A GLOBAL VERSION OF MM5

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1. INTRODUCTION

It is well known that lateral boundaries are often a limiting factor in the long-term behavior of limited-area simulations (e.g. see Warner et al., 1997). This is because of the low temporal and spatial resolution in global datasets. Having a global version of the model avoids many of these problems by not requiring externally set boundary conditions and it can be initialized with a single analysis.

Here we will outline a method used to make MM5 a global model, and present some results to show that it works.

There are several motivations for developing a global version of MM5.

(i) Computer power is now sufficient to routinely run 5-day forecasts with mean global grid sizes of less than 100 km, as we have at NCAR since October 1999. A global grid of 210x210 points for each hemisphere has such resolutions and is comparable with today's operational medium-range models. Typical timesteps would be more than 200 seconds.

(ii) A global model allows us to extend MM5 studies into the areas of medium-range weather prediction, and global data assimilation. Predictability limits can be explored for the planetary-scale waves that affect mid-latitude weather in the 5-10 day forecast range. Feedback from small to large scales can also be studied.

(iii) Since a global model requires no boundary files, it can be run indefinitely, particularly if sea-surface temperature and land-surface properties are allowed to vary. This allows testing of the long-term behavior of the model physics and dynamics which is of use for regional climate studies.

2. MODEL EQUATIONS

Since 1998 MM5 has had a complete set of curvature terms which we document here in the equations for the substantial derivatives of the three momentum components.

$$\frac{Du}{Dt} = -\frac{m}{\rho}\frac{\partial p'}{\partial x} + \left(f + u\frac{\partial m}{\partial y} - v\frac{\partial m}{\partial x}\right)v - ew\cos\alpha - \frac{uw}{r} + D_u \quad (1)$$

$$\frac{Dv}{Dt} = -\frac{m}{\rho}\frac{\partial p'}{\partial y} - \left(f + u\frac{\partial m}{\partial y} - v\frac{\partial m}{\partial x}\right)u + ew\sin\alpha - \frac{vw}{r} + D_v \quad (2)$$

$$\frac{Dw}{Dt} = -\frac{1}{\rho}\frac{\partial p'}{\partial z} - g\frac{\rho'}{\rho} + e(u\cos\alpha - v\sin\alpha) + \frac{u^2+v^2}{r} + D_w \quad (3)$$

where m is the map-scale factor given by

$$m = \frac{1+\sin\lambda_t}{1+\sin\lambda} \quad (4)$$

for the polar-stereographic map projection, and is only a function of latitude (λ). For the global version of the model, we choose a true latitude (λ_t) of 60 degrees. The p' terms represent pressure gradients, and the ρ'/ρ term is the buoyancy. For brevity we have not written the terrain-following equations or expanded buoyancy as the temperature and pressure terms that MM5 actually uses (see Dudhia 1993).

The equations are written with u, v and w representing the velocities in the x, y and z directions respectively. The e and f terms represent the full Coriolis force, where $e = 2\Omega\cos\lambda$, and $f = 2\Omega\sin\lambda$, and g is the gravitational acceleration. The angle α is that between the y-axis and the meridians that is required to represent the terms with e. Although x, y, and z are locally orthogonal and Cartesian, on a large scale they are curved, and so apparent forces are needed due to curvature. The terms with r represent the vertical curvature force due to the earth's finite radius, and the definition of consequently curved z surfaces parallel to the earth's surface. The terms dependent on the gradient of m represent a fictitious force due to the horizontal curvature of the coordinate.

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3. METHOD

The global model is formed by two overlapping hemispheric domains, each centered on a pole, and extending only slightly beyond the equator. The polar stereographic projection is used for each domain, so no formulation changes are required for the standard model equations. The main new piece here is a method of allowing the two domains to interact with each other instead of reading boundary files.

Each hemispheric domain is like an MM5 nest, but with a round boundary. They are responsible for calculations on the north and south side of the equator respectively, taking information beyond the equator from the other domain, somewhat like a nest boundary. This exchange occurs after both domains have completed each timestep, and is done using a simple four-point interpolation of all the relevant fields. In this way, the points beyond the equator are boundary conditions for the hemispheric domains. No relaxation zone is required near the boundary zone.

In order to carry this method out, arrays are pre-calculated that store the corresponding positions of points beyond the equator on the other domain. Furthermore, for the velocities a rotation is involved in addition to the interpolation because the u and v components do not coincide in direction. The rotation angle is a simple linear function of longitude.

In practice this method appears to work well, showing no evidence of the equatorial interface probably because both domains have the same resolution there, and exchange occurs every timestep. The model code is not modified much by this method at the loop level because both domains calculate tendencies for their full square domain, even though the points beyond the equator will be overwritten by the other domain.

The polar stereographic projection used here means that the true grid length at the equator is half that at the pole. For example, for a true latitude of 60°N and a 120 km grid distance, the map-scale factors mean that the actual grid distance is 128 km at the pole and 64 km at the equator. It could be argued that the tropics are the best place for high resolution in the global model because of the smaller scale of the dominant weather systems there, and also because of the equatorial interpolation.

4. OTHER CONSIDERATIONS

Since this model is designed for use on medium-range forecast time-scales of 5-10 days, with grid lengths on order 100 km, and to be initialized with global analyses, several additions have been made to this version of the model, and more are being considered for addition.

Snow cover prediction has been added by using a heat and moisture budget equation to predict water equivalent snow depth. This can be initialized from existing global analyses that carry such a variable, such as the MRF. We are not yet running the global model with the land-surface model, but that would have its own snow-cover prediction, as well as a soil moisture prediction that would benefit medium-range forecasts.

Sea-ice cover is initialized based on the sea-surface temperature. Currently a threshold of 273 K is used to discriminate between sea-ice and water. This would also depend on the incoming dataset, and some may already contain sea-ice information. As with the regular model, sea-ice is treated like permanent ice.

For 100 km grid-lengths there are some other considerations that are not normally needed for mesoscale grids ($<$ 50 km). MM5 does not have a gravity wave drag formulation that many global models have to represent the effects of sub-grid momentum transport in mountainous regions. This should be included as it may improve predictions of tropospheric wind speeds.

Effects of fractional cloud coverage, such as in the older radiation scheme, should be included in the newer schemes which currently consider the grid box uniform. This adds the need for assumptions about how clouds at various levels overlap. Microphysics could also take account of sub-grid variability and allow partially cloudy grid boxes.

5. REAL-TIME FORECAST TESTS

We have run the global model almost every day since October 18 1999, displaying plots on the real-time Web pages, and this has helped us understand its behavior and predictive capabilities. We have mostly been using the MRF 00Z analysis as a first guess, including water-equivalent snow depth, and using GTS observations with little-r to do a reanalysis on each hemisphere. Probably more than half these runs have been extended to ten days.

Global model output files are not saved, because there are 1.7 Gb of output for each 5-day forecast, so extensive statistical evaluation is not possible. However a six-day period (March 1-6 2000) of five-day forecasts was saved, and has been studied by examining the 500 hPa height field's correlations between pairs of forecasts verifying at the same time.

As seen in Table 1, forecasts verifying at the same time have a higher correlation with each other than with the analyses at the verifying time. The

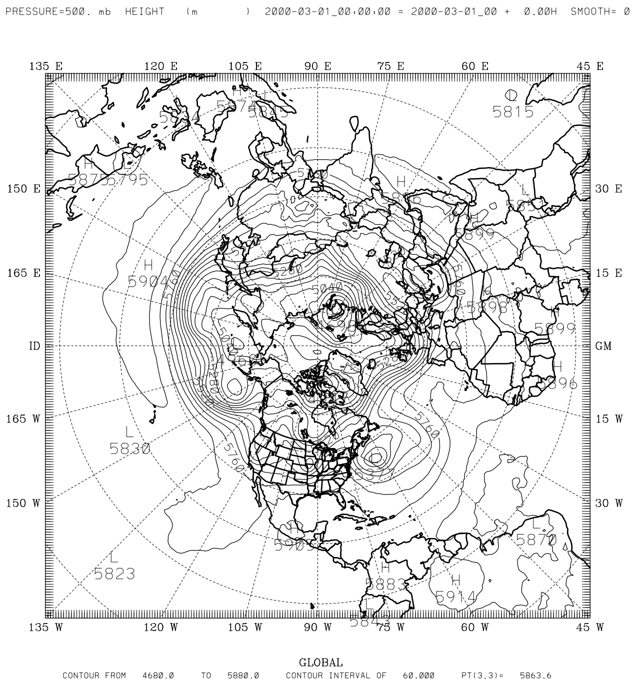

Figure 1a. The 500hPa height analysis for 00Z 1st March 2000 (contour interval 60 m).

best correlation was between the 3-day forecasts and 2-day forecasts where the 5 cases had an average correlation of 0.993, compared to, for

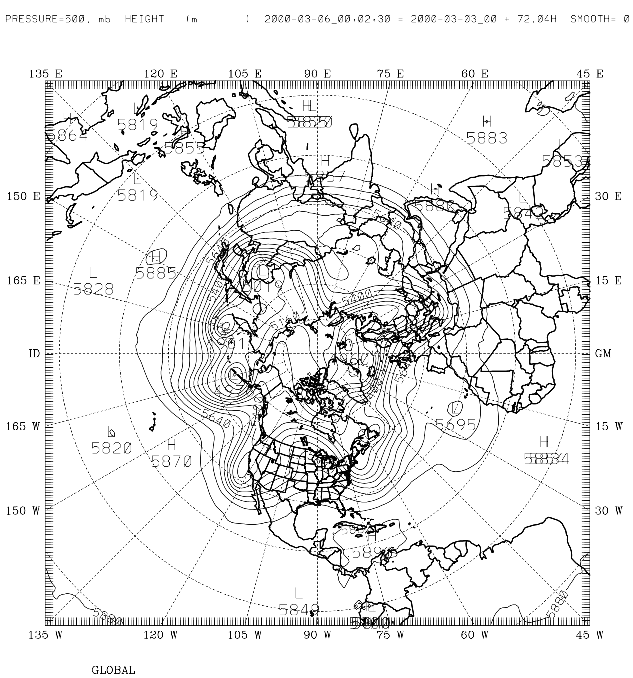

Figure 1c. As Fig.1a but 72-hour forecast verifying at 00Z 6th March.

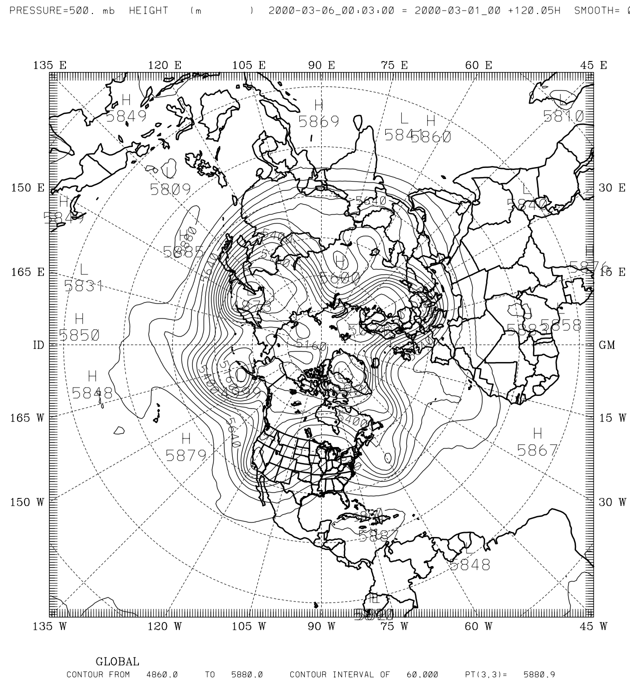

Figure 1b. As Fig.1a but 120-hour forecast verifying at 00Z 6th March.

example, five 1-day forecasts only having a 0.980 correlation with the analysis. While 0.980 shows considerable skill compared to the 0.954 average

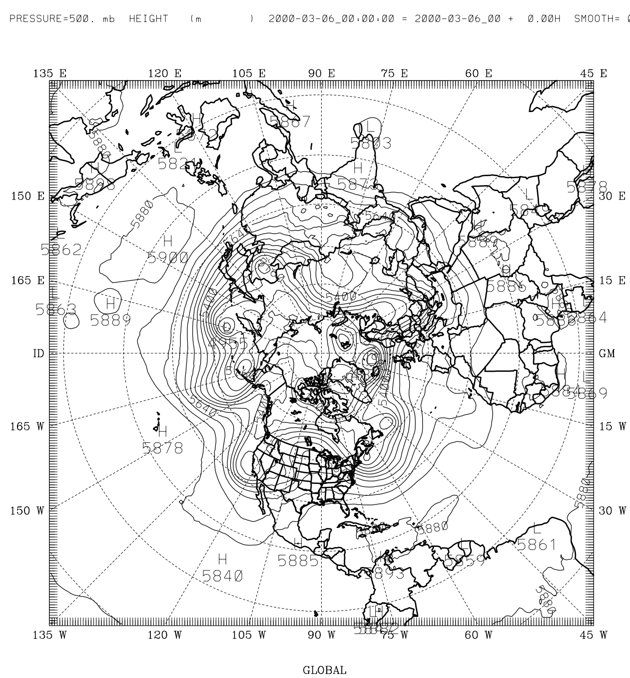

Figure 1d. As Fig.1a but analysis for 00Z 6th March 2000.

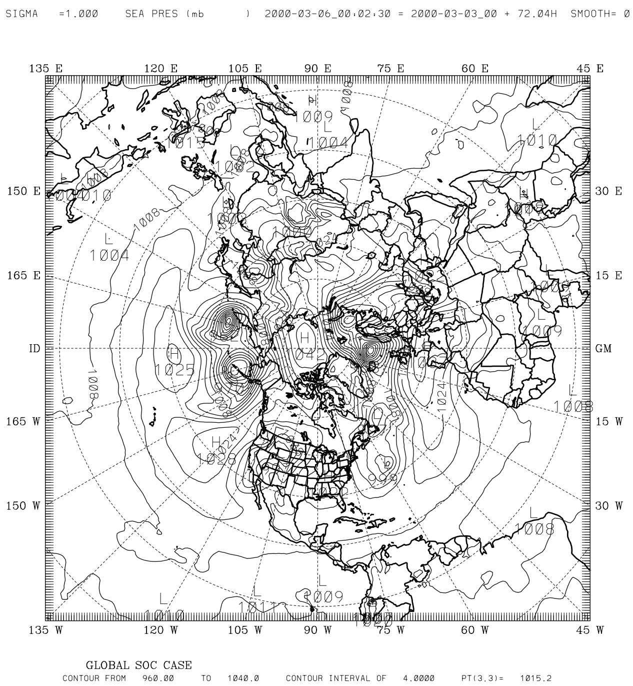

Figure 2a. Sea-level pressure 72-hour forecast verifying at 00Z 6th March (contour interval 4 hPa).

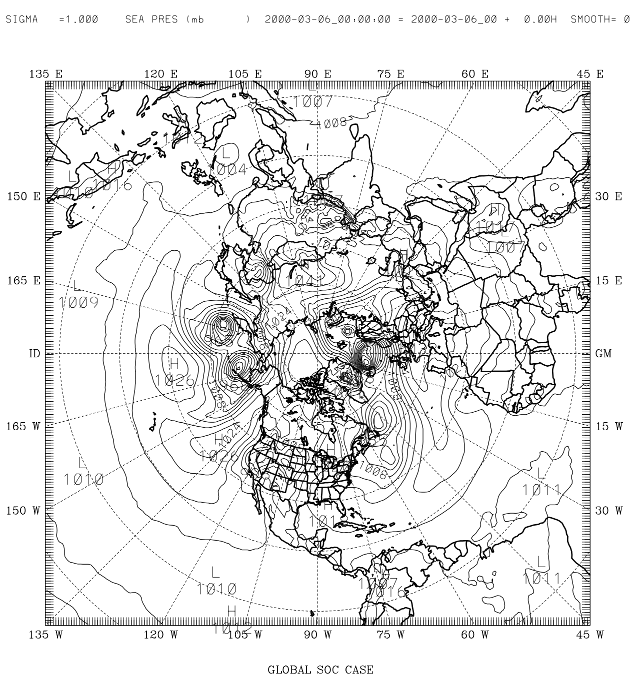

Figure 2b. As Fig.2a but analysis for 00Z 6th March 2000).

correlation between all pairs that did not have the same verifying time, it is at first surprising that the 3-day forecast looks more like the 2-day forecast, than the 1-day forecast looks like the analysis. However this is possibly explained by the fact the objective analyses represent non-realizable states because they are unbalanced by the analysis procedure. Once the transients introduced by these imbalances decay, forecasts look more similar to each other, despite starting with different analyses.

TABLE 1

Correlations between forecasts verifying at same time

	0 day	1 day	2 day	3 day	4 day
1 day	.980				
2 day	.967	.987			
3 day	.960	.983	.993		
4 day	.957	.977	.987	.985	
5 day	.947	.974	.985	.981	.987

Figure 1 shows an initial analysis for 00Z March 1 2000, and the 5-day, and 3-day forecasts, and analysis valid at 00Z March 6 2000. This period was not chosen for any particular reason, other than being the beginning of a month, and so represents a random sample from our forecasts. There is skill in even the 5-day forecast in capturing all the large-scale troughs in the 500 hPa height field. Figure 2 shows that at the surface two Pacific cyclones and an Atlantic cyclone are captured well by a 3-day forecast. The predicted depths were 962, 970, and 968 hPa for the cyclones respectively near Kamchatka Peninsula, the Aleutians, and Iceland, versus 965, 968, and 958 hPa in the analysis.

These results give us confidence in the usefulness of the model, but we still would like to do some idealized tests to verify the dynamics.

6. ACKNOWLEDGMENTS

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