NMC NOTES

Changes to NMC's Regional Analysis and Forecast System

RALPH A. PETERSEN, GEOFFREY J. DIMEGO, JAMES E. HOKE,
KENNETH E. MITCHELL AND JOSEPH P. GERRITY

National Meteorological Center, NWS, NOAA, Washington, DC

RICHARD L. WOBUS, HANN-MING H. JUANG AND MICHAEL J. PECNICK

Centel Federal Services, Corp., Reston, Virginia

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ABSTRACT

The final set of changes to NMC's Regional Analysis and Forecast System (RAFS) is described. The changes include modifications to both the forecast model and the analysis model, as well as development of a Regional Data Assimilation System (RDAS). The forecast model changes were developed to correct a number of known deficiencies in the Nested Grid Model (NGM), while the RDAS development will allow the RAFS to take advantage of the new asynoptic data sets soon to be available. Several of the changes were implemented on 7 November 1990. The remaining changes (including the RDAS) are planned for implementation before mid 1991. Results from tests of the revised forecast model and the combined RDAS/NGM system are presented and discussed.

1. Introduction

An important source of regional forecast guidance for the National Weather Service (NWS) since March 1985 has been the Regional Analysis and Forecast System (RAFS) (Hoke et al. 1989). In the five years following the introduction of the RAFS, a number of enhancements have been implemented to improve the system. These include among others the introduction of an advanced physics package (Tuccillo and Phillips 1986), expansion of grid C (Hoke 1987), removal of the hemispheric temperature bias (Phillips and Tuccillo 1987), and modifications to the initialization procedure (Carr et al. 1989; Parrish 1989).

Over the next several years, NMC will be shifting the primary focus of its short-range model development towards a new mesoscale model used to support the local watch and warning missions of the NWS modernization. Preceding this shift of focus, a recent 18-month development effort was devoted to establishing a final version of the RAFS. The purpose of this note is to outline the final developments, specify the changes approved for implementation, and discuss their effects on forecast skill. Initial implementation began on 7 November 1990 and will culminate before mid 1991 with the final version of the RAFS (anticipated to run operationally through at least the mid 1990s).

Besides the obvious goal of improving model forecast accuracy, an additional objective of this final RAFS development effort was to avoid compromising the earlier endeavors of the Techniques Development Laboratory (TDL) to transfer the production of Model Output Statistics (MOS) guidance from the LFM to the RAFS. Since July 1989, NGM MOS forecasts of daytime maximum/nightime minimum (max/min) temperature, probability of precipitation (PoP), surface wind speed and direction, and opaque cloud amount have been generated twice daily and sent to users. Achieving this milestone required the use of a relatively long historical model-performance data set spanning a period in which the NGM configuration was fixed. Such a data set existed between October 1987 and November 1990, when the only operational changes to the NGM were a change in December 1987 to the frequency of calculating certain parameterized physical processes (e.g., radiation and precipitation) to achieve significantly shorter model run times and a change in December 1988 to the NGM initialization (Parrish 1989). Both changes had negligible impact on NGM forecast fields.

Rather than waiting for a several-year period to elapse after the final RAFS changes to develop MOS, TDL in late 1988 took advantage of the aforementioned earlier period of essentially unchanging NGM configuation to develop its historical data base. Using the NGM operational version of December 1987, TDL re-executed a series of forecasts using archived operational initial analyses from the 1-year period prior to October 1987. These forecasts were then added to the

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Corresponding author address: Ralph A. Petersen, National Meteorological Center, WWB, Room 204, 5200 Auth Road, Camp Springs, MD 20746.

archive of all operational forecasts made since that date. This allowed TDL to expand the dependent data set used to generate RAFS-based MOS coefficients to ultimately include nearly 2½ years of RAFS forecasts from October 1986 to March 1989 (two warm seasons and three cool seasons). Results of this effort, described by Jacks et al. (1990), led to improvements in MOS guidance in many areas when compared to that provided by the LFM.

It should be pointed out that the MOS equations statistically account for and correct a model's systematic errors or biases, based on the historical performance of the forecast model. Any subsequent changes that significantly improve model biases may actually degrade MOS products, which account only for biases in the historical data set. As such, the major TDL MOS development effort for the RAFS would have been compromised by any drastic changes to the systematic errors of the RAFS. Nevertheless, a number of factors suggested that several final RAFS modifications should be considered to improve the accuracy of the RAFS throughout its remaining lifetime. First, some of the proposed modifications were intended to correct known deficiencies in the forecast component of the RAFS, the Nested Grid Model (NGM). Secondly, and more importantly, other modifications were needed to allow the RAFS analysis system to take full advantage of the new, high temporal frequency data sets (see Section 3 for examples) which will become available over the United States as part of the National Weather Service Modernization and Associated Restructuring (MAR). These new data sets will, for the first time, provide the quasi-continuous reporting of upper-level atmospheric conditions needed to detect and to improve short-range forecasts of small-scale weather events.

The various modifications were tested individually and in combination for extended periods throughout 1989 and early 1990 in twice daily (0000 UTC and 1200 UTC) test runs. The results were verified against the corresponding unmodified operational RAFS forecasts. Based on the results of these tests, modifications that seriously impacted the systematic behavior of the RAFS forecasts were discarded in order to retain consistency with the historical RAFS forecast sample used to develop MOS. The set of modifications finally approved for operational implementation reduced primarily random errors rather than significantly affecting bias errors.

The modifications tested in the NGM forecast component of the RAFS are described in section 2. Enhancements tested in the analysis system to incorporate more frequent data reports and to improve the resolution of the forecast model's initial conditions are presented in section 3. Test results of the combined analysis/forecast system are discussed in section 4. All changes were tested on the Cyber 205 computer, but will be implemented only on the Cray Y-MP system to take advantage of its increased computing speed to meet operational time constraints.

2. Modifications to the Nested Grid Model

This section describes a number of changes within the NGM component of the RAFS that were designed to address known deficiencies of the forecast system. These changes include 4th-order finite differencing, improved specification of subsoil temperature, improved calculation of radiative heating rates, higher-resolution orography, stability-dependent surface fluxes over water, 1-way boundary conditions, a modified soil wetness specification, an alternative convective parameterization scheme, increased evaporation over water, and modification of the precipitation calculation frequency.

Those modifications that were implemented on 7 November 1990 are described in section 2a, followed by those to be implemented by mid 1991 in section 2b. Noteworthy modifications that were tested but not implemented are presented in section 2c. Finally, section 2d presents results comparing the performance of the revised NGM (i.e., with the changes of section 2a and 2b) with that of the forerunner operational version (prior to November 1990).

a. Implemented changes

RAFS subsoil temperature specification: Efforts were undertaken to improve the RAFS subsoil temperature (T_{ss}) field, which is reinitialized at each analysis time and then held constant during the forecast. The T_{ss} field provides the lower boundary temperature (20-cm depth) used to predict ground surface temperature, which in turn influences surface heat and moisture fluxes and low-level air temperatures. The previously operational specification of T_{ss} was based on instantaneous surface energy balance conditions (ignoring soil heat fluxes). The procedure, which was overly sensitive to initial low-level air temperature, humidity, and cloud cover, yielded T_{ss} values that 1) showed erroneously large variability from cycle to cycle at a given point and 2) were systematically too cold, thus contributing to a cold bias in the low-level air temperature. This is readily apparent in the 13-day trace of subsoil and analyzed air temperatures in the lowest model layer (Fig. 1). Experiments in which T_{ss} was set alternatively to a 15-day running average of the RAFS analyzed air temperature at the model's lowest sigma layer (thereby simulating the lagged dependence of subsoil temperature on the preceding mean low-level air temperature) eliminated the cycle-to-cycle variability and modestly improved the mean and random temperature forecast errors in the model's lowest forecast layer (Fig. 2). (Note in Figs. 1 and 2 that references to "operational" refer to the version of the NGM operational prior to November 1990.) A shorter running average length of

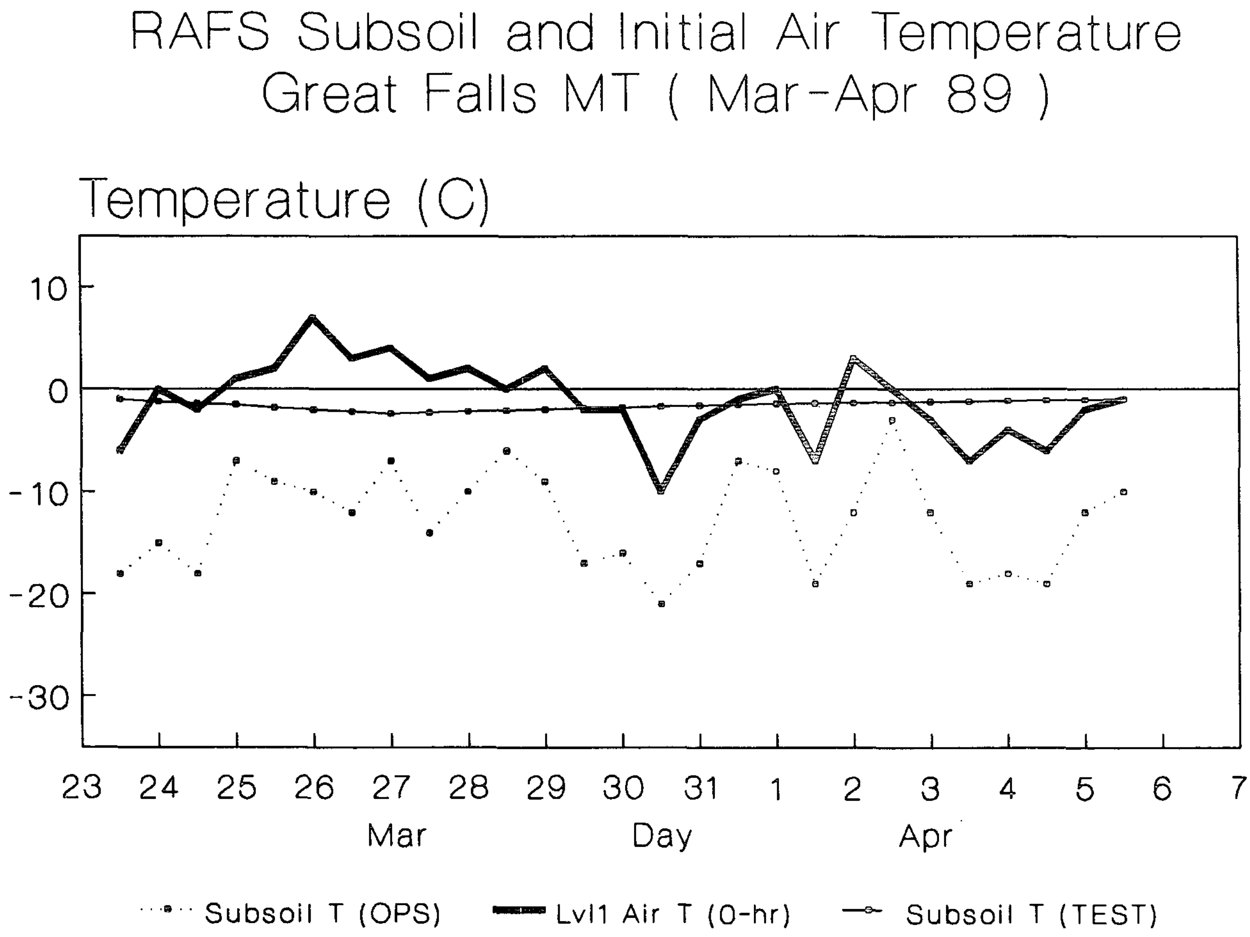


FIG. 1. RAFS operational (dotted) and test (solid) subsoil temperature and 0-h lowest-layer analyzed air temperature (bold) at Great Falls, Montana for each 12-h analysis cycle from 1200 UTC 23 March 1989 to 1200 UTC 5 April 1989.

ten days was chosen for implementation, to allow a more rapid response to sudden but prolonged changes in temperature.

RAFS radiation package: Investigations of the previously operational RAFS radiation parameterization revealed spurious maxima in the mean longwave cooling rates in three areas, one near the surface, a second in the upper troposphere, and a third at the top of the model. These errors were caused, respectively, by 1) low clouds being invariably assigned to just the second (thin) model layer, 2) an incorrect method of extrapolating water vapor in the upper troposphere and lower stratosphere in the initial moisture analysis, and 3) omission of ozone in the stratosphere. A modification of the moisture extrapolation procedure and inclusion of a zonal mean ozone climatology rectified the latter two problems and thus were implemented. Tests had indicated that the above changes reduced the RAFS cold bias at high levels, but had little effect in the mid and lower tropospheric levels that are most important to MOS. However, because the 300-mb moisture fields were systematically changed by the different extrapolation technique, they are no longer used as MOS predictors (see Erickson et al. 1991).

Tests of an alternative radiation scheme (identical to that used in the global spectral model) partially corrected the low-cloud problem noted above. However, the scheme systematically changed the character of the temperature profiles in the several bottom-most model layers, with the potential for an adverse effect on MOS maximum and minimum temperature forecasts. As such, the original radiation scheme was retained.

Enhanced orography: A study was conducted to improve the resolution of the RAFS terrain. The topography used in the previously operational NGM consisted of terrain data from various sources filtered to triangular 72 (T72) resolution and represented on the 2° × 1.5° RAFS analysis grid (see DiMego 1988). Problems associated with that terrain data set included insufficient resolution of important features, differences in the quality and detail of terrain data used over the United States and that used over Canada and Mexico, misrepresentations along mountainous coastlines, and anisotropic truncation outside North America. A new

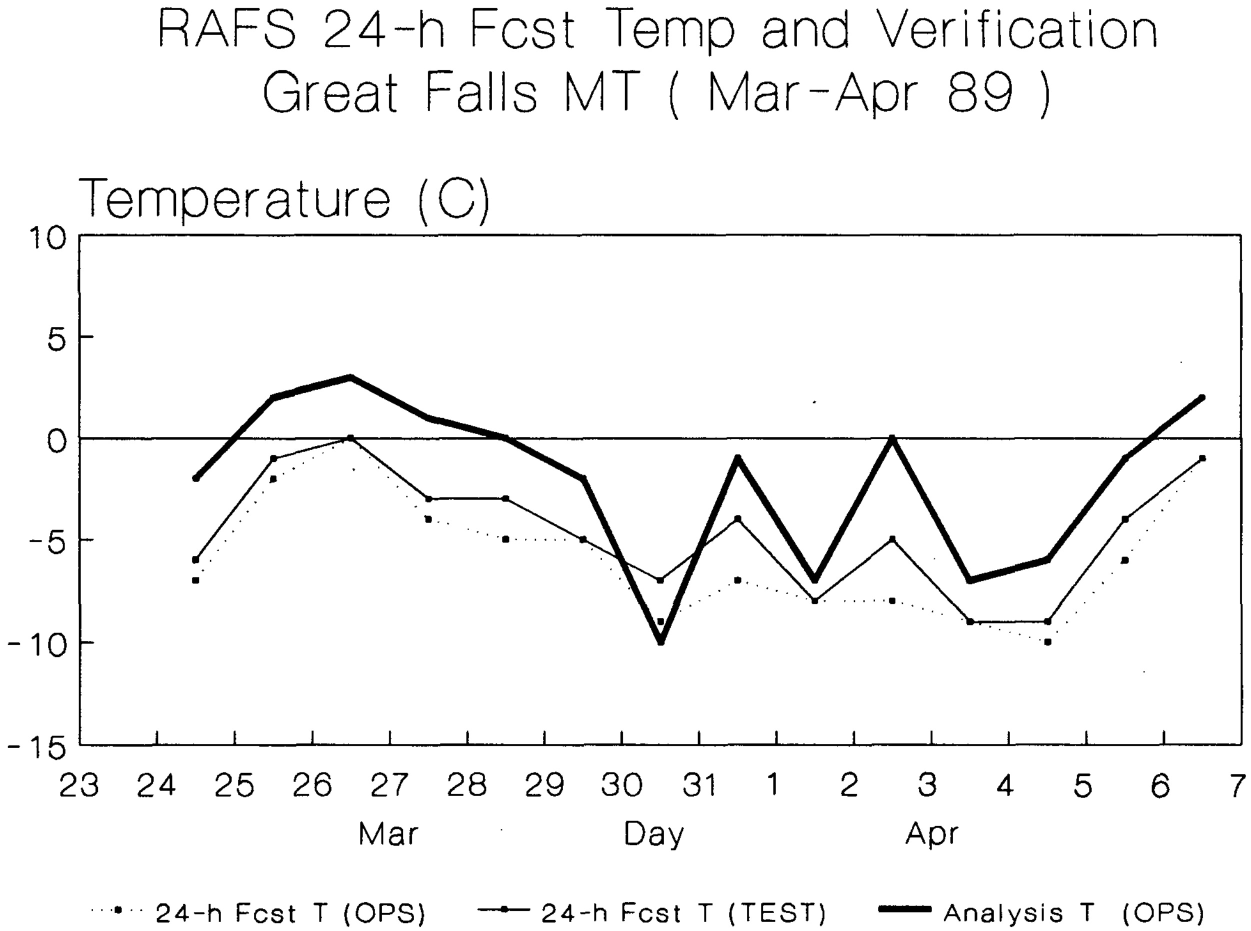


FIG. 2. RAFS 24-h lowest-layer air temperature forecasts valid at 1200 UTC for runs using operational (dotted) and test (solid) subsoil temperature, with verifying analyzed temperature (bold), for same period and location as Fig. 1.

mean topography field was developed based on the United States Navy 10-minute resolution terrain data, with some missing or obviously erroneous data points corrected from atlases. A general filtering procedure was used to generate fields at T80 resolution, commensurate with the NGM grid. (Finer resolution than this could have adversely affected MOS and produced increased noise in the forecast.) These changes are readily apparent in Fig. 3, especially over northern Mexico, western Canada, eastern Alaska, the Mississippi Valley, and the Sacramento and Columbia River Valleys. Tests with the new fields showed more realistic orographic precipitation and a slightly reduced tendency for erroneous leeside cyclogenesis, without indications of unacceptably noisy forecasts.

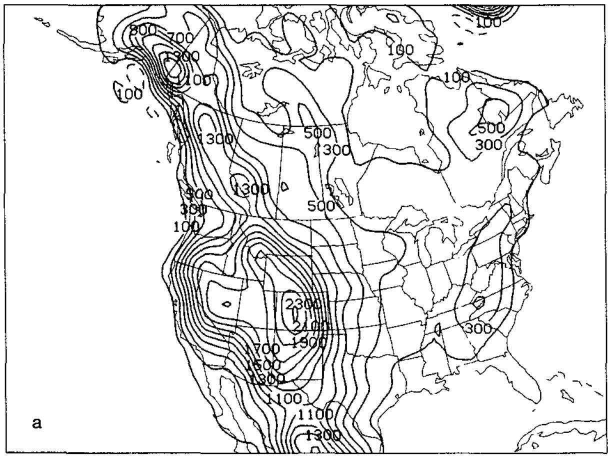
Decreased soil moisture along coastal areas: A local problem of erroneously large surface wetness over coastal land points was corrected. The error occurred in the interpolation of the surface wetness fields from the 1° × 1° grid on which it is specified onto the NGM's grid points. (Over land, this wetness field is derived from a spatially varying, annual climatological vegetation index that remains constant from day to day). In the interpolation, large oceanic wetness values were erroneously being allowed to affect nearby coastal land points. The excessive wetness of these coastal land points often contributed to overprediction of coastal convective precipitation, especially along the gulf and northeast coast of the U.S. The revised interpolation procedure reduced this problem.

Stability-dependent surface fluxes over water: The previously operational NGM used stability-dependent fluxes in the calculation of surface drag, evaporation, and sensible heat flux only over land. Over water, a neutral stratification was assumed. This resulted in misrepresentation of surface fluxes in situations of stability extremes in the boundary layer. Tests with stability-dependent fluxes over water have produced more realistic evaporation rates. The technique has significantly reduced fluxes into warm air masses over the cold California current and increased evaporation into cold air masses over the Great Lakes and Gulf Stream, along with improvements in the intensity of forecast oceanic cyclogenesis.

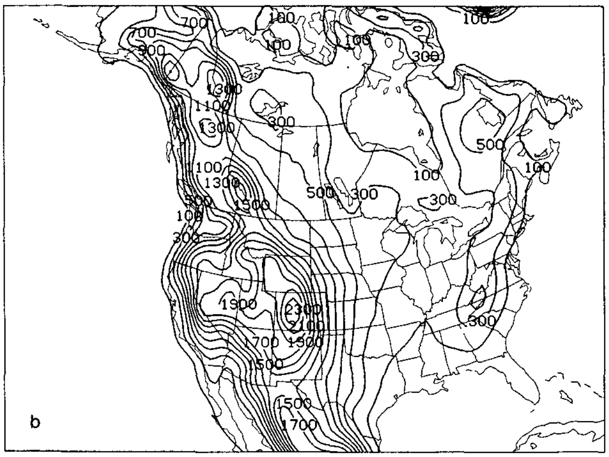
b. Future changes to be implemented

Fourth-order finite differencing: In an effort to increase the effective spatial resolution of the forecast model, 4th-order finite-differencing and interpolation formulations were tested against the 2nd-order forms used operationally to date. Tests showed a slight improvement in forecast accuracy resulting from the higher-order formulations, especially along frontal boundaries, but required approximately 30% more time for the forecast model's execution. This additional computing cost is more than offset by the increased speed of the Cray over the Cyber 205.

Expansion of Grid C: The southern boundary of grid C will be extended southward by eight grid rows (approximately 600 km) especially to improve forecasts in southerly flow regimes. Additional expansions to the west and north will be considered for the Alaska region if computer time limitations on the Cray will allow it.



RAFS OPERATIONAL TOPOGRAPHY



RAFS NEW TOPOGRAPHY

FIG. 3. Comparison of (a) operational and (b) experimental orography fields used in NGM. Height contours in m. Contour interval is 200 m.

c. Changes not implemented in NGM forecasts

One-way boundary conditions: The NGM is a hemispheric model with three telescoping nested grids yielding highest resolution in the area around North America covered by the innermost grid C (see Hoke et al. 1989). Two-way boundary conditions (which allow the inner and outer grids to interact and influence each other) are used at the grid interfaces, with a wall boundary at the equator. The system also includes identical vertical structures and physical parameterizations across the grid boundaries.

When the NGM was originally developed in the late 1970s, NMC did not have an operational global model. With the development of an advanced global spectral model (Kanamitsu 1989), the question arose regarding whether the benefits of the NGM nesting concept (using current analyses on all grids and hence more timely forecast boundary conditions) still outweighed those of a system using 1-way boundaries from a *previous* cycle of the global model, which has higher resolution and is usually more accurate outside of the grid C area. Experiments showed that although NGM grid forecasts using boundaries from the preceding 12-h old spectral aviation (AVN) forecast were more accurate than the operational NGM forecasts in some weather regimes, this 1-way NGM system produced significantly worse forecasts in situations of high index flows. The problem was especially apparent at the longer forecast periods and in the western part of the forecast domain. *Although this change was not implemented in the forecast model, the 1-way boundary capability will form an important component of the new Regional Data Assimilation System (RDAS) described in section 3.*

Modified soil moisture: The NGM's problem of overpredicting light amounts of summertime precipitation was traced, in part, to excessive evaporation from the land surface. The present formulation makes use of a simple bulk aerodynamic evaporation proportional to the moisture availability, or wetness, of the soil. Several alternate schemes were tested. One particularly promising scheme was that of Penman and Monteith, which is used in the global spectral model (Pan 1990) and is known to reduce the overprediction of potential evaporation given by bulk aerodynamic schemes. Unfortunately, the scheme decreased surface evaporation to the extent that precipitation forecast skill was also decreased. A simple alternative, in which the operational soil moisture availability was decreased by 20%, led to a 25% reduction in the overprediction of summertime precipitation, but would have required seasonal adjustment. The change would also have adversely affected MOS by changing the systematic performance of the model.

Alternative convective parameterization: The Betts-Miller (1986) convective parameterization was tested extensively in the NGM. This scheme, which is also used in NMC's new Eta model (Janjic 1990), produced forecasts in which the problem of overprediction of light amounts of summertime precipitation was reduced, the underprediction of heavy amounts in the cool season was less severe, the strength of tropical cyclones was more accurate, and the precipitation forecasts were less noisy. Unfortunately, the scheme also caused the NGM to overdeepen some extratropical cyclones significantly. For this reason and because of the potential impact of the change to the model's systematic behavior on MOS, the change was not implemented.

Increased evaporation over oceans: The rate of evaporation of water from the ocean surface to the atmosphere was increased by factors of two and four in an attempt to improve forecasts of tropical-cyclone movement and development by increasing precipitation and latent heat release. Although the experiments were remarkably successful, the systematic behavior of the model was changed, thereby affecting MOS.

Reduced precipitation time step: Tests showed that increasing the frequency at which precipitation is calculated within the model from 15 min to 75 seconds improved NGM wintertime precipitation forecast biases by about 10 percent. Although similar improvements were observed in threat scores, the systematic nature of the changes would have adversely affected MOS.

d. Tests of forecast model improvements

The NGM changes that were accepted for implementation and discussed in Sec. 2a and 2b were tested in combination for a two-week period from 26 January to 9 February 1990 using initial conditions identical to the then operational NGM. Forecast results are compared in Table 1 with radiosonde height, temperature, and wind observations over the conterminous United States. The test system showed improvement in the fit of the forecast fields to observations at all forecast times from 12 to 48 h and at most standard evaluation levels. Temperature biases at 850 mb were reduced from −0.7 to −0.5C at 48 h, with standard deviation errors (STDE) for geopotential reduced by nearly 5%, from 34.5 to 32.9 m and 45.3 to 43.5 m, at 850 and 500 mb, respectively. Similarly, both the bias and STDE for the winds were also reduced at all levels (most notably at 500 mb, where the errors again decreased by 5%). In no case, was a significant forecast degradation found.

TABLE 1. Verification of operational and experimental (revised NGM) 48-h RAFS forecasts of height, temperature, and vector wind against conterminous U.S. radiosonde observations over the period 1200 UTC 26 January 1990 to 0000 UTC 9 February 1990. (Note: STDE = standard deviation errors).

	Grid-to-station verification (48-h)			
	BIAS		STDE	
	Operational	Experimental	Operational	Experimental
850 mb				
Height (m)	−13.6	−15.9	34.5	32.9
Temp (c)	−0.7	−0.5	3.4	3.1
Wind (m/s)	7.3	7.0	4.4	4.3
500 mb				
Height	−22.3	−24.4	45.3	43.5
Temp	−0.3	−0.4	2.6	2.5
Wind	9.4	9.0	6.2	5.9
250 mb				
Height	−14.2	−16.3	59.4	58.8
Temp	1.2	1.4	3.3	3.3
Wind	11.9	11.7	7.7	7.7

Precipitation forecasts were also evaluated using analyses of 24-h accumulated precipitation data from a high resolution rain gauge network that exists over the eastern two-thirds of the U.S. Results (not shown) for the 24–48-h forecast period showed improvements in both the bias and threat scores for the test period, with improvements most notable for amounts in excess of 0.25 in. Similar performance was noted for all forecast periods.

3. Development of a Regional Data Assimilation System (RDAS)

Improvements in future regional forecasts will require not only enhancements to the numerical prediction forecast models, but also improved, higher-resolution analyses for initial conditions. It is essential that these analyses be able to take advantage of the new, high temporal frequency data sets [such as Automated Surface Observing System (ASOS), ARINC Communication Addressing and Reporting System (ACARS) aircraft reports developed by Aeronautical Radio, Inc. (ARINC), Next Generation Radar (NEXRAD), satellite products and wind profilers; all with at least hourly vs. twice daily reporting]. The analysis system must be able to blend observations from the many different sources into a dynamically consistent set of gridded data compatible with the forecast model. In addition, the forecasts should be applicable for shorter time ranges than routinely used today.

As originally implemented, the operational RAFS analysis (DiMego 1988) makes corrections to first-guess fields provided by the Global Data Assimilation System (GDAS) 6-h forecasts. Two major deficiencies exist in this analysis approach. First, because over grid C the GDAS fields are from a lower resolution global spectral forecast model, up to 6 h of forecast time are required for frontal gradients in the NGM grid C area to be maximized and for the precipitation rate to be fully spun-up. Second, a global assimilation system based on a 6-h analysis cycle is not appropriate for assimilating the new, high-frequency data sets soon to be available on an hourly basis over the U.S.

An NGM-based Regional Data Assimilation System (RDAS) has been developed that circumvents these deficiencies and provides higher resolution analyses. The system is expected to be implemented operationally in early 1991. Unlike the currently operational RAFS analysis, the RDAS analyses are tied directly to the higher resolution regional NGM forecasts. In effect, a series of very short range (3- to 6-h) forecasts produced by the regional forecast model are corrected and updated repeatedly by a sequence of high resolution analyses. Repeating this process for a period of 6 to 12 h prior to the normal analysis time incorporates the new asynoptic data in the analyses, allows the gradients in the analyses to be more fully developed, and leads to a precipitation rate that is more uniform during the early period of the subsequent model forecast.

In addition to the development of the NGM-based RDAS, a number of changes were incorporated in the analysis procedure itself. These changes were implemented on 7 November 1990. Most noteworthy was the use of a "unified" analysis code, which not only added an analysis level at 10 mb, improved the quality control of satellite temperature and wind data, and performed the analysis on a higher resolution grid (1° × 0.75° vs. 2° × 1.5°), but also will reduce future software maintenance, since the same analysis code may be used for both the regional and global analyses.

The RDAS is also designed to take optimum advantage of the superior performance of analyses from the Global Data Assimilation System (GDAS) in data sparse oceanic areas. Rather than allowing flow from the lower-resolution grid A and B regions to enter the lateral boundaries of the NGM's grid C during the regional data assimilation period, contemporaneous analyses and short-range forecasts from the GDAS are used to provide one-way boundary conditions for the grid C forecasts used during the RDAS period (see section 2c). This approach results in a minimum error growth along the grid C boundary during the RDAS.

In its final form, the RDAS was configured and tested as follows:

1) A regional analysis and initialization are performed using data from 12 h prior to the forecast initiation time (T-12) and first-guess fields from the GDAS analyses valid at that time.

2) A 6-h NGM grid C forecast is produced using one-way boundary conditions provided by the T-12 and T-06 GDAS analyses.

3) A second regional analysis (T-06) is performed using all data available between 3 and 9 h prior to the forecast initiation time. (It should be noted that once sufficient new sources of asynoptic data are available, it is anticipated that the RDAS will be performed using a 3-h, rather than a 6-h, cycle.)

4) Another 6-h NGM grid C forecast is produced for the period from T-06 to T-00, this time obtaining grid C boundary conditions from forecast tendencies of the GDAS forecast produced from the T-06 GDAS analysis.

5) At the synoptic analysis time (T-00), the higher-resolution NGM forecast from grid C is merged with the GDAS first guess fields over the remainder of the hemisphere. Together they provide the first guess over the grids A, B, and C for the regional analysis.

6) A final regional analysis and initialization are performed over the full Northern Hemisphere and an NGM forecast is then produced using the traditional two-way Nested Grid Model configuration.

Tests of the RDAS (using the revised version of the NGM including the higher resolution topography) showed significant increases in the detail present in its final analysis when compared with the operational regional analysis. As shown in Fig. 4, not only are the

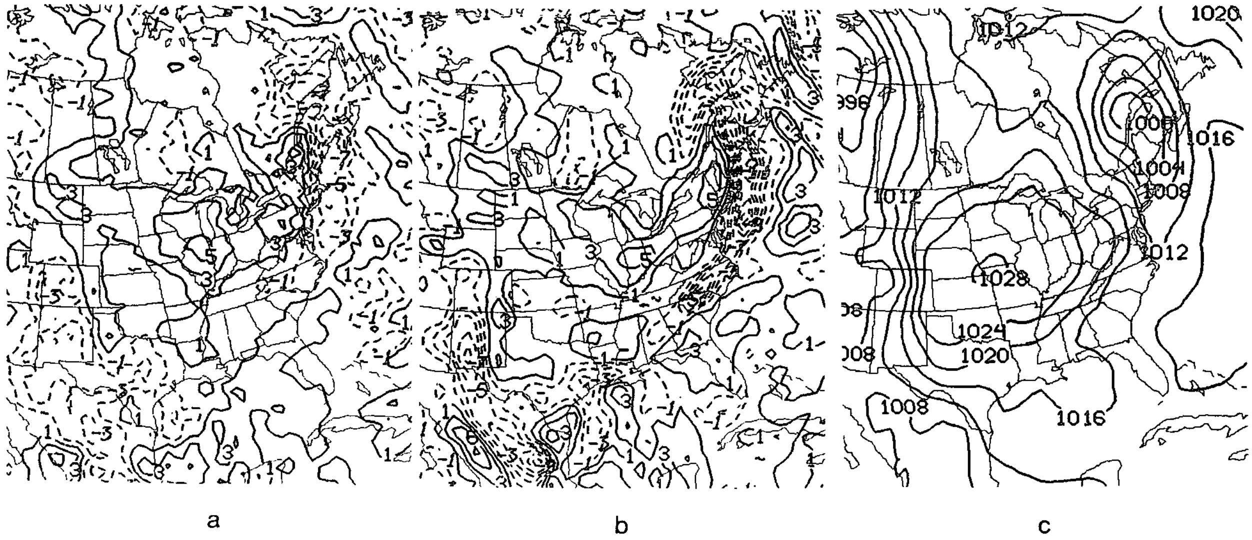


FIG. 4. Comparison of (a) operational RAFS and (b) experimental RDAS/RAFS (0-h) 700-mb vertical velocity (μb s^{-1}) fields for 0000 UTC 18 April 1990. Mean-sea-level pressure analysis (mb) shown in panel (c).

orographically forced vertical motions better defined from Colorado through Mexico, but also the patterns of rising and sinking motion along the cold front extending from Maine southward along the East Coast are more pronounced and continuous, with stronger horizontal gradients than in the operational analyses. Elsewhere, in areas of more quiescent flow, the RDAS has not introduced undesirable levels of noise into the initial conditions for the subsequent NGM forecast.

4. Results of tests with the combined RDAS and revised NGM system

The combined RDAS/NGM analysis and forecast system was tested for a 4-week period from 0000 UTC 6 April to 1200 UTC 4 May 1990. The results were compared with those from the operational RAFS. The results showed notable improvement in radiosonde station verification statistics. The improvements were more pronounced in the short-term, low-level temperature and height forecasts, and over the portion of the United States east of the Rockies, where the 850-mb height STDE was reduced from 14.4 to 14.0 m at 24 h (Table 2). Precipitation forecasts showed a lessening of spin-up effects noted in the first 6 h of the operational NGM forecast. The total volume of precipitation produced with the new system, however, was slightly less (~3%) than that from operations during the test period.

In an effort to verify that the additional information present in the higher-resolution initial analysis was being retained throughout the entire NGM forecast period and that it led to improvements in forecasts of smaller-scale features, systematic comparisons of a number of higher-order fields were also obtained. These comparisons included temperature tendency, vorticity, and vorticity advection. The RDAS/NGM system showed improvements throughout the troposphere, again with the largest benefits apparent below 500 mb. (Recall that the primary sources of asynoptic data for these tests were surface reports, along with a small number of manual aircraft reports.) For example, the 850-mb 12-h temperature-tendency skill score (Fig. 5), which can be used to judge the accuracy of local temperature-change forecasts related to frontal passages, showed a strong improvement throughout the forecast cycle. Likewise, the geostrophic vorticity correlation coefficient (Fig. 6) using the new RDAS/NGM system maintained an improvement over the operational system throughout the forecast. Even the relative humidity field (not shown) showed improved correlations throughout the forecast cycle at 850 and 700 mb.

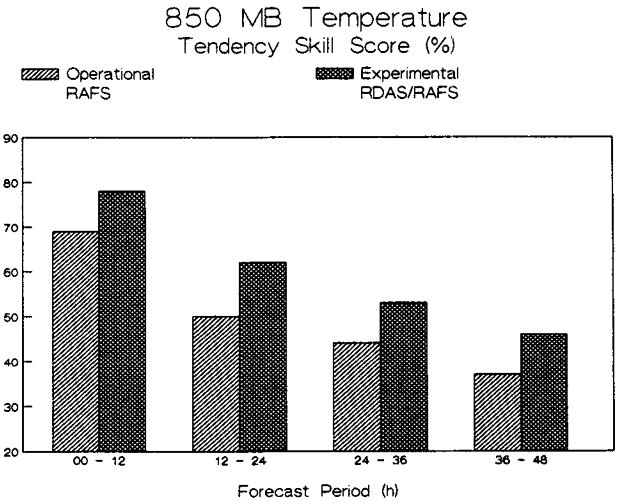


FIG. 5. Comparison of skill scores (%) of 12-h temperature tendency at 850 mb for operational RAFS and experimental RDAS/RAFS systems. Higher scores indicate superior performance.

TABLE 2. Verification of operational and experimental (RDAS plus revised NGM) 24-h RAFS forecasts of height, temperature, and vector wind against U.S. radiosonde observations east of the Rockies over the period of 0000 UTC 6 April 1990 to 1200 UTC 4 May 1990.

	Grid-to-station verification (24-h)			
	Bias		STDE	
	Operational	Experimental	Operational	Experimental
850 mb				
Height (m)	−1.9	−0.3	14.4	14.0
Temp (c)	0.5	0.4	2.1	2.1
Wind (m/s)	4.3	4.2	2.9	2.8
500 mb				
Height	1.8	1.0	17.5	17.4
Temp	0.0	−0.1	1.4	1.4
Wind	4.9	4.8	3.2	3.1
250 mb				
Height	−1.7	−4.8	28.1	27.6
Temp	0.4	0.7	1.8	1.9
Wind	7.5	7.5	5.1	5.0

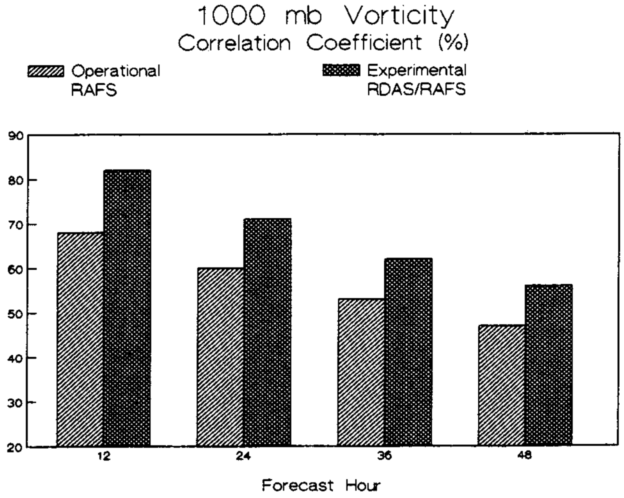


FIG. 6. Same as Fig. 5, except for correlation coefficient (%) of geostrophic vorticity at 1000 mb.

During this test period, TDL also performed a comparison of the accuracy of MOS products derived from the operational and test forecast systems, using in each the operational MOS coefficients derived from the historical RAFS data sample. These experiments, described in detail in this issue by Erickson et al. (1991), showed only minor changes in the skill of most of the forecast elements. However, an increase in the skill of the short-term precipitation forecasts was noted during the test period, consistent with the expected contribution of the RDAS to the total forecast system.

5. Summary

Over the next several years, NMC will be refocusing its short-range model development efforts from the RAFS to a new mesoscale system in support of the NWS Modernization. Prior to that time, a final set of changes are being made to NMC's Regional Analysis and Forecasting System. These include improvements in the NGM forecast model to increase the effective computational resolution, enhance orography, improve radiative processes, and improve the specification of surface processes. Improvements in the regional analysis included development of a Regional Data Assimilation System designed to provide high-resolution analyses and to utilize the new, higher temporal frequency data sets that will be available during the 1990s. Evaluations of forecasts from the new system were consistently positive, both for the direct model fields and for the statistically produced MOS guidance. A number of the changes to the forecast model and analysis were implemented operationally on NMC's Cray Y-MP in early November 1990. The remainder of the forecast model changes and the RDAS will be implemented before mid 1991.

Larger improvements in the forecast system would have been possible if the restrictions imposed by MOS had not prevented changes to the systematic performance of the forecast model. Development of statistical procedures which are not incumbered by such far reaching limitations will allow for more substantial improvement to future operation analysis and forecast systems.

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