTS

Figure 4 shows rms errors of NMC 24-h 250 mb wind forecasts, verified at 102 Northern Hemisphere rawinsonde stations, for the period 1982–88. Notice the downward trend in the errors from an average of 10 m s<sup>-1</sup> in 1982 to 8.25 m s<sup>-1</sup> in 1988. The initial error (fit of the analysis to the rawinsonde data) at 250 mb is about 5 m s<sup>-1</sup>. Using this as a baseline, errors

### 500 MB HEIGHT ANOMALY CORRELATION

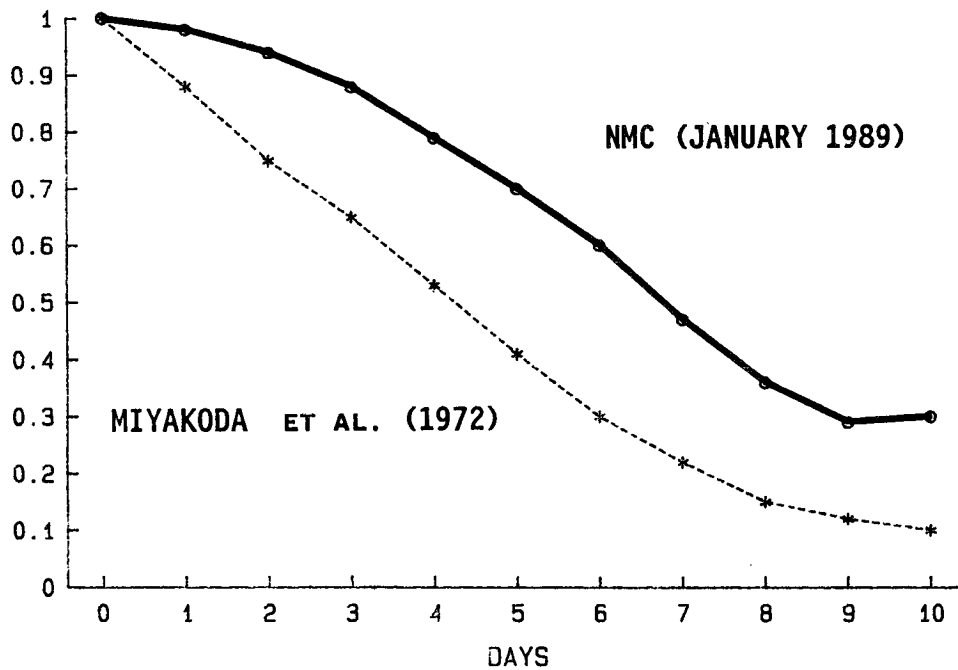


FIG. 2. Comparison of scores obtained by Miyakoda et al. (1972) in 12 experimental January forecasts with NMC scores in January 1989. Anomaly correlation coefficients for 1- to 10-day forecasts of 500 mb height in Northern Hemisphere extratropics.

### SEA-LEVEL PRESSURE FORECASTS STANDARDIZED ANOMALY CORRELATION COEFFICIENT 1970 THROUGH 1988

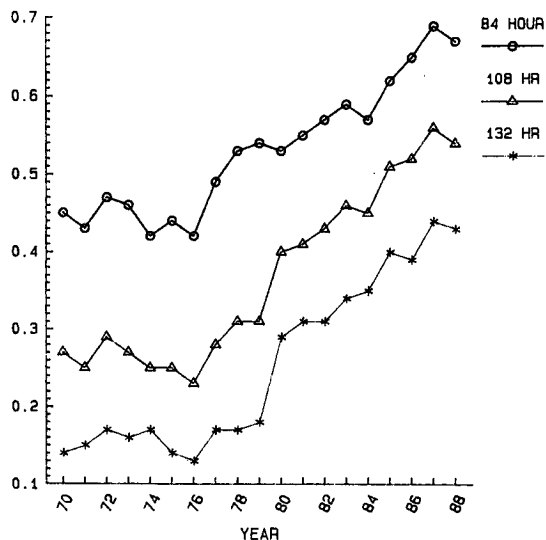


FIG. 3. Skill of 84-, 108- and 132-h NMC numerical forecasts of sea level pressure, verified over North America, 1970-88.

since 1982 have decreased by a third; this corresponds to about a 12-h increase in 24-h forecast skill.

Because of the general downward trend of the curve and the masking of model changes by month-to-month variations in forecast skill, it is difficult to identify clearly those changes (from Table 2) that were most effective in reducing the errors. However, two major changes appear to stand out:

- 1) the introduction of the improved global forecast system (MRF) in the GDAS in May 1986;
- 2) the increase in horizontal resolution of the forecast model in GDAS and AVN systems in August 1987.

### 3) SHORT RANGE SEA LEVEL PRESSURE FORECASTS

Figure 5 shows the annual average errors from 1981-88 of NMC 48-h sea level pressure forecasts produced by the early (AVN) run of the global spectral model. The error measure is the S1 score (Teweles and Wobus 1954) computed on a 49-point grid centered over the United States. Scores for LFM forecasts during the same period are shown for comparison. The LFM model and its analysis system were frozen in 1983 and scores during the period remain relatively constant, as they should. The slight downward trend in error almost

250 MB RMS VECTOR ERROR FOR NMC  
OPERATIONAL 24-HOUR FORECASTS  
JANUARY 1982 THROUGH JANUARY 1989

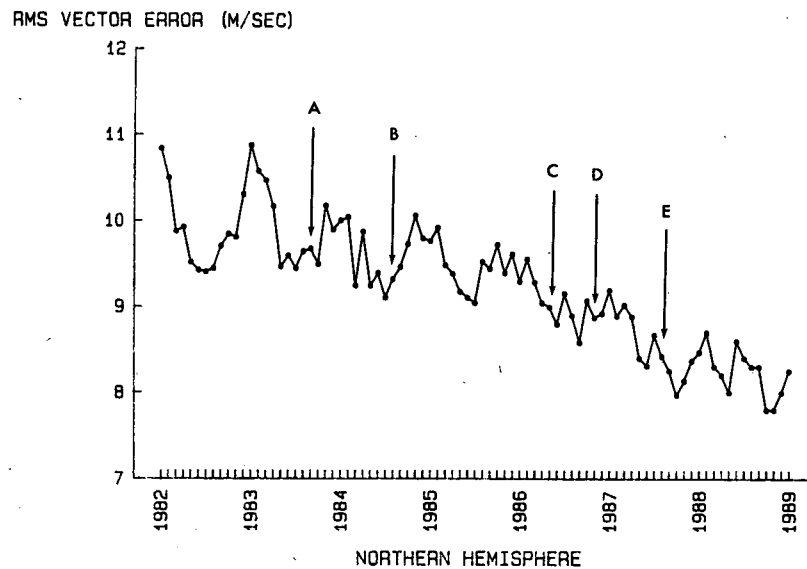


FIG. 4. The rms vector error of NMC 250 mb wind forecasts, January 1982–December 1988. Arrows denote months in which the following changes were made (see Table 2): A: resolution of forecast model increased from R30 to R40; B: Optimum interpolation analysis introduced; C: R40, 18 layer, full physics model introduced in GDAS; D: same model introduced for AVN forecasts; E: resolution of model in GDAS and AVN systems changed from R40 to T80.

certainly results from improvements in the first guess fields for the LFM analysis from improvements in the GDAS (see Table 2). Figure 6 compares the LFM and spectral model scores in a somewhat different way, showing the difference in S1 score (LFM-spectral) averaged for each month from January 1986–December 1988. Note from Fig. 5 that the slight superiority of the LFM in 1981 and 1982 (and previous years, not shown) disappeared in 1983. The introduction of the full physics version of the spectral model into the AVN run in November 1986 (see Table 2) produced a dramatic improvement in S1 scores between 1986 and 1987 (Figs. 5 and 6).

#### 4. Future plans

The NMC CYBER-205 computers that made possible the major advances in numerical prediction at NMC in the mid- to late-1980s are now nearly saturated. We have almost fully exploited the potential of these computers for improvement in prediction models. Small gains can be made over the next several years. However, major progress at NMC awaits the next generation of computers. The National Meteorological Center assumes that such computers with processing speeds of 1 to 10 gigaflops, and significantly larger core memories than in the CYBER 205 will become available by about 1991.

New observing systems are planned, as well, for the 1990s. Improved sounding systems on NOAA-K, -L, and -M should increase the accuracy of satellite-derived temperatures, improving especially the ability of these systems to derive soundings with higher vertical resolution in partly cloudy and cloudy areas. Perhaps the major revolution expected in the 1990s that involves observations for numerical weather prediction is the introduction of mesoscale observations over the conterminous United States from Doppler radar (NEXRAD), wind profilers and aircraft observations. The emphasis that was placed on global data assimilation during the 1970s and 1980s will continue, but a major new challenge lies in the development of systems for the use of high-time resolution observations over the United States in global and regional data assimilation and forecast systems.

Requirements will continue to exist for medium-range weather forecasts to the limit of useful predictive skill, for short-range global forecasts of temperature and wind for international flight planning, and for short-range weather forecast guidance for local forecasts and warnings. Thus, NMC will continue to run systems providing guidance for different purposes. The major change in NMC thinking in this regard is the realization of the need to move from an independent model to a modular approach, making individual components of systems as similar and interchangeable as possible in

## 48 HOUR SEA LEVEL PRESSURE FORECASTS

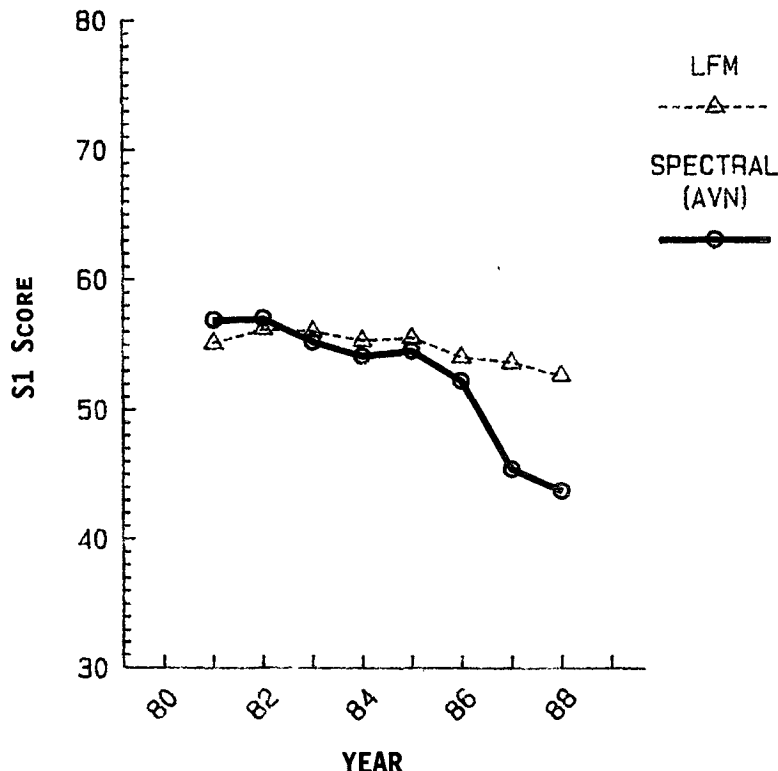


FIG. 5. The S1 scores for spectral (AVN) and LFM 48-h sea level pressure forecasts, 1981-1988. The S1 scores computed on a 49-point grid centered over the United States.

order to limit the number of different systems that must be developed and maintained at NMC. Physics modules for processes such as radiation, convection, and air-sea, air-land interaction will be developed as separate modules that can be easily tested and used within both global and regional systems. This type of configuration is much more economical to maintain and will facilitate greatly the test of new ideas.

Another important problem with current prediction systems is the conflict between the need for stability of models for derivation of model output statistics, and the need to improve forecast models as new ideas are developed and tested. We consider the statistical output from NMC models to be an important component of NMC guidance. However, we expect that new statistical systems in the 1990s will be based upon modified "perfect prog" techniques that can adapt more quickly to the introduction of new models or changes in existing models [See paper in this issue by Carter et al. (1989).]

Let me now speculate on the NMC numerical prediction system on next generation computers:

*Global model.* More powerful computers will allow us to increase the horizontal resolution of the global spectral model from triangular 80 wave (roughly 160 km equivalent) to perhaps triangular 160 wave (80 km equivalent). The number of vertical levels will be increased from the current 18 to as many as 30. Each doubling of the three-dimensional resolution of the model requires a factor of 16 in computer power. Thus, resolutions actually achieved will depend very much on the power available in next generation machines.

Improvements to the model physics will continue to be introduced, especially with respect to the biosphere-atmosphere interactions that determine the fluxes of heat, moisture, and momentum between the atmospheric boundary layer and the land.

We plan to run this model to either 30 or 36 h, four times daily to provide aviation wind forecasts and automated updates. Once-per-day runs to 15 days will provide daily forecasts to 7 days, "week two" guidance for extended range forecasts, and "forecasts of forecast skill" (Kalnay and Dalcher 1987) determined from

**48 HOUR SEA LEVEL PRESSURE FORECASTS  
DIFFERENCE IN S1 SCORES  
(LFM - SPECTRAL)  
JANUARY 1986 THROUGH DECEMBER 1988**

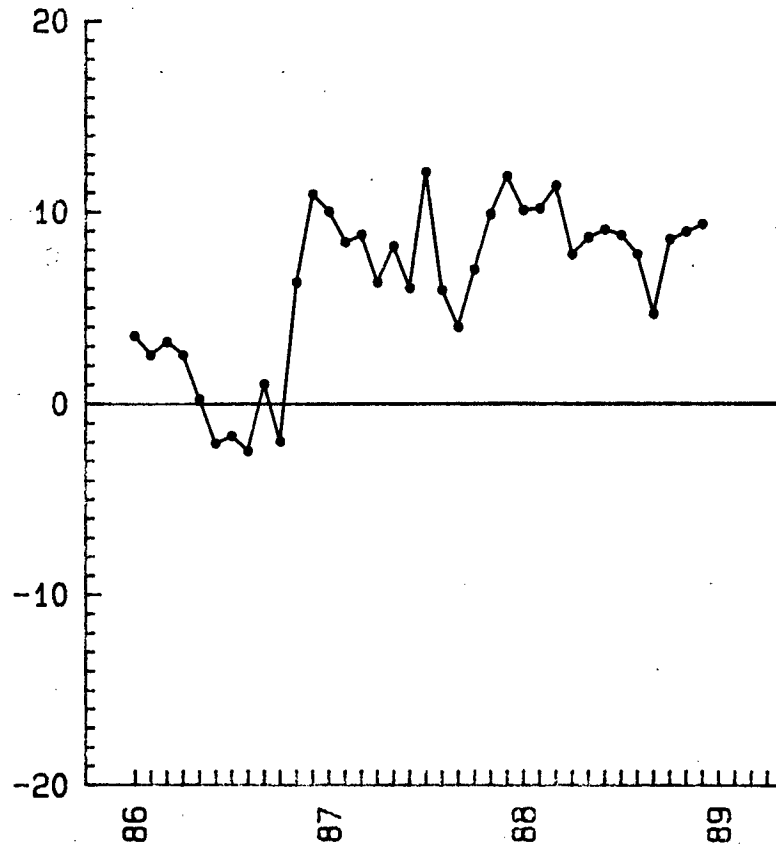


FIG. 6. Relative accuracy of spectral (AVN) and LFM 48-h forecasts of sea level pressure expressed as the difference (LFM-spectral) in monthly averaged S1 scores from January 1986–December 1988. Positive values indicate lower S1 scores (better forecasts) from the spectral model.

factors that include the consistency of successive forecasts valid on the same day.

*Mesoscale model.* We would like to introduce, on next generation computers, a high resolution model for mesoscale guidance. The model would be run on demand to perhaps 18 or 24 h, as often as four times per day. The purpose of this “storm model” would be to provide detailed guidance on the evolution of precipitation patterns, low level winds and parameters such as moisture convergence and stability indices related to severe convective weather. It could be run, for example, for hurricanes threatening coastal areas of the United States, for major convective outbreaks, for large-scale floods or major winter storms. The anticipated horizontal resolution of the model, on next gen-

eration computers, is 20 to 30 km, with 30 or more vertical levels. It is unlikely, even with next generation computers, that the domain of this model could cover the entire United States. Boundary conditions, from the NMC spectral model, would dominate the large-scale solutions beyond 18 or 24 h. This is an appealing concept, but one that needs to be agreed to by our users and requires day-to-day management decisions on where and when to run the model.

We would not anticipate the development of statistical output around this model. Instead, the information would be contained in detailed regional maps, time sections at various locations, and gridded fields which time sections and cross sections could be constructed from. We would expect that the hurricane and “storm”



models would be essentially the same but with special analysis and initialization procedures required for hurricane track prediction.

*Regional model.* Plans are to continue to improve the NGM model through 1989. By January of 1990, we plan to freeze further development of this model. Development of model output statistics (MOS) based upon the RAFS is already well underway, and by 1992 it is expected that a full set of MOS products, similar to those available now on the LFM, will have been developed and implemented for RAFS (see article in this issue by Carter et al. 1989). The RAFS system, developed for the CYBER 205 computers, will become the LFM of next generation machines and will provide the continuity and stability required through the transition to new computers. We expect to retire the LFM by about 1992—after nearly 20 yr of continuous and useful service.

By about 1995, a separate regional system may no longer be required. One to 3-day guidance and input to statistical models could be provided by high-resolution global forecasts or by regular forecasts from a low-resolution version of the mesoscale model.

*Global data assimilation.* The GDAS on next-generation computers will be based upon the global forecast model described above. We anticipate that the GDAS will continue to use optimum interpolation analysis with nonlinear normal model initialization and that a 6- or perhaps 3-h forecast cycle will be appropriate for the global forecast problem. Work is underway on more sophisticated techniques, e.g. adjoint methods (Lorenç 1988; Derber 1989); however, the computer time required for such techniques may delay their implementation at NMC to a following generation of computers in the late 1990s. Efforts at improving the current GDAS focus on the quality control of observations, better use of satellite observations (including estimates of humidity and precipitation), and improved specification of observational and forecast errors that determine the weights to be given to each observation.

*Regional data assimilation system.* By mid-1990 we expect to implement an optimum-interpolation-based Regional Data Assimilation System (RDAS) capable of handling wind observations from the profiler demonstration network across the central United States. This initial version of the RDAS will be similar to the current GDAS but with a 2- or 3-h forecast cycle. It will feed off the global system and provide the initial start up for current regional and future storm models. By 1993 we expect to have developed a more sophisticated RDAS based upon some form of continuous data assimilation. Development of such a system will be essential in order to take full advantage of the new observing systems expected in the 1990s, and to provide the appropriate model spinup for short-range precipitation forecasting.

*Climate data assimilation system.* Global analyses produced by the NMC GDAS or a similar system at ECMWF are becoming increasingly important tools for monitoring the global climate. There is a problem, however, in that the goals of global data assimilation, which provide first-guess fields for operational forecasts, and climate information, often conflict. The global data assimilation system must be run early enough each day to provide first-guess fields by the time a forecast must be made. Thus, the collection of data for these analyses is often incomplete. Second, improvements are made frequently in the GDAS in order to capture even small improvements in forecast accuracy. Changes in the analysis scheme may introduce changes in climate statistics that are not real and represent only the effects of changing the way in which the analysis is done. By about 1993, NMC plans to introduce a special assimilation system for climate purposes. This system would not run under operational time constraints; it could lag the real atmosphere by a week or perhaps a month in order to collect additional data. It would not be changed without prior testing of the effects of the proposed change on important climate statistics. This is a new responsibility for NMC, supported by the NOAA Climate and Global Change Program and consistent with the mission of the NMC Climate Analysis Center.

*Wave models.* Wave models, developed by the joint OPC and run by NMC will continue to be improved on next-generation computers. More accurate weather forecast models will provide better estimates of the surface frictional stress for generation of waves. Satellite-based surface wind and wave height estimates will improve initial conditions for wave models and permit more representative verification of forecasts. Work is underway within the OPC to develop and test the so-called "third-generation" wave models for both regional and global prediction.

*Extended range forecasts.* Numerous experiments have shown the potential of general circulation models to predict time-averaged features of the flow for periods well beyond the limits of day-to-day predictability (Shukla 1981; Miyakoda et al. 1986). Forecasts beyond 10 days show significant skill in certain situations (Tracton et al. 1989). The problem in this case is not simply to make a forecast, but to assign to that forecast some probabilistic level of skill. The National Meteorological Center has recently begun to extend its 10 day forecasts to 15 days, twice each month, as an experimental tool for 30 day forecasts. By 1992 we expect that the major component of 30 day forecasts will be extended dynamical model runs. For seasonal prediction and longer, the most promising approach appears to be the use of coupled ocean-atmosphere models, in which ocean surface conditions do not simply drive the atmospheric model, but are affected by them as well. We would expect by the mid 1990s to be making

experimental seasonal predictions based upon the output from coupled ocean-atmosphere models. This is clearly an important topic for research with next-generation computers. Implementation of routine, extended-range forecast runs with coupled ocean-atmosphere models will depend upon the results of this research and upon available computer power. I would estimate that operational dynamical forecasts, for periods of a season or more, are a reasonable possibility with the next, yet-to-be developed class of supercomputers in the late 1990s.

### 5. Concluding remarks

We know the general characteristics of future observing systems because of the long lead times required to plan for, budget, develop, and implement such systems. Continued advances in the power of supercomputers are predictable at least through the 1990s. We can anticipate, to some degree at least, national priorities such as the emphasis on climate and global oceans that will effect NOAA, NWS, and NMC priorities. We cannot predict funding and it is difficult to predict the results of research. These are the major uncertainties in the scenario presented in section 4.

Continued progress in numerical prediction skill at NMC depends not only on research and development efforts within NMC, but upon progress in numerical prediction, in general, and the interest and ability of scientists at laboratories and universities to work with NMC in translation of their research into NMC operations.

In recognition of the need to involve scientists from the research community more actively in its programs, NMC established a visiting scientist program in 1984 through the University Corporation for Atmospheric Research (UCAR). The program is open to senior scientists, recent Ph.D.s and graduate students working on doctoral degrees. A second program, established jointly with the National Science Foundation, seeks both to support academic research in numerical weather prediction, and to foster cooperative research involving the use of NMC facilities and collaboration with NMC scientists by university faculty and graduate students.<sup>1</sup> These two programs plus enhanced participation by NMC scientists in national and international programs and working groups have played, and will continue to play, important roles in providing the broad influx of new talent and new ideas that is essential to NMC progress. The development of more "user-friendly" systems for testing and evaluation at NMC, and the change to a more modular, standardized form for forecast model development (Kalnay et al. 1989)

can only enhance the productivity of visiting scientists and the ability of NMC to test forecast system components developed at universities, laboratories, and other forecast centers.

I would like to make one final point. Those of us concerned with numerical prediction have tended over the years to think of the computer revolution only in terms of supercomputers. There is another revolution going on that may be of equal importance. That is the development of powerful workstations and interactive display capabilities that will allow forecasters access to the full range of predictive fields that modern prediction models, run on supercomputers, can produce. We have gone well beyond the time when it was appropriate to consider the output of a numerical forecast run as a series of snapshots at 12-h intervals of 1000, 500, and 250 mb wind flow. It may be that the most dramatic improvements in the utility of NMC forecasts in the 1990s will result at least as much from advances in the ability to display forecasts of clouds and precipitation [as well as humidity, wind and temperatures in time sections, cross sections, or animated maps (Plummer 1989)], as from improvements in the accuracy of the models. The kind of display capability will be an absolute requirement to capture the information available from future mesoscale models.

*Acknowledgments.* I would like to express my thanks to the many NMC researchers and visiting scientists responsible for the progress described in this paper. My thanks as well to Dick Hallgren for his support and guidance and to three institutions: the National Center for Atmospheric Research, the Geophysical Fluid Dynamics Laboratory of NOAA, and NASA's Goddard Laboratory for Atmospheres. They all contributed in varying ways to the development of new NMC systems described in this issue of *Weather and Forecasting*. Plans for new NMC systems in the 1990s were developed in consultation with Eugenia Kalnay and the Development Division staff. My thanks to the authors of the articles in this issue, and especially to Wes Junker of Meteorological Operations Division, who orchestrated and edited the NMC contributions.

We at NMC appreciate the decision by the editors to devote this issue to a description of forecast guidance systems at NMC and welcome this opportunity to describe these systems to our users.

### REFERENCES

- Alpert, J., M. Kanamitsu, P. Caplan, J. Sela, G. White and E. Kalnay, 1988: Mountain induced gravity wave drag parameterization in the NMC medium range forecast model. *Preprints Eighth Conf. on Numerical Weather Prediction*, Baltimore, Amer. Meteor. Soc., 726-733.
- Bengtsson, L., 1984: Medium range forecasting—the experience of ECMWF. WMO/TD-No. 33, III-12-III-45.
- Bergman, K., 1979: Multivariate analyses of temperature and winds using optimum interpolation. *Mon. Wea. Rev.*, 107, 1423-1444.

<sup>1</sup> See program announcement in the *Bulletin of the American Meteorological Society*, August 1987.

- Bonner, W., 1986: Achievements by NMC Washington in NWP applications based on Global Weather Experiment data and methods. WMO/TD-No. 107, 659–670.
- , G. H. White, M. S. Tracton, V. E. Kousky and G. P. Cressman, 1986: Global analysis and prediction at NMC Washington, *Proceedings, Second International Conf. on Southern Hemisphere Meteorology*, Wellington, New Zealand, Amer. Meteor. Soc., 1–9.
- , 1988: Recent progress and future plans for numerical weather prediction at the National Meteorological Center. *Preprints Eighth Conf. on Numerical Weather Prediction*, Baltimore, Amer. Meteor. Soc. J26–33.
- Carr, F., R. Wobus and R. Petersen, 1989: Normal mode initialization experiments with the NMC nested grid model. *Mon. Wea. Rev.*, submitted.
- Carter, G., J. P. Dallavalle and H. R. Glahn, 1989: Statistical forecasts based on NMC's numerical weather prediction system. *Wea. Forecasting*, **4**, 401–412.
- Derber, J., 1989: A variational continuous assimilation technique. *Mon. Wea. Rev.*, submitted.
- Flattery, T., 1971: Spectral models for global analysis and forecasting. *Proc. Sixth AWS Technical Exchange Conference*, U.S. Naval Academy, Annapolis, Air Weather Service Tech. Rep. 242, 42–54.
- Gerrity, J., 1977: The LFM Model—1976: a documentation. NOAA Technical Memorandum NWS NMC-60 (NTIS PB-279-419), 68 pp.
- Hoke, J., N. Phillips, G. DiMego, J. Tuccillo and J. Sela, 1989: The regional analysis and forecast system of the National Meteorological Center. *Wea. Forecasting*, **4**, 323–334.
- Kalnay, E., and M. Kanamitsu, 1988: Time schemes for strongly nonlinear dampening equations. *Preprints Eighth Conf. on Numerical Weather Prediction*, Baltimore, Amer. Meteor. Soc., 815–820.
- , M. Kanamitsu, J. Pfendtner, J. Sela, M. Suarez, J. Stackpole, J. Tuccillo, L. Umscheid and D. Williamson, 1989: Rules for interchange of physical parameterizations. *Bull. Amer. Meteor. Soc.*, **70**, 620–622.
- , and A. Dalcher, 1987: Forecasting forecast skill. *Mon. Wea. Rev.*, **115**, 249–256.
- Lorenz, A., 1988: A practical approximation to optimal four-dimensional objective analysis. *Mon. Wea. Rev.*, **116**, 730–745.
- Mathur, M., 1983: A quasi-Lagrangian regional model designed for operational weather prediction. *Mon. Wea. Rev.*, **111**, 2087–2098.
- McPherson, R., K. Bergman, R. Kistler, G. Rasch and D. Gordon, 1979: The NMC operational Global Data Assimilation System. *Mon. Wea. Rev.*, **107**, 1445–1461.
- Miyakoda, K., G. Hembree, R. Strickler and I. Shulman, 1972: Cumulative results of extended forecast experiments. 1: Model performance for winter cases. *Mon. Wea. Rev.*, **100**, 836–855.
- , J. Sirutis and J. Ploshay, 1986: One-month forecast experiments—without anomaly boundary forcing. *Mon. Wea. Rev.*, **114**, 2363–2401.
- Parrish, D., 1989: Application of implicit normal mode initialization to the NMC nested grid model. *Mon. Wea. Rev.*, submitted.
- Petersen, R., and J. Stackpole, 1989: An overview of the NMC production suite. *Wea. Forecasting*, **4**, 313–322.
- Plummer, D., 1989: Diagnostic and Forecast Graphic Products at NMC using high frequency model output. *Wea. Forecasting*, **4**, 83–89.
- Rao, D. B., 1989: A review of the activities of NOAA's Ocean Products Center. *Wea. Forecasting*, **4**, 427–443.
- Sela, J., 1980: Spectral modeling at the National Meteorological Center. *Mon. Wea. Rev.*, **108**, 1279–1292.
- , 1988: The new T80 NMC operational spectral model. *Preprints Eighth Conf. on Numerical Weather Prediction*, Baltimore, Amer. Meteor. Soc. 312–313.
- Shukla, J., 1981: Dynamical predictability of monthly means. *J. Atmos. Sci.*, **38**, 2547–2572.
- Shuman, F., 1989: History of numerical weather prediction. *Wea. Forecasting*, **4**, 286–296.
- Teweles, S., and H. Wobus, 1954: Verification of prognostic charts. *Bull. Amer. Meteor. Soc.*, **35**, 455–463.
- Tracton, S., K. Mo, W. Chen, E. Kalnay, R. Kistler and G. White, 1989: Dynamical extended range forecasting (DERF) at the National Meteorological Center. *Mon. Wea. Rev.*, submitted.
- Tuccillo, J., 1988: Parameterization of physical processes in NMC's nested grid model. *Preprints Eighth Conf. on Numerical Weather Prediction*, Baltimore, Amer. Meteor. Soc., 238–43.