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# NORMAL MODE INITIALIZATION OF THE NESTED GRID MODEL OF THE METEOROLOGICAL CENTER

James E. Hoke, Norman A. Phillips, and Joseph G. Sela
National Meteorological Center

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## NORMAL MODE INITIALIZATION OF THE NESTED GRID MODEL OF THE NATIONAL METEOROLOGICAL CENTER


James E. Hoke, Norman A. Phillips, and Joseph G. Sela

National Meteorological Center, NWS, NOAA
Washington, DC


### 1. INTRODUCTION

Work is underway at the National Meteorological Center to improve the numerical analysis and forecast system in preparation for the scheduled upgrade of computational capability this year. Under the new system, very high priority will be given to improving operational forecasting of major precipitation events. One of several numerical models under consideration to supplement the Limited-area Fine-mesh Model (LFM) in this effort is the NMC Nested Grid Model (NGM). In this paper we will describe our efforts to overcome a key hurdle in implementing a regional-scale forecast model such as the NGM--initialization.

The application of normal mode initialization to regional-scale models has been studied recently at NMC. Investigation has followed two paths. One approach involves determining the normal modes of the regional-scale model itself. In the second, normal mode initialization of a global or hemispheric model provides the initial conditions for the regional-scale model. Discussion of the latter approach will be presented here.

Our experimental procedure, including description of the analysis and initialization steps, is provided in the next section. Section 3 details the results of the experiments, with concluding remarks in Section 4.

### 2. EXPERIMENTAL PROCEDURE

Two 48-h forecasts were made with NMC's Nested Grid Model. The initial conditions for both forecasts were derived from the Presidents' Day storm case of 1200 GMT 18 February 1979. Equatorial boundary conditions consistent with those of the NGM were then applied, followed by a hemispheric normal mode initialization. Finally, one forecast was made from the fields before the normal mode initialization and one following the initialization.

### 2.1 Structure of the Model

The NGM is a grid-point, primitive-equation model that explicitly forecasts surface pressure and the pressure-weighted potential temperature, velocity, and specific humidity. The original version of the NGM has been described by Phillips (1979). In the vertical, meteorological variables are staggered in a sigma system in a manner based on that of Arakawa (Arakawa et al., 1974). Geopotential and pressure-weighted potential temperature, velocity, and specific humidity are located in the middle of layers, whereas vertical velocity and vertical fluxes are carried at the interface of layers.

The NGM uses the Eliassen (1956) method of horizontal and temporal staggering of variables in conjunction with two-step, second-order Lax-Wendroff finite differencing. Thus, at any forecast time the variables are staggered horizontally as in the Arakawa D grid (Arakawa, 1972). This system of discretization has the benefits of slight damping and reasonably good phase speeds for the gravity and geostrophic modes. It also has no computational modes. A major disadvantage, of course, is that about twice as many arithmetic calculations as in the leapfrog scheme are required to advance one full time step.

Model physics currently includes bulk aerodynamic formulations for surface fluxes, vertical eddy transport of the Fickian-diffusion type, and large-scale precipitation processes. A modification of the Kuo (1965) scheme is used to simulate cumulus convection. A dry adiabatic adjustment, in which dry enthalpy of a column is preserved, is performed when super-adiabatic layers develop. Currently, there are no radiative processes and no evaporation of falling large-scale precipitation.

For the current experiment the NGM was run in a 3-grid configuration (Figure 1). The outermost grid was hemispheric, and each interior grid had twice the resolution of the grid surrounding it. The grids were two-way interacting. Resolution of the innermost grid was 99 km at 45°N. Twelve layers were used to resolve the vertical structure.

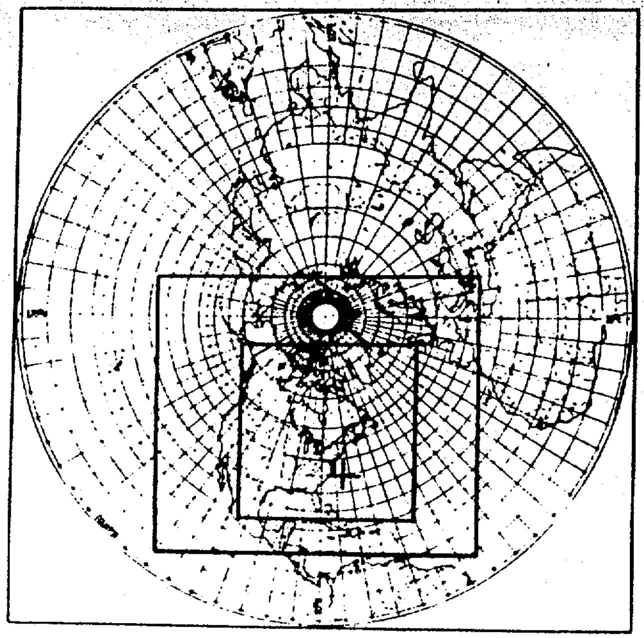


*Figure 1. The forecast domains for the three-grid configuration of the NGM for this study. The outer grid was hemispheric. Resolutions of the outer, middle, and inner grids were 396 km, 198 km, and 99 km, respectively, at 45°N. The X in the western Atlantic is the location of the grid point whose surface pressure traces are shown in Figure 2.*

## 2.2 Analysis

The data case was that of 1200 GMT 18 February 1979. At that time the Presidents' Day storm was rapidly developing into a heavy snow producer along the East Coast of the U.S. The case was also within a Special Observing Period of the Global Weather Experiment. The observations were analyzed by a global, multivariant optimum interpolation to the middle of the 12 sigma layers of the NGM. The resultant analyses of wind by zonal and meridional components, virtual temperature, specific humidity, and surface pressure were represented in the spherical harmonic form of the NMC Spectral Model (Sela, 1982). Horizontal resolution was that of wave number 30 rhomboidal truncation. The analysis at 1200 GMT 18 February 1979 was part of a data assimilation system that used the FGGE IIb observational data set starting from 1200 GMT 14 February 1979. Analyses were performed with data at 6-h intervals and using 6-h forecasts of the Spectral Model for the first guesses.

## 2.3 Application of Lateral Boundary Conditions

The lateral boundary of the NGM is located just south of the equator. The boundary conditions there are not specified by the forecasts of a large-scale model, but from equatorial symmetry considerations. Variables such as terrain, temperature, specific humidity, surface pressure, and zonal wind component (but not meridional wind component) are required to have even symmetry at the equator. That is, the latitudinal variation of these quantities must be zero at the equator. The meridional wind component, on the other hand, is required to be zero at the equator, thereby eliminating cross-equatorial flow. Another effect of these boundary conditions is to impose irrotational flow at the equator. The same equatorial symmetry conditions were applied to the global optimum-interpolation analyses, and the resultant fields than horizontally interpolated to the NGM grid points.

## 2.4 Normal Mode Initialization

Nonlinear normal mode initialization with a hemispheric version of NMC's Spectral Model provided the initial fields for one of the NGM forecasts. Although the normal modes of a hemispheric (or global) spectral forecast model are different from those of a limited-area grid-point model, we hypothesized, if the basic dynamics and physical processes of the two models are similar, that a satisfactory initialization could be achieved. The Spectral Model in the study had 30-wave resolution with rhomboidal truncation and 12 vertical layers. A first-order Baer-Tribbia initialization for all 12 vertical modes was employed. The method consists of removing gravity wave noise from the analysis, followed by one iteration of Machenhauer's procedure, with an extra iteration for the external mode. To avoid vertical interpolation and the uncertainties it introduces, for the purpose of this experiment the 12 layers of the Spectral Model and the NGM were identical. The terrain used in the initialization with the Spectral Model was the same as for the NGM forecast. The initialized fields and the terrain were horizontally interpolated to the NGM grid points. The 48-h NGM forecasts with and without initialization were made next.

## 3. RESULTS

We assessed the impact of the normal mode initialization by studying the differences in the two 48-h forecasts. Forecast A proceeded from fields produced by the optimum interpolation analysis followed by the application of the equatorial symmetry condition. The fields produced by the normal mode initialization of these symmetric fields were the initial conditions for Forecast B.

The evaluation consisted of three parts: 1) a comparison of the external gravity wave, 2) a subjective comparison of the forecast charts, and 3) a comparison of grid-to-station verification statistics for the two forecasts.

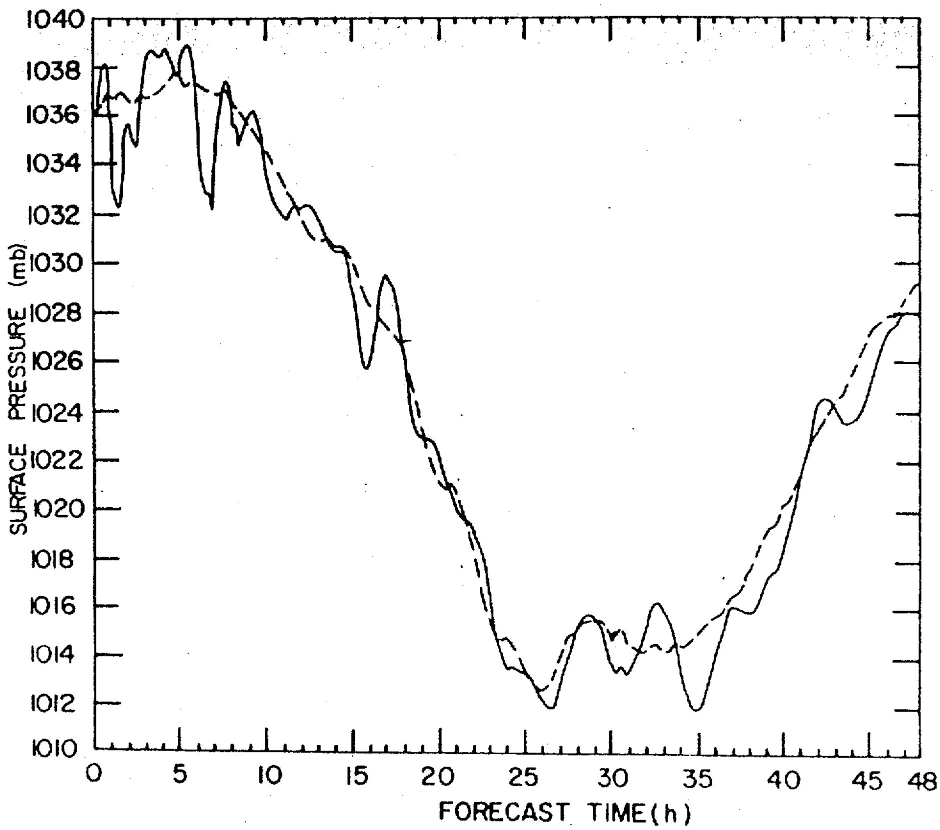



*Figure 2. Variation in the surface pressure at a grid point near Cape Hatteras during forecasts of the NGM: (a) forecast not preceded by normal mode initialization (solid line) and (b) forecast preceded by normal mode initialization (dashed line). Location of the point is indicated in Figure 1.*

### 3.1 The External Gravity Wave

An improper balance between the fast and slow modes of a numerical forecast model will lead to the propagation of the fast modes (Leith, 1980), including the external gravity wave. Truncation error originating in the pressure-gradient-force terms of sigma coordinate models is one source of the external gravity wave mode, which can have impulses exceeding 6 mb in the time variation of surface pressure (Hoke, 1982). This problem is exacerbated by steep terrain and a sharp tropopause.

Figure 2 shows the impact of the normal mode initialization on the external gravity wave. The figure indicates the variation in surface pressure at a grid point at 35.2°N, 72.4°W, which is near Cape Hatteras. The surface pressure dropped about 25 mb through the first 26 h of the forecast as the East Coast storm intensified. A moderate-strength high moved in during the second half of the forecast as the storm headed off across the North Atlantic.

In the forecast without initialization there were large variations in surface pressure during the first 10 h. The pressure dropped by about 6 mb in the second hour, then increased by 7 mb in the third hour, followed by a drop of 7 mb in hour 6 and an upward jump of 5 mb in hour 7. The likely primary source of these oscillations was the truncation error in the pressure-gradient-force terms over the Rocky Mountains.

The 4-mb impulse around 15 h was caused by the arrival of the external gravity waves generated in the Himalayan region. These disturbances propagated in all directions from their source region, reflected off the equatorial boundary, and then reinforced each other over the U.S. at about this time into the forecast. Additional impulses, including one of 4.5 mb around 32 h and 1 mb around 43 h, are apparent in Figure 2.

The other curve in Figure 2 is the surface pressure trace for the forecast following normal mode initialization. The short-period oscillations of the uninitialized forecasts were of no consequence in the initialized forecast. The largest transient oscillation is only about 0.5 mb. Thus, the normal mode initialization was very successful at reducing the external gravity wave.

### 3.2 The Forecast Charts

The two 0-48 h forecasts were compared as displayed on the conventional LFM 4-panel chart. We found that the normal mode initialization did make some noticeable changes to the mass analyis. Figure 3 contains the mean-sea-level pressure and 1000/500-mb thickness fields before and after initialization. The initialization filled many of the lows, by as much as 5 or 6 mb. The intensity of the highs was not significantly altered, although the ridge extending southward through the central U.S. was weakened by initialization, as evidenced by the 1032-mb isobar. The 1000/500-mb thickness was slightly altered by the initialization. In general, according to the height fields, the intensity of the low pressure systems was weakened at all levels. Inspection of the wind fields revealed wind speed changes up to 10 m/s at several levels. Although this was of the order of 10-15% of the mean wind speed above the lowest model layer, it was a significant fraction of the mean speed for the lowest layer.

Although the initialization made some large changes to the initial conditions for the forecasts, the differences between the forecasts were, in general, small. In most cases, the lows weakened by the initialization were as deep or nearly as deep as those in the uninitialized case by 12 h. By 24 h the two forecasts were very similar in almost all respects. The most apparent differences were in the precipitation forecasts, with the biggest differences occurring in the accumulated precipitation from 12-24 h (Figure 4). Nevertheless, this figure shows that the areal coverage of precipitation was very similar in both forecasts. Amounts were similar, with the major exception being in the Presidents' Day storm itself. Although double maxima were predicted in both model runs, the initialized forecast emphasized the southern maximum more. The difference in 12-h accumulated precipitation there was about 0.6 inch.

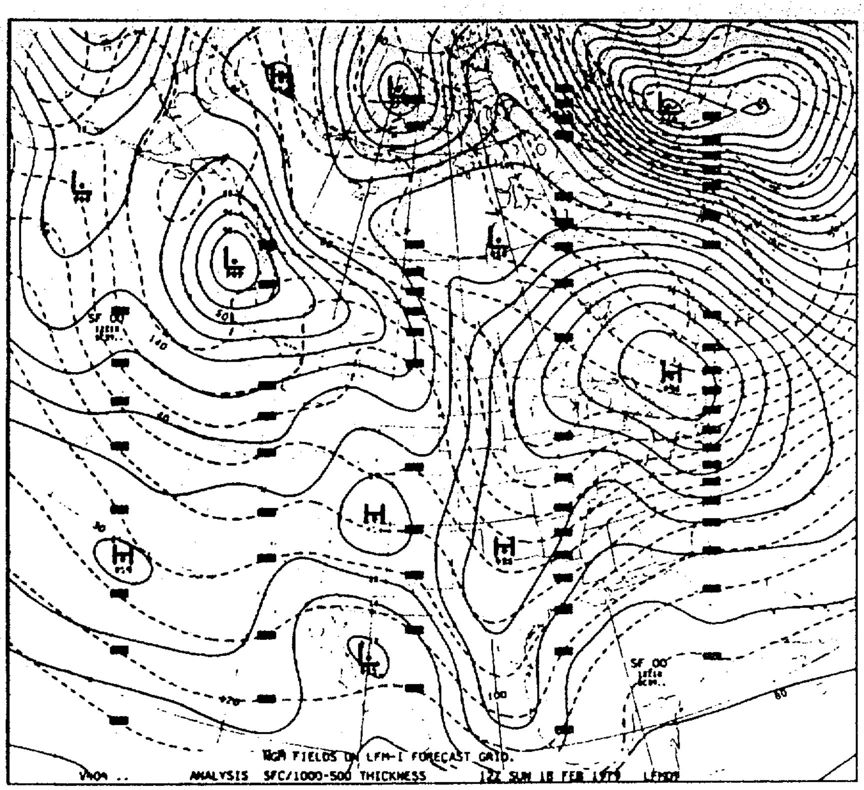
### 3.3 Error Statistics

The forecasts with and without the normal mode initialization were compared with the actual observations of the 110-station North American verification network used at NMC. Results for several forecast fields are presented in Table 1. Verifying observations were only available for the first 24 h of the forecasts. The differences between the two forecasts were of mixed sign and, for the most part, small. The S1 scores for the mean sea level pressure was a little better for the initialized forecast, but the 850-mb temperature statistics were nearly identical in the two runs. The errors in the initialized 500-mb height field were much less than for the uninitialized case, but the differences greatly decreased during the forecast. Finally, the magnitude error in the 250-mb velocity was a little worse in the initialized case.

Table 1. S1 score and mean and standard deviation error statistics for the uninitialized forecast (Forecast A) and the initialized forecast (Forecast B). The initial data time was 1200 GMT 18 February 1979.

| Forecast Variable | | Forecast Time | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0 h | | 12 h | | 24 h | |
| | | A | B | A | B | A | B |
| mean sea level pressure | S1 | --- | --- | 48.0 | 44.4 | 50.9 | 49.6 |
| 850-mb temperature (°K) | mean | 0.3 | 0.4 | -0.5 | -0.5 | 0.2 | 0.2 |
| | s.d. | 3.1 | 3.0 | 2.5 | 2.5 | 2.8 | 2.8 |
| 500-mb height (m) | mean | -13.9 | -7.8 | -7.6 | -7.4 | 8.9 | 5.9 |
| | s.d. | 17.3 | 12.7 | 18.3 | 17.4 | 20.3 | 20.5 |
| 250-mb wind vector (m/s) | mean | 6.3 | 6.9 | 5.5 | 5.5 | 8.9 | 9.2 |
| | s.d. | 3.5 | 4.2 | 3.7 | 3.6 | 6.2 | 6.7 |

(a)




(b)

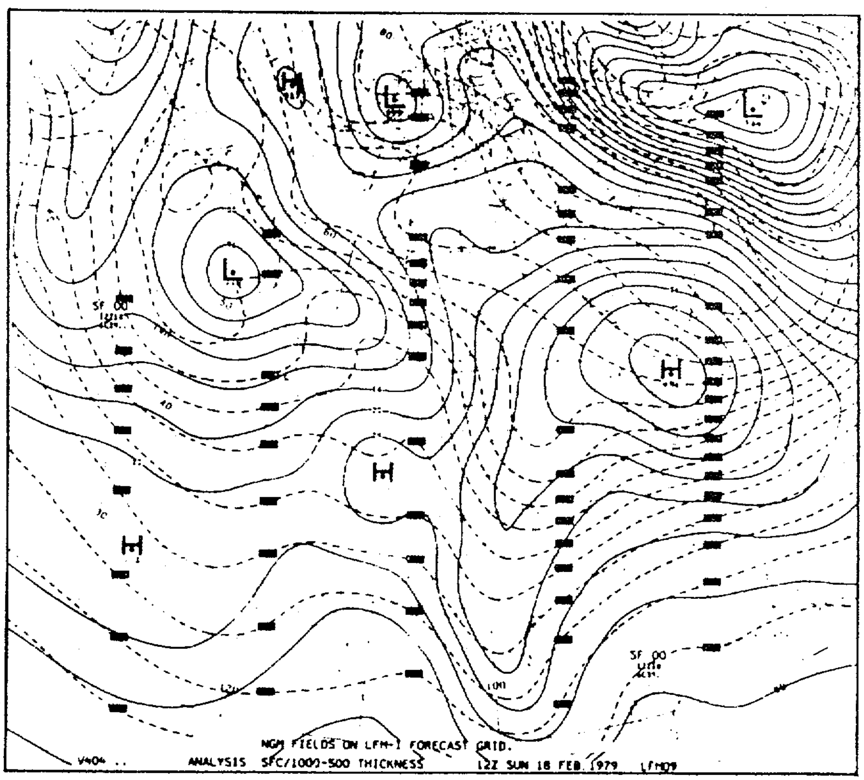
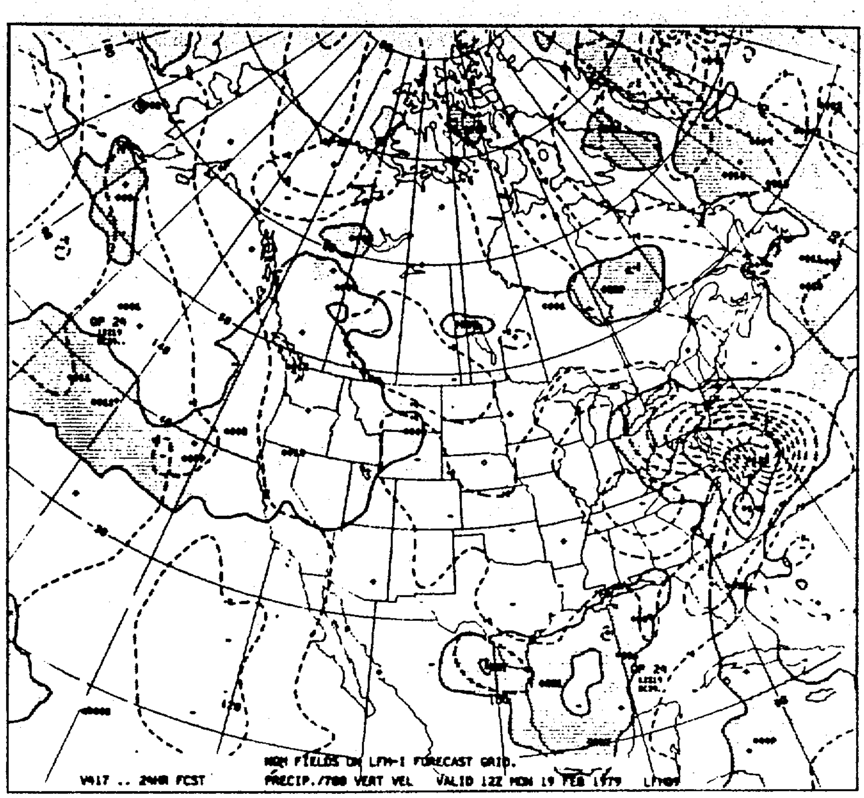



*Figure 3. Initial mean sea level pressure (solid line, contour interval = 4 mb) and 1000/500-mb thickness (dashed line, contour interval = 60 m) for the NGM forecasts from 1200 GMT 18 February 1979: (a) initial conditions for the forecast not preceded by normal mode initialization, and (b) initial conditions for the forecast preceded by normal mode initialization.*

(a)




(b)

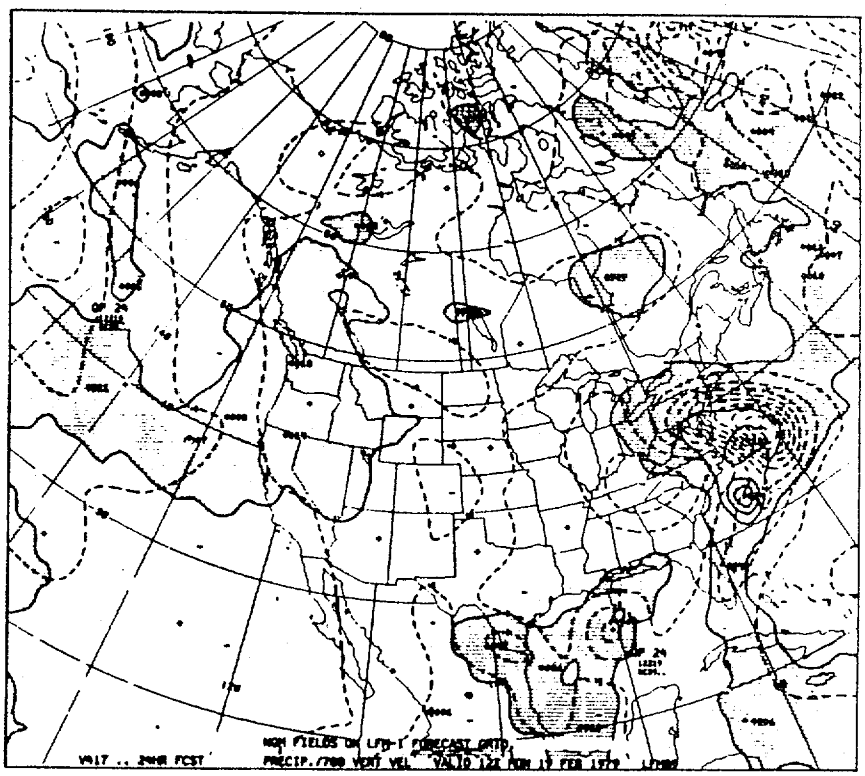



*Figure 4. The predicted accumulated precipitation from 12-24 h (solid line, units: 0.01 in., contour interval: 0.50 in) and vertical velocity at 24 h (dashed line, contour interval: 2 x $10^{-3}$ mb/s, positive for upward motion) for (a) the forecast not preceded by normal mode initialization, and (b) the forecast preceded by normal mode initialization.*

## 4. CONCLUDING REMARKS

The study presented here was undertaken to determine whether normal mode initialization of a hemispheric (or global) forecast model was a feasible source of initial conditions for a regional forecast model. We feel that the results show it is. The initialization was very successful in reducing the nonmeteorological external gravity wave, a feature created in part by truncation error in the pressure-gradient-force terms of sigma coordinate models. With two exceptions the impact of the initialization was not nearly as obvious in the analysis and forecast fields displayed at the 0, 12, 24, 36, and 48 h forecast times as in the surface pressure trace. First,the initialization often weakened the depth of low pressure systems at the initial time. The difference, however, greatly decreased during the forecast. Second, the precipitation forecast from 12-24 h for the region of the Presidents' Day storm differed by 0.6 inches for one area of intense precipitation. Differences in the precipitation forecasts were much less at other times and places. Verification of the two forecasts with observations indicated that one forecast was not significantly better than the other.

In the application of this initialization method to operational regional-scale forecast models, such as NMC's LFM, several questions will have to be answered. First, the lateral boundary conditions used in the initialization probably will not match those of the regional-scale forecast model such as the LFM as well as they matched those of the NGM, for which the lateral boundary is near the equator. Will this problem significantly degrade the impact of the initialization? The answer is uncertain at this time. Secondly, is it important for the initialization model and the regional-scale forecast model to have the same number of layers? This probably will be a mute point because the adaptation of the vertical resolution of the initialization model to that of the regional-scale model should not be difficult, as long as both models use the same vertical coordinate. Third, the normal mode initialization of this study was performed with a horizontal resolution much coarser than that supported by the data density over the domain on which a regional-scale forecast model would be run. Will sufficient computer resources be available so that the horizontal resolution of the Spectral Model used in the initialization can be made high enough for regional models like the LFM or NGM? With the availability of the CYBER 205 computer, the answer should be yes. As the resolution of the initialization is increased, however, the error introduced when horizontally interpolating from the initialization model to the regional model will increase. Will this degrade the impact of the initialization? We do not think so, because the resolution of the initialization model can be selected to be high enough to support the data density, but not so high to create large interpolation errors. Finally, will the results presented here be supported by additional experiments using other data cases? We feel that these results are representative, except for the case of strong flow over mountains, in which case large nonlinear effects can undermine the effectiveness of normal mode initialization. This problem will be investigated by additional testing.

## 5. ACKNOWLEDGEMENTS

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## 6. REFERENCES

Arakawa, A., 1972: Design of the UCLA general circulation model. Technical Report 7, Numerical Simulation of Weather and Climate, Dept. of Meteorology, University of California, Los Angeles, 116 pp.

__________, Y. Mintz, A. Katayama, J.-W. Kim, W. Schubert, T. Tokioka, M. Schlesinger, W. Chao, D. Randall, and S. Lord, 1974: The UCLA atmospheric general circulation model. Workshop notes, University of California, Los Angeles.

Eliassen, A., 1956: A procedure for numerical integration of the primitive equations of the two-parameter model of the atmosphere. Science Report 4, Department of Meteorology, University of California, Los Angeles, 53 pp.

Hoke, J. E., 1982: Several methods for initializing mesoscale forecast models. Proceedings of the NATO Advanced Study Institute on Mesoscale Meteorology. Bonas, France, 13-30 July 1982.

Kuo, H. L., 1965: On formation and intensification of tropical cyclones through latent heat release by cumulus convection. J. Atmos. Sci., 22, 40-63.

Leith, C. E., 1980: Nonlinear normal mode initialization and quasi-geostrophic theory. J. Atmos. Sci., 37, 958-968.

Phillips, N. A., 1979: The Nested Grid Model. NOAA Technical Report NWS 22, Dept. of Commerce, Silver Spring, Maryland, 80 pp.

Sela, J. G., 1982: The NMC Spectral Model. NOAA Technical Report NWS 30, Dept. of Commerce, Silver Spring, Maryland, 36 pp.