15A.3 FROM GLOBAL TO MESO SCALES WITH A UNIFIED MODEL

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1. INTRODUCTION

The Nonhydrostatic Mesoscale Model (NMM) has been developed at NCEP within the Weather Research and Forecasting (WRF) effort building on NWP experience (Janjic et al., 2001; Janjic, 2003; see also Janjic et al. elsewhere in this volume). With this approach the nonhydrostatic equations are split into two parts: (a) the part that corresponds to the hydrostatic system, but including corrections due to the vertical acceleration, and (b) the part that is used to compute the corrections appearing in the first system. Thus, the nonhydrostatic effects are introduced as an add–on module that can be turned on or off. In this way the hydrostatic and nonhydrostatic solutions can be compared, or the model can be run in the hydrostatic mode at lower resolutions in order to reduce the computational cost. The described approach does not require any additional approximation or linearization.

The numerical schemes used in the model were designed following the principles set up in Janjic (1977; 1979; 1984). “Isotropic” horizontal finite differencing is employed that conserves a variety of basic and derived dynamical and quadratic quantities. Among these, the conservation of energy and enstrophy (Arakawa, 1966) improves the accuracy of the nonlinear dynamics.

In the vertical, the hybrid pressure-sigma coordinate (Arakawa and Lamb, 1977) has been chosen as the primary option. Since the hydrostatic pressure is used as the vertical coordinate above 400 hPa, the possible inaccuracies due to the sloping coordinate surfaces are restricted only to about the lower half of the mass of the atmosphere. Note that, generally, the largest errors in the sigma coordinate occur in the stratosphere. Thus, the most serious problems associated with the sloping sigma surfaces are eliminated.

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The forward-backward scheme is used for horizontally propagating fast waves, and an implicit scheme is used for vertically propagating sound waves. The Adams-Bashforth scheme is applied for the horizontal advection of the basic dynamical variables and for the Coriolis force. However, in order to eliminate stability problems due to thin vertical layers, the Crank-Nicholson scheme is used to compute the vertical advection tendencies.

In spite of the complexity of the spatial differencing and the CFL restriction on the time step, the NMM has been efficient computationally. In high resolution NWP applications, its efficiency has been higher than the computational efficiency of most established nonhydrostatic models. The high computational efficiency of the NMM is primarily due to the design of the time-stepping procedure.

In very high resolution two-dimensional runs, the model successfully reproduced a number of classical nonhydrostatic tests. In three-dimensional real data runs the model dynamics demonstrated the ability to develop the observed –3 and –5/3 spectral slopes that were induced by the model physics, and not by computational noise. In a decaying turbulence case on the cloud scales with 1 km resolution, the model dynamics developed the –5/3 spectrum consistent with the 3D turbulence theory.

The NMM has been run operationally in NCEP High Resolution windows in six nested domains (West, Central, East, Alaska, Hawaii, Puerto Rico). In addition, the model is used for fire weather forecasting and other purposes on call. In terms of performance, statistical scores and numerous examples indicate that the NMM adds value to the forecasts of the driving regional model. This applies particularly to the details of flow over complex terrain.

In addition to operational forecasting the model has been tested in many case studies and several validation campaigns. The NMM model demonstrated the ability to predict tropical storms realistically, and efforts are under way to implement it operationally as the Hurricane WRF.

Particularly interesting scientific results were obtained in a carefully controlled field experiment (Weiss et al., 2004) in which the model was run at near-cloud resolving resolution of 4.5 km without parameterized convection. The model demonstrated the ability to spin-up severe convective systems more frequently, and with stronger signal, than if this were happening only by chance. This was reflected in the verification scores (Weiss et al., 2004) that showed that the WRF NMM with near-cloud resolving resolution for the first time clearly outperformed the forecasts of the NCEP mesoscale Eta model with parameterized convection. This result also suggests that further improvements in deterministic forecasting of severe weather phenomena may be achievable with increased resolution.

2. EXTENSION TO GLOBAL SCALES

In order to explore the capabilities of the formulation on larger spatial and temporal scales, a unified version of the model is being developed for the scales ranging from LES to global. Several possibilities for handling the spherical geometry have been explored, but none was found to have a decisive advantage over the latitude-longitude grid with polar filtering. Thus, the model on the latitude-longitude grid with polar filtering is being developed as the reference version. However, an alternative approach that does not require polar filtering is being pursued as well (see Purser et al. elsewhwere in this volume).

As the major deviation from the WRF-NMM, the unified model is being developed on the Arakawa *B* grid shown in Fig. 1. The symbol h in the figure denotes the mass point variables, and $\mathbf{v}$ stands for the velocity vector. As already pointed out in Janjic (2003), the finite-difference schemes on the *B* grid were obtained by reformulating the WRF NMM *E* grid schemes. The B grid schemes preserve all major features of the conservative *E* grid schemes of the WRF NMM.

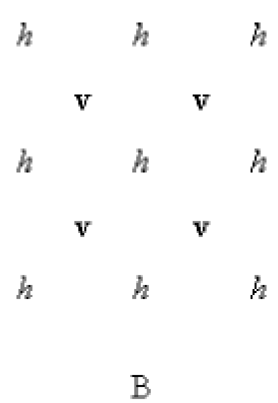

Fig. 1. The Arakawa *B* grid.

The polar boundary conditions are specified following Nickovic (1982). With this method, the polar row of mass points is treated as a rigid wall. The tangential component of wind preserves the same sign across the polar row, while the normal component changes sign. The specification of the velocity components beyond the polar points is schematically represented in Fig. 2. Note that this polar boundary condition does not violate the conservational properties of the finite-difference schemes.

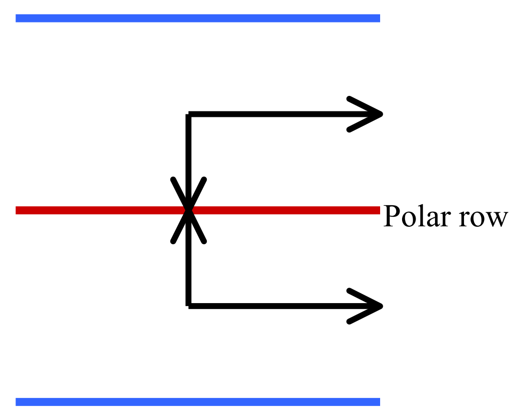

Fig. 2. Schematic representation of specification of velocity components beyond the polar row of points.

A pseudo 2-point averaging FFT filter of the form

$$\cos(\frac{k\Delta x}{2})^n$$

is applied to the waves shorter than a threshold in Fourier space and faster than waves of equal wavelength propagating in the meridional direction. The filter is applied to the tendencies of mass variables and to the velocity components.

3. PRELIMINARY RESULTS

The unified model has been tested on both the regional and global scales using the existing Fortran 90 serial code. The parallel code is being developed and is nearing completion.

So far, most of the tests in the global domain have been performed on personal computers with 256 by 181 points and 32 levels in the vertical, which corresponds to a modest horizontal

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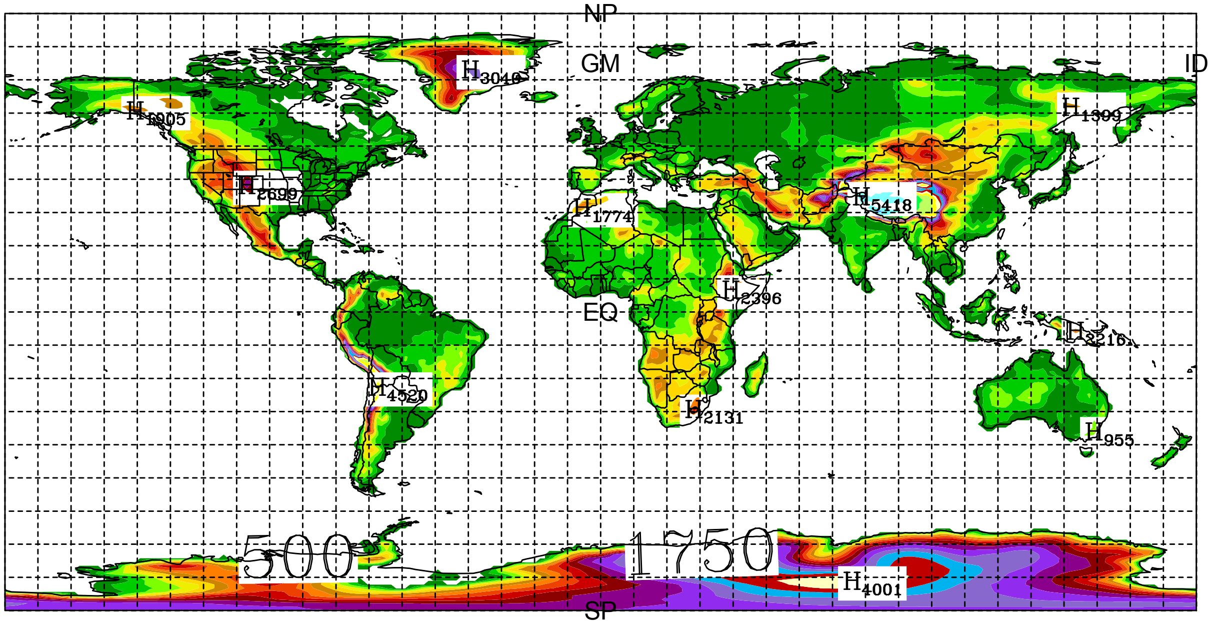
Topography



minimum= .0000E+00 maximum= .5250E+04 interval= .2500E+03

Fig. 3. Global topography with 256 x 181 points.

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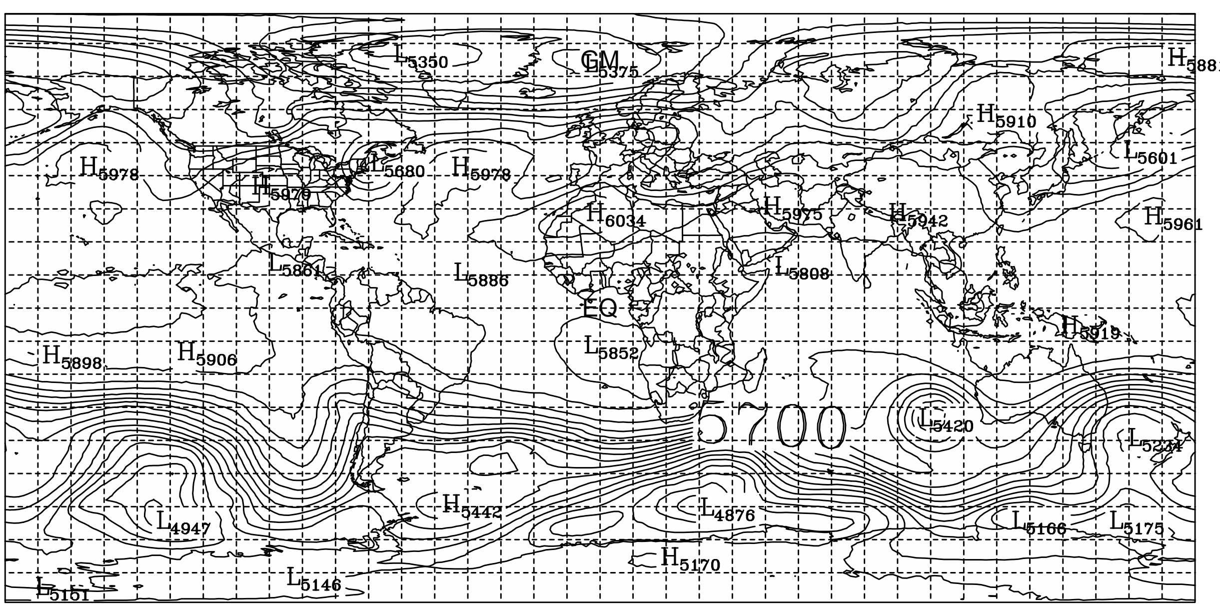

minimum= .4860E+04 maximum= .6000E+04 interval= .6000E+02

Fig. 4. The 500 hPa map obtained in a 20 day simulation initialized with real data. The contour interval is 60m.

resolution of about 110 km. The topography used in the tests is shown in Fig. 3. It was derived from the USGS 30'' global data.

With the resolution used in the global domain, a one-day simulation takes about 45 minutes on a 1.5 GHz Pentium M laptop. The estimates based on results obtained with the serial code indicate that the computational efficiency of the model may be competitive with the computational efficiency of semi-Lagrangian models. The accuracy of extended experimental forecasts with the currently used modest horizontal resolution is also encouraging.

As an example, the 500 hPa map obtained in a 20 day simulation initialized with real data is shown in Fig. 4. The contour interval is 60 m. By this forecast time the model presumably reached its own climatology. Still, no visible deterioration of large scale synoptic disturbances can be detected.

4. CONCLUSIONS

Encouraging initial results have been obtained in the development of the reference version of the unified model. Further work is needed in order to optimize the code for use on parallel super computers, and to develop a suitable physical package.

Successful completion of this project will allow use of the same model on a very wide range of spatial and temporal scales, from LES studies to climate simulations. Moreover, the high computational efficiency of the model promises the possibility of application of nonhydrostatic dynamics on the global scale when single digit resolutions become affordable.

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