NMC NOTES

Recent Changes Implemented into the Global Forecast System at NMC

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ABSTRACT

A number of improvements were implemented on 6 March 1991 into the National Meteorological Center's global model, which is used in the global data assimilation system (GDAS), the aviation (AVN) forecast, and the medium-range forecast (MRF):

- The horizontal resolution of the forecast model was increased from triangular truncation T80 to T126, which corresponds to an equivalent increase in grid resolution from 160 km to 105 km.
- The use of enhanced orography has been discontinued and replaced by mean orography.
- A new marine-stratus parameterization was introduced.
- A new mass-conservation constraint was implemented.
- The horizontal diffusion in the medium scales was reduced by adopting the Leith formulation.
- A new, more accurate sea-surface temperature analysis is now used.

In this note, we discuss each of the changes and briefly review the new model performance.

1. Introduction

At the National Meteorological Center, a global numerical forecast model is used for the global data assimilation, aviation, and medium-range forecasts, and is one of the most essential components of the NMC forecast facilities. Until 6 March 1991, a triangular truncation 80 (T80) global spectral model with full physics had been running operationally. The details of the model and the assimilation system were presented by Kanamitsu (1989) and the performance, application, and near-future improvements were described by Kalnay et al. (1990).

This note describes the most recent upgrades of the model, namely the increase of horizontal model resolution from T80 to T126 and several additional model physics improvements.

2. Description of changes

a. Increase of horizontal resolution

The increase in horizontal resolution from T80 to T126 truncation corresponds to an increase in the grid resolution from about 160 km to 105 km. The vertical resolution remains the same, with 18 levels. There are two major improvements expected from the resolution change in terms of model dynamics and physics. First, the orography has more detail (example over the continental United States is presented in Figs. 1a and 1b) and, accordingly, we expect more-accurate handling of dynamics and physics near rugged terrain. The details of the coastlines, including lakes, sea-ice boundaries, and boundaries of different surface characteristics over land (e.g., snow lines) should also be better represented in the high-resolution model. Secondly, smaller-scale features such as fronts and associated precipitation are handled better, both in terms of dynamics and physics.

The increase in computer time due to the increase in resolution was totally compensated by the speed and capacity of the newly installed Cray YMP 8-processor computer. The program codes were restructured in standard FORTRAN, to use parallel processors more efficiently. The radiation code was merged into the model code for better flexibility.

The analysis system was changed only by increasing the north–south resolution from 122 to 190 grid points. The east–west resolution remains as 180 grid points.

b. Use of mean orography

The use of enhanced orography (silhouette orography, Mesinger et al. 1988) has been discontinued in

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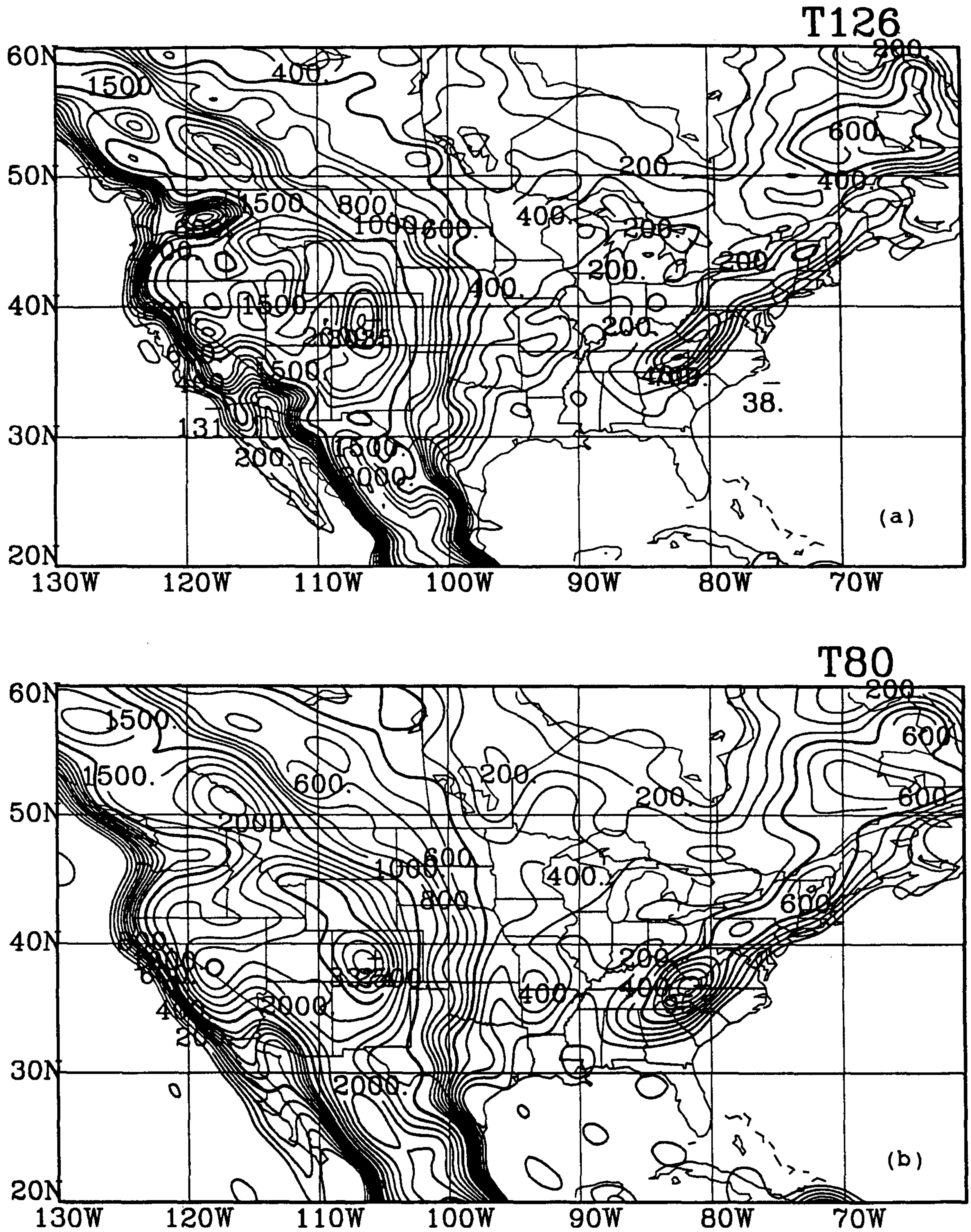


FIG. 1. Orography used in the model over the continental United States (a) for the T126 model and (b) for the T80 model. Contour interval 100 m up to 1000 m, 250 m over 1000 m.

the T126 model. Mean orography is used instead. This decision is based on the following two considerations: 1) The T80 parallel experiments performed during the summer and winter of 1989 and 1990 showed no systematic difference in 5-day forecast skill between the two orographies; 2) the new variational analysis system, which is now being tested, utilizes surface data over land (currently, surface data are not used over land). Fewer data are rejected near the terrain due to more realistic station-height values in the model guess field and, accordingly, a better analysis is produced.

Because of the use of mean orography in the T126 model, terrain heights are generally lower (by about 600 to 1000 m over the Rockies—compare Figs. 1a and 1b).

c. *Marine-stratus parameterization*

Clouds in the present model act only to modify radiative fluxes through the processes of absorption, emission, and reflection/scattering. Stratiform clouds are modeled in high, middle, and low cloud domains, and their fractional coverage is computed as a quadratic function of layer relative humidity (RH) wherever the RH exceeds a critical threshold (as in Slingo 1987). Within each domain, the cloud top is chosen as the cloudiest layer within the domain and the cloud is generally one model layer thick (Campana et al. 1989). Prior to 6 March 1991, the cloud scheme did not search the lowest 10% of the model atmosphere for possible clouds, because strong longwave (LW) cloud-top radiational cooling in the thin model layers would be detrimental to the forecast. In order to reduce the magnitude of the LW cooling in the lower atmosphere, clouds were required to be at least 90 hPa thick, thereby encompassing several model layers. Low-level marine stratus of the west coast of continents was therefore not well simulated.

The cloud scheme implemented with the T126 model relies on the ability of the forecast model to produce a realistic well-mixed layer topped by dry subsiding air above a low-level inversion in regions that

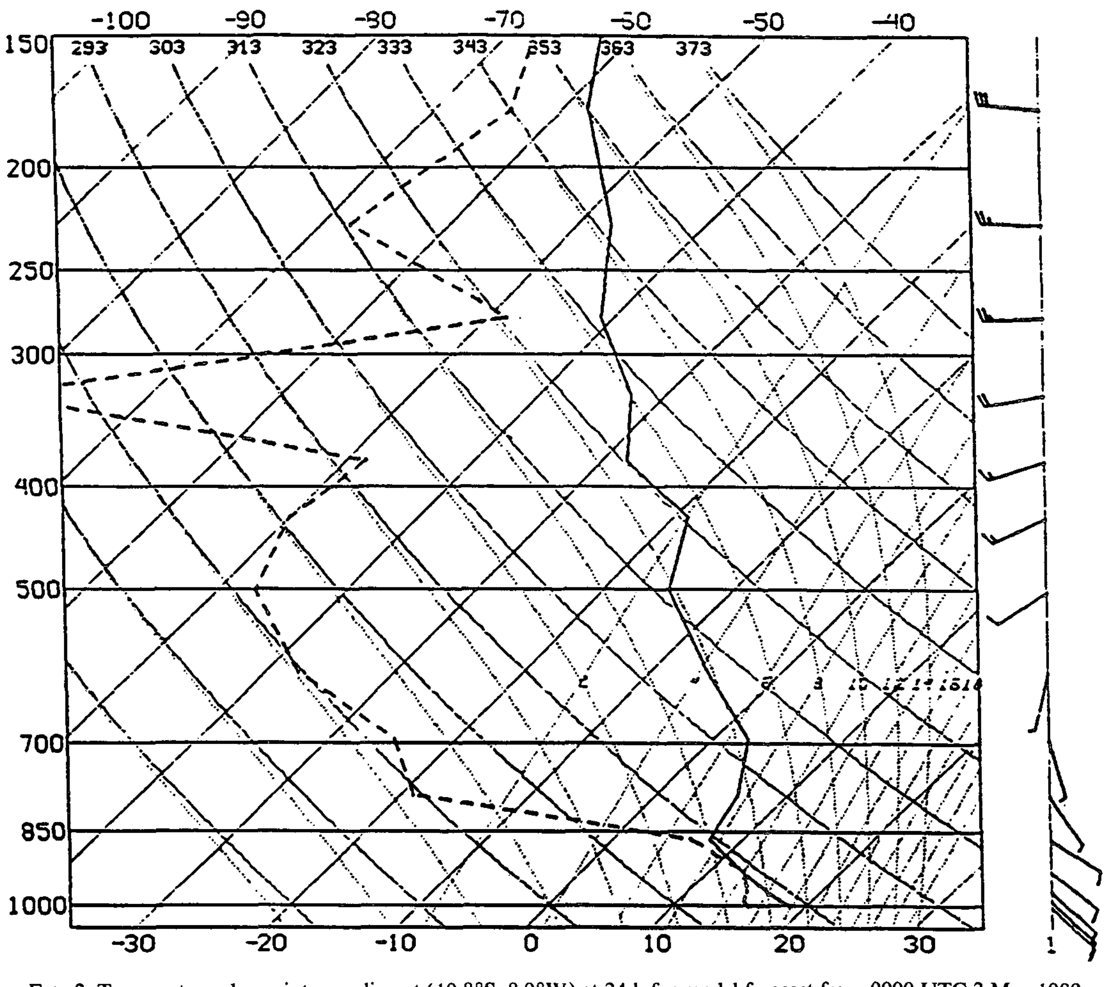


FIG. 2. Temperature–dewpoint sounding at (19.8°S, 8.9°W) at 24 h for model forecast from 0000 UTC 2 May 1989.

are climatologically favorable to marine stratus (Fig. 2). There is ample model moisture beneath these inversions, so it is possible to determine the regions where marine stratus are likely. In those regions we then use the current cloud-fraction-versus-RH relationship in the lowest 10% of the atmosphere (excluding the surface layer). This low-atmosphere search occurs only if a "gridpoint": 1) is over ocean, 2) has a sufficiently strong model-level inversion (0.05 K/hPa), and 3) is capped by dry air. Since these clouds are not frontal in nature, vertical motion is not employed as a condition for the presence of clouds. Furthermore, model-generated marine stratus is thickened upward through sufficiently moist layers to the model inversion base.

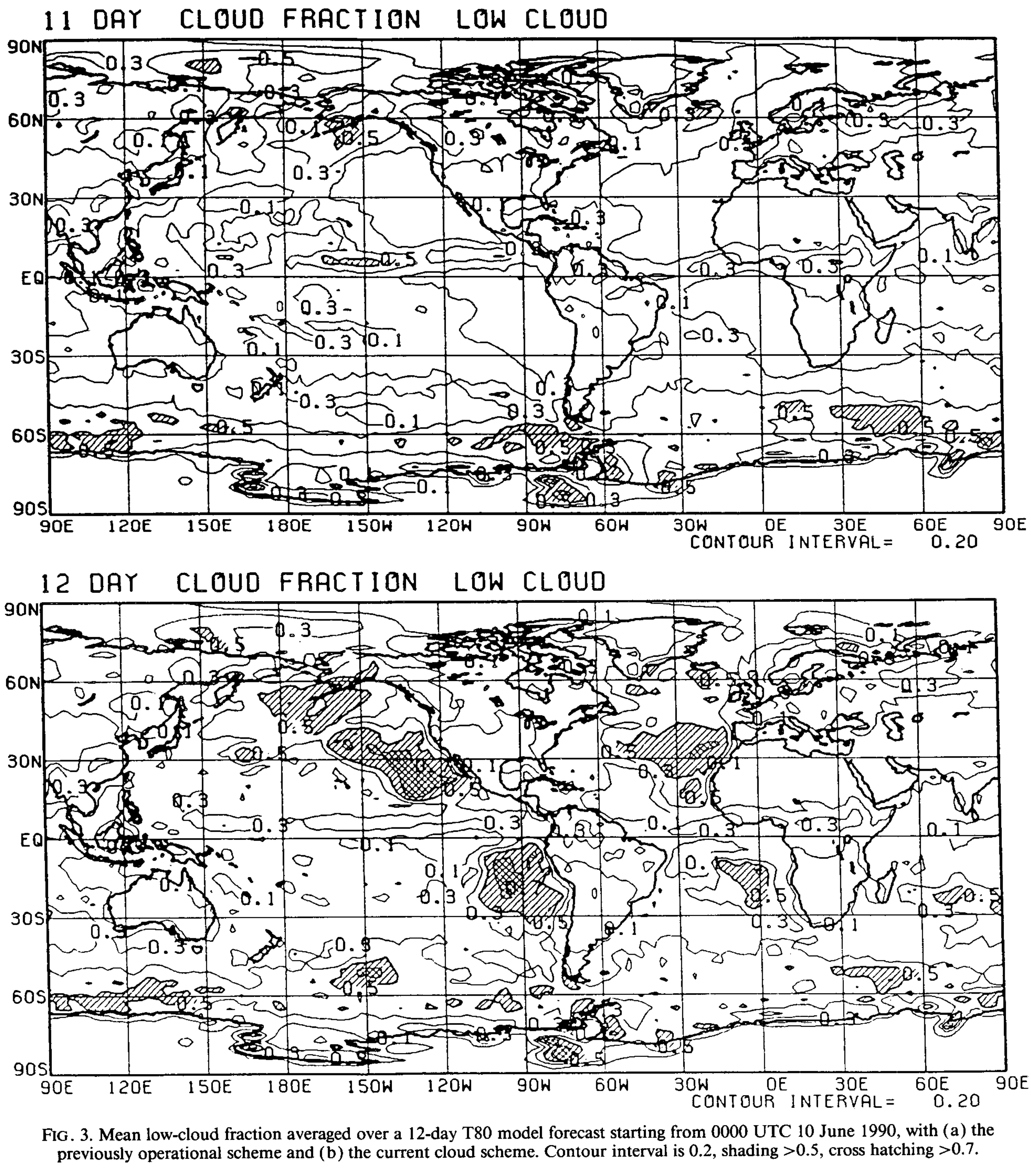


FIG. 3. Mean low-cloud fraction averaged over a 12-day T80 model forecast starting from 0000 UTC 10 June 1990, with (a) the previously operational scheme and (b) the current cloud scheme. Contour interval is 0.2, shading >0.5, cross hatching >0.7.

Comparison of mean low-cloud fraction for a T80 12-day forecast, using the previous cloud scheme (Fig. 3a) and the current formulation (Fig. 3b), shows that the latter realistically depicts marine stratus in regions where it is expected climatologically. The impact of the marine stratus on the synoptic forecast is small; the anomaly correlations between the above two forecasts at 500 hPa are quite high (0.99 at day 7; 0.90 at day 12). This is not unexpected, as the new clouds are confined to subtropical ocean regions, where surface temperatures are held fixed, and thus there is no surface radiative feedback.

d. Introduction of a mass-correction time scheme

The spectral method is known to be quite accurate in maintaining conservation of mass, momentum, and energy in the analytic equations. However, we discovered that the mass in the model gradually decreases with a rate of about 2 hPa in 30 days in the T80 version of the model. This problem was traced to the use of split physics introduced in 10 August 1989, combined with the semi-implicit integration of gravity waves. A scheme to correct semi-implicit mass, divergence, and temperature tendencies by taking into account the changes due to the model physics was developed and tested. The scheme reevaluates the semi-implicit tendency due to physics changes, which is equivalent to combining the dynamics and physics parts of the model without splitting them. The new scheme reduced the loss of mass to a negligible amount. The impact of the scheme on the forecast is not very large, but through the correction of divergence, a slight increase in convective activity was observed. This improvement is important for the application of the operational model to climate and long-range forecast problems.

e. Reduction of horizontal diffusion in the medium scales

Various diagnostic studies of the NMC global model have indicated a loss of wave energy with time. The loss is most prominent in the medium scales, which correspond to total wavenumber 10 to 40. One of the major causes of this loss has been found to be in the use of the del-4 horizontal diffusion formulation. The del-4 diffusion is used worldwide due to its good scale selectivity, but it has been shown that the scale selectivity is not sufficient for the NMC model. Furthermore, the scheme lacks a physical foundation. For these reasons, the scheme developed by Leith (1971) was tested and implemented. This Laplacian-type scheme, based on turbulence theory, defines a limiting wavenumber above which no diffusion is allowed:

$$-\eta^{1/3}A\left(\frac{n-n_0}{n_k}\right)^{\beta} \quad \text{for} \quad n \geqslant n_0$$

$$0 \quad \text{for} \quad n < n_0.$$

For the NMC model application, the following values of the parameters were used:

$$A = 4$$

$$\beta = 2$$

$$n_0 = 0.55 \times 126$$

$$n^* = 126$$

$$\eta = 848 \times 10^{-15}.$$

The value of η is obtained by equating the dissipation time scale of the smallest scale of the T126 model to that of the T80 model, and is three orders of magnitude larger than the values used in the general circulation model by Boer et al. (1984). This inconsistency with the other study is partly due to the inapplicability of simple two-dimensional turbulence theory to a very high resolution primitive equation model with full physics.

With the use of the new formulation, the loss of energy in the medium scale has been reduced by roughly 30% to 50%. According to a recent kinetic energy budget study, the remainder of the kinetic energy loss is due to the lack of sufficient potential energy sources in these scales. Further research to attack this problem is in progress.

f. Other changes to the physics

When the horizontal resolution is increased, the magnitude of some of the prediction parameters increases significantly because the model is able to resolve smaller scales. The most dramatic increase was seen in the magnitude of the convergence, which increased the precipitation to an unrealistic level. After extensive testing of the high-resolution model with the above mentioned changes, we increased the threshold moisture convergence for convective precipitation from 2×10^{-6} gm/gm/sec to 6×10^{-6} gm/gm/sec, which reduced precipitation to a reasonable amount.

In the course of testing the high-resolution model, it was discovered that the gravity-wave drag parameterization may lead to numerical instability in special cases when the deceleration by the gravity-wave drag in one time step exceeds the wind speed at that time. This is purely a numerical instability problem, and a simple constraint was introduced to prohibit the deceleration in a single time step from exceeding the current wind speed. The impact of the change in the forecast was shown to be very small because this situation occurs very rarely in the model.

3. Use of new sea-surface temperature analysis

The sea-surface temperature is taken from the new SST analysis implemented on 20 February 1991 (Reynolds 1991). The new SST analysis has an effective horizontal resolution of about 2°, and a temporal resolution of a week. It is based on optimal interpolation, using persistence as a first guess. It replaces the previous operational "blended" analysis, which had an effective resolution of about 5°, and a 2-week temporal average.

4. Comparison of the T126 versus T80 model

The T126 was tested in parallel to the T80-version operational model for five months. Each model was

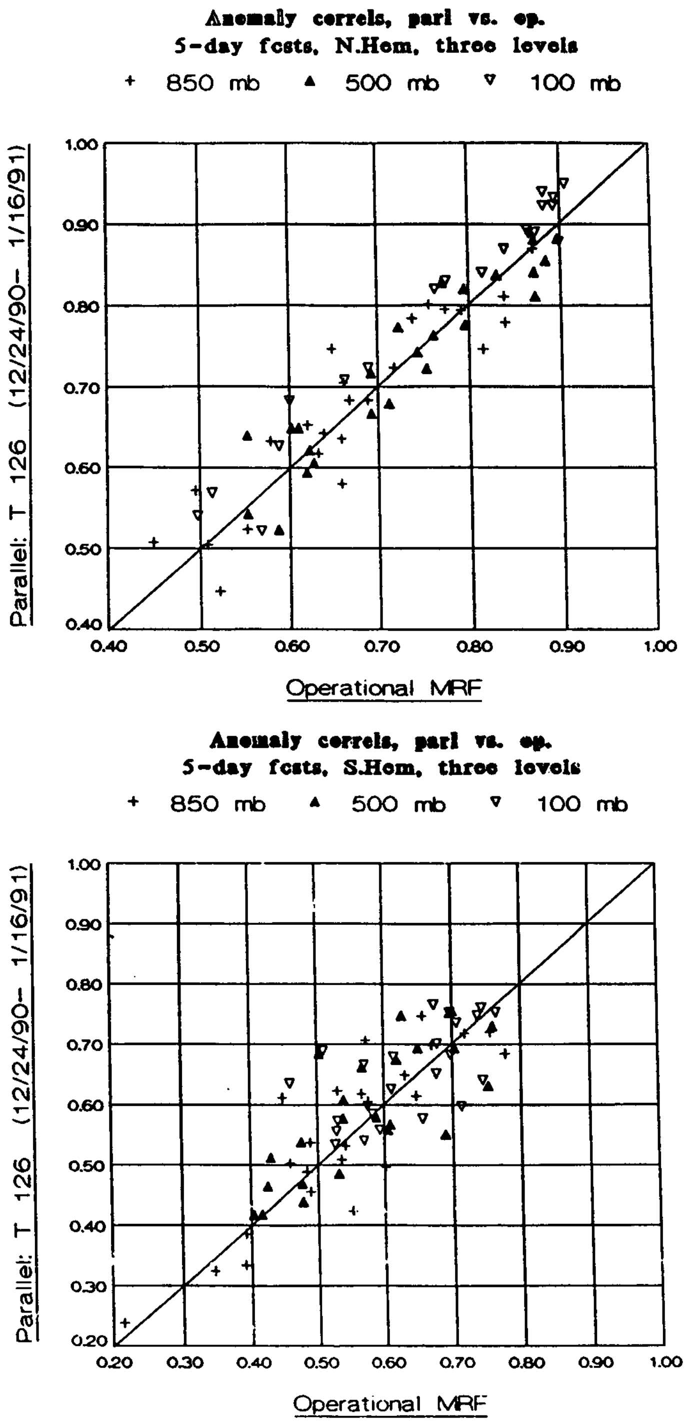


FIG. 4. Scatter diagram of forecast anomaly correlation of heights from T80 vs T126 models at 850, 500, and 100 hPa, (a) latitudes 20°–80°N and (b) latitudes 20°–80°S. Cases are from 24 December 1990 to 16 January 1991.

part of a complete forecast system including data assimilation. The results shown in the scatter diagram (Figs. 4a and 4b) include only 24 days, but are typical of the whole testing period. At 1000 and 500 hPa, the two models produce very similar anomaly-correlation scores for five-day forecasts outside the tropics. At 100

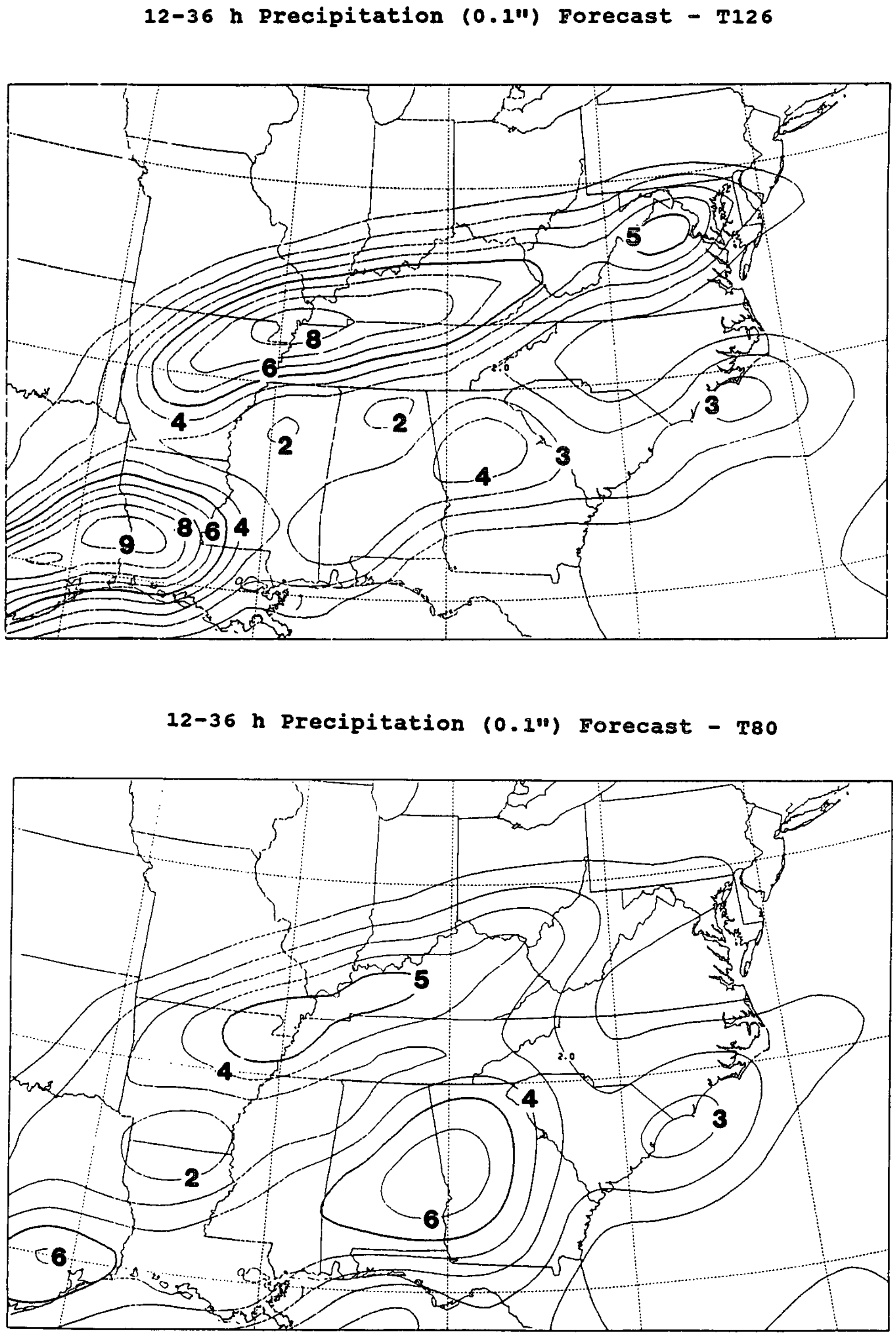
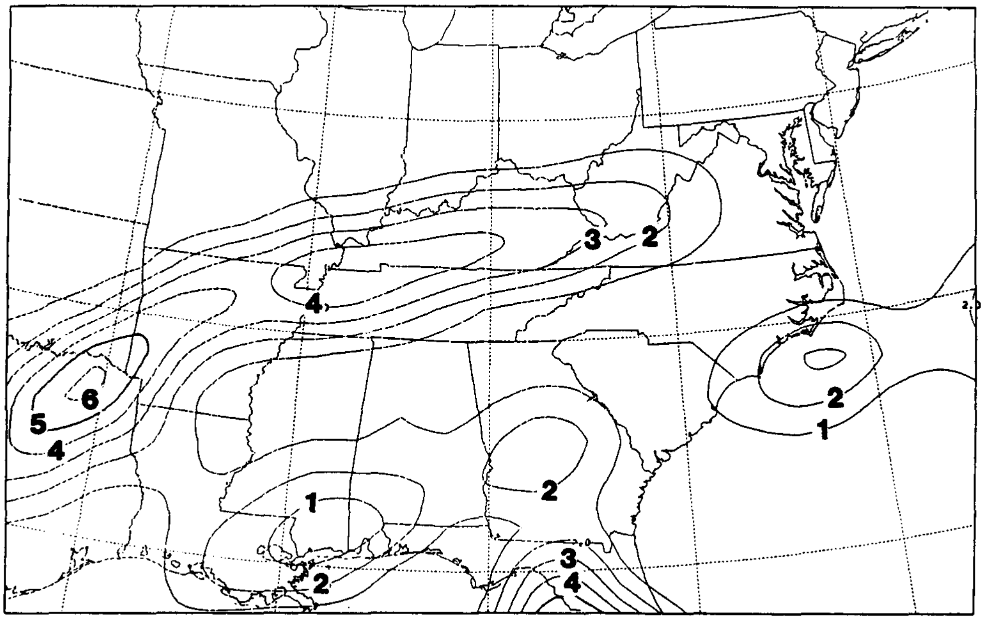
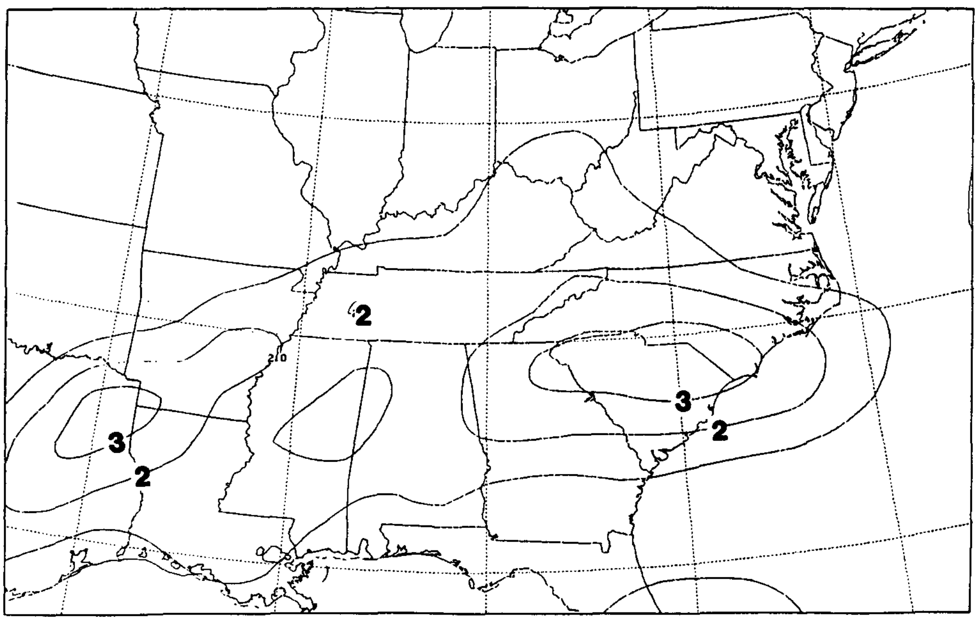


FIG. 5. The 12- to 36-h precipitation predicted by the T126 model (a) and that for the T80 model (b) over the eastern United States. Initial state is from 6 January 1991. Contour interval is 0.1″.

36-60 h Precipitation (0.1") Forecast - T126



36-60 h Precipitation (0.1") Forecast - T80



0000 UTC Initial: January 5, 1991

FIG. 6. As in Fig. 5, except for the 36- to 60-h forecast.

hPa, the T126 is better in both hemispheres. Both models were verified against the operational (T80) analysis.

While the higher-resolution model does not appear to be much of an advantage when evaluated with standard objective scores like the anomaly correlation, (which gives more weight to larger scales), the T126 model nevertheless was found in subjective tests by operational forecasters to be much more useful in producing meteorologically realistic fields. For example, for the 12–36-h forecast from 0000 UTC 6 January 1991 (Fig. 5a and b), the T126 produced not only more rainfall, but gave much more detailed structure and a better forecast (observed rainfall is shown in Fig. 7). This is even more dramatically evident in the 36–60-h forecasts (Fig. 6a and 6b) initialized at 0000 UTC 5 January 1991.

The objectively determined behavior of the precipitation forecast from the two models in a sample of 36 winter cases in the eastern United States is shown in Fig. 8. The fraction of the total area for which precipitation in excess of 0.1″ or 0.5″ was either forecast or observed is shown, along with the area in which the forecast was correct. For the smaller amount, the threat scores (not shown) were 0.402 and 0.393 for the T80 and T126 models, respectively, with biases of 1.02 and 1.13. For the 0.5″ threshold, the threat scores were 0.240 and 0.293 for the T80 and T126, with biases of 0.62 and 0.73. The higher-resolution model seems to be about comparable to the T80 at the lower threshold and noticeably better for the higher threshold. It is noted that threat scores computed for higher resolution tend to be penalized by the more detailed structure of the forecast precipitation area.

There are some changes to model systematic error, namely a reduction in the tropical temperature bias (Fig. 9). The use of a higher-resolution mean orography results in some changes in the regional biases. Elsewhere, except in the tropics, little change in the model bias has been noted.

5. Summary and future plans

The horizontal resolution of the NMC operational global spectral model was increased from T80 to T126 on 6 March 1991. Several improvements to the physics

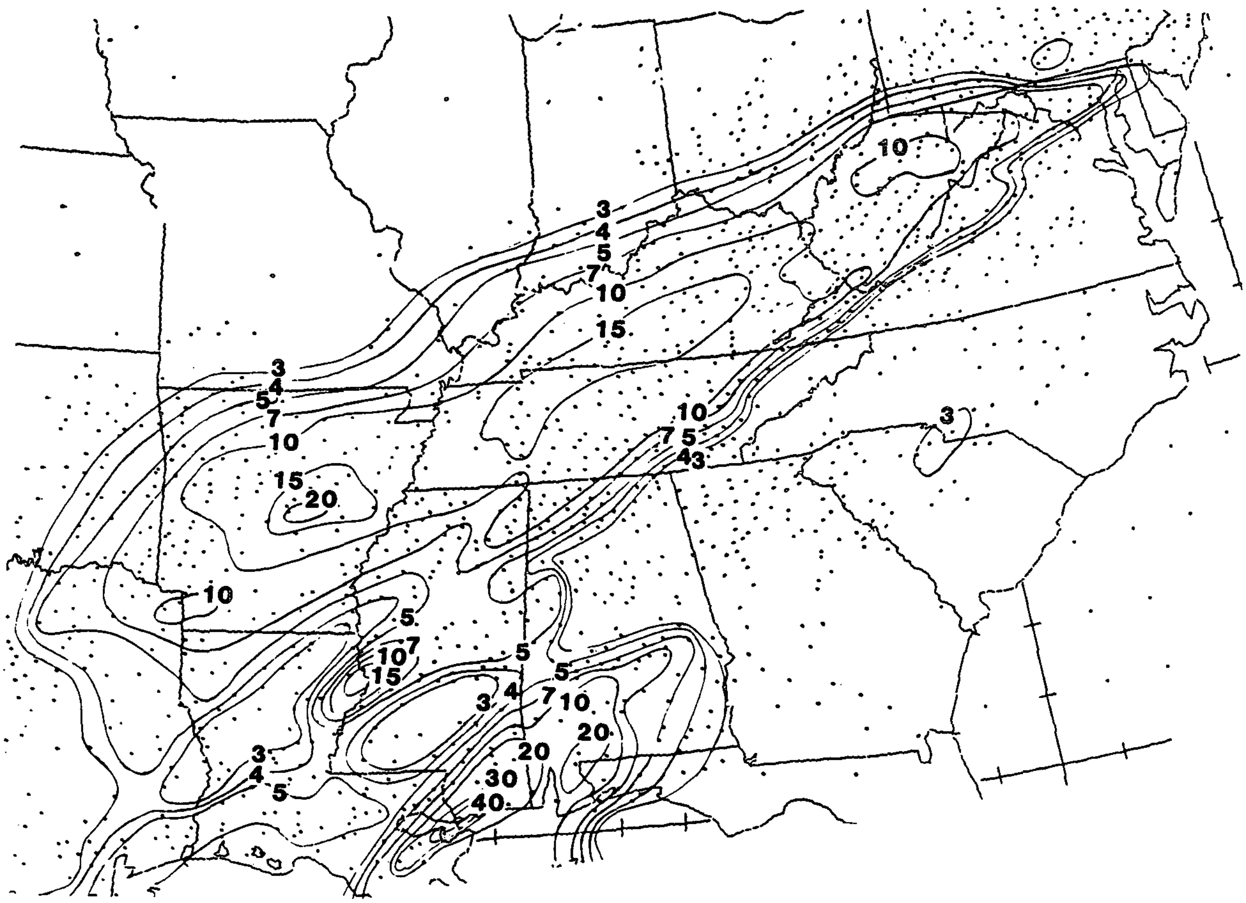


FIG. 7. Observed 24-h precipitation, 1200 UTC 6 January 1991–1200 UTC 7 January 1991. Units are tenths of an inch.

and numerics of the model were also incorporated at the same time. The new model produces very realistic and finer-scale forecasts in the 2–3-day range, but the objective large-scale scores are not much affected. Due to the changes in physics and numerics, the model now reproduces subtropical marine stratus very well, conserves mass, and is better in maintaining the kinetic energy of the medium scales.

Two major changes in the global system are currently planned for this year. The first one, planned for the spring of 1991, is the replacement of the analysis scheme, from the conventional Optimum Interpolation (OI) to Spectral Statistical Interpolation (SSI) developed by Parrish and Derber (1991). The new scheme has a number of advantages over the current conventional OI: 1) the entire global three-dimensional dataset is used at the same time, thus eliminating data selection; 2) explicit handling of scales by analyzing spectral coef-

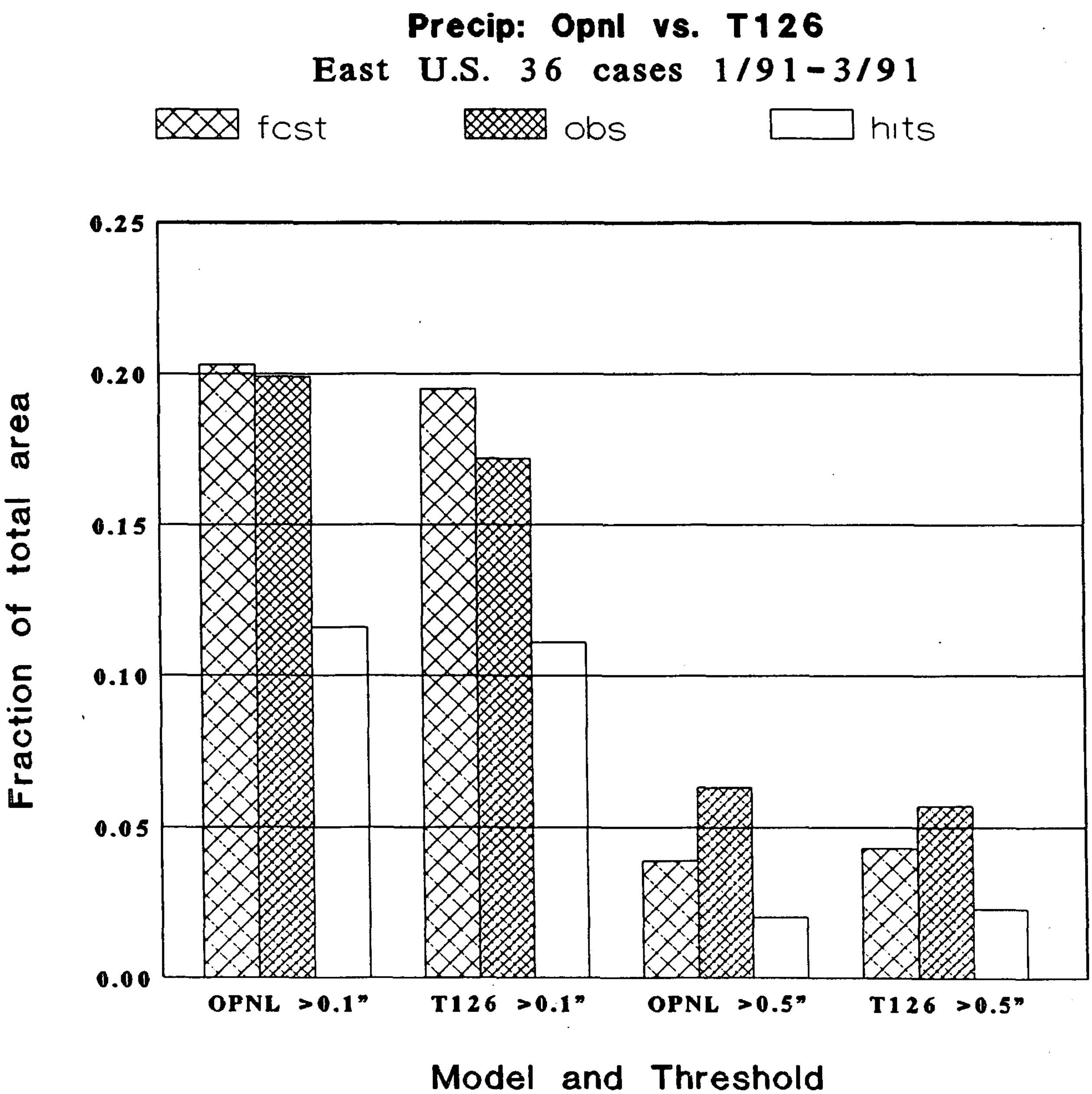


FIG. 8. Precipitation verification for the T80 and T126 models over the eastern United States, averaged over 36 cases from January to March 1991.

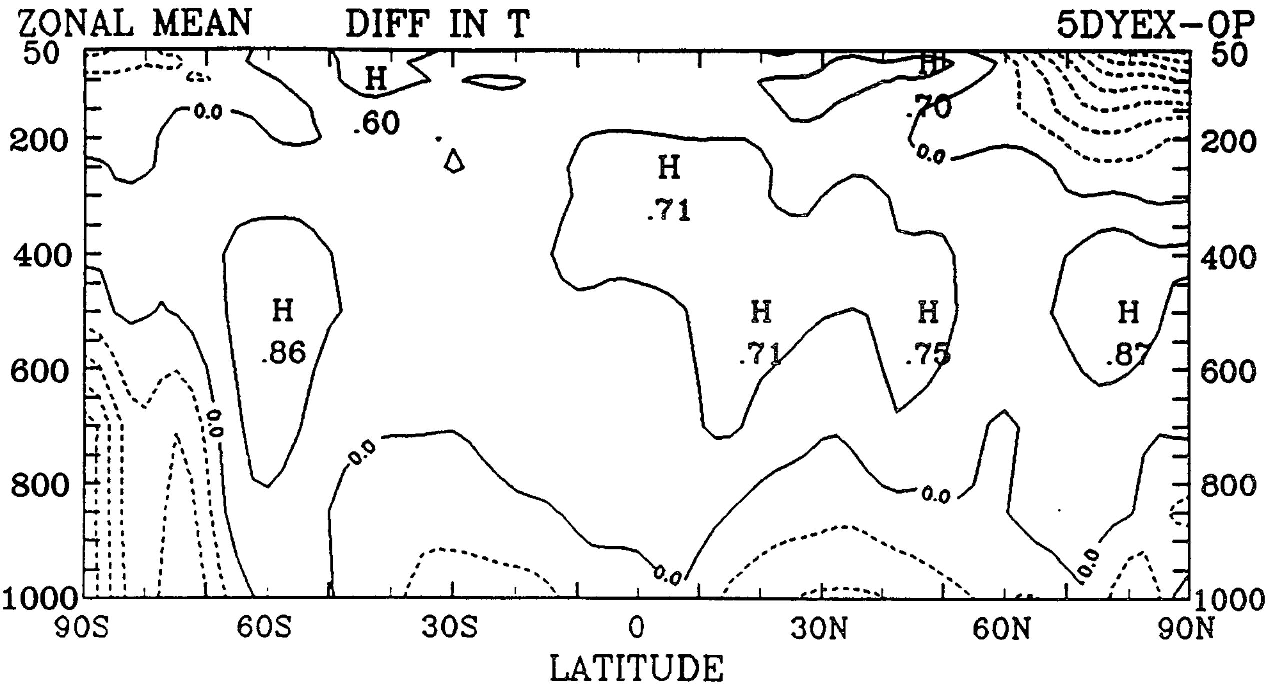


FIG. 9. Latitude-pressure cross section of zonally averaged temperature difference between T80 and T126 at forecast day 5. Contour interval is 0.5 K. Note the 0.7 K warmer tropical troposphere in the T126 runs, which reduces bias in the tropics.

ficients; 3) direct analysis on model sigma levels; 4) better balance between mass and motion; and 5) flexibility in incorporating complex relations among the analysis and observed variables. The scheme has been tested in a parallel mode for the last several months and has proved to produce much better forecasts, more consistent analyses, and a substantial decrease of the spinup problem.

The second change, planned for the winter of 1991, is to increase the number of model levels from 18 to 28. Most of the additional levels will be placed near the tropopause and in the stratosphere. In addition to the change in the number of levels, the frequency of the radiation calculation may be increased from the current 12 h to 3 or 6 h. Additional improvements in numerics and physics are also planned at the same time.

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