Successes and Problems in Developing a Real-time MM5 Forecast System

Todd A. Hutchinson, Steven J. Honey, Stephen Marshall
Weather Services International, Billerica, Massachusetts

1. Introduction

Weather Services International (WSI) has developed a real-time numerical weather prediction (NWP) system used operationally by WSI's forecast operations in both the United States and United Kingdom. The MM5 modeling system is the core of WSI's NWP system. The purpose of this paper is to discuss the modeling problems and successes encountered while developing, implementing, and operating the system.

2. System Setup

The system is based upon version 3.2 of the MM5. Data output by the MM5 is exported to a graphics generation and data processing system, where users can analyze and display the MM5 output. Through the graphics system, users have the ability to display, derive and analyze numerous meteorological fields, as well as produce high-quality graphics.

In the standard configuration, the MM5 is run with three domains having horizontal resolutions of 90 km, 30 km and 10 km and 21 vertical levels. The lowest sigma level is .996, or approximately 30 m above the ground (the lowest half-sigma level is ~15 m above the ground). The center point of the 10 km domain is located to the user's specifications; the 30 km and 90 km grids are automatically located relative to this center point. Fig. 1 shows an example of the nest configuration.

For simulations in most of the continental United States (US), the MM5 is initialized with a first-guess Eta initialization (80 km horizontal resolution, data available every 50 mb). Outside the US, the AVN model (1.25 degree grid) is used for the first-guess field. The first-guess is refined with surface and upper-air observations. Additionally, the Oregon State University Land Surface Model (LSM) is turned on and initialized with 40 km Eta initialization data (in the US) or NCEP's Global Data Assimilation System (GDAS) data (outside the US). For systems initialized with the Eta, the MM5 is run 4 times daily out to 48 hours with initialization data from the 00 UTC, 06 UTC, 12 UTC, and 18 UTC analyses, and, for systems initialized with the AVN, the MM5 is run twice daily out to 48 hours with initialization data from the 00 UTC and 12 UTC AVN analyses.

The MM5 is run with the following parameterizations:

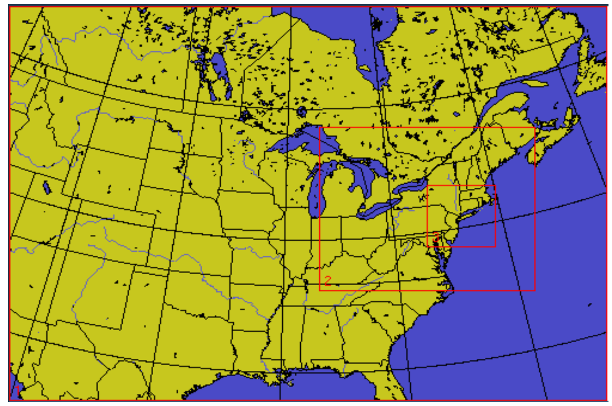

Fig. 1. The low-resolution (90 km), medium-resolution (30 km) and high-resolution (10 km) domains for a New York City regional simulation.

- Oregon State University Land Surface Model (Chen et al., 2001)
- MRF Planetary Boundary Layer
- Schultz Microphysics
- Rapid-Radiative Transfer Model (RRTM)
- Grell Cumulus parameterization

The parameterizations have been chosen to minimize forecast error in low-level temperatures and precipitation and to maximize computational efficiency.

3. Initialization issues

There are many options for initializing numerical weather prediction (NWP) models. For our forecast system, we began simply by initializing the MM5 with the initialization from the Eta model (from the 80 km "211" grid). However, over time, we found several problems when initializing with the Eta. First, the Eta initialization of low-level fields was often different from reality. An example of this is shown in Figure 2. Notice that the Eta initialization is between 2 ^{o}C cooler and 6^{o}C warmer than observations.

Differences between the Eta initialization and observations at levels above the surface were found to be much smaller, except near locations where soundings were missing and not included in the Eta initialization. In order to reduce initialization errors, we found it necessary to refine the initialization with conventional surface and upper air observations (Fig. 2b). In comparing simulations with and without using observations, typically, both runs produced similar results at forecast times beyond 3-6 hours. However,

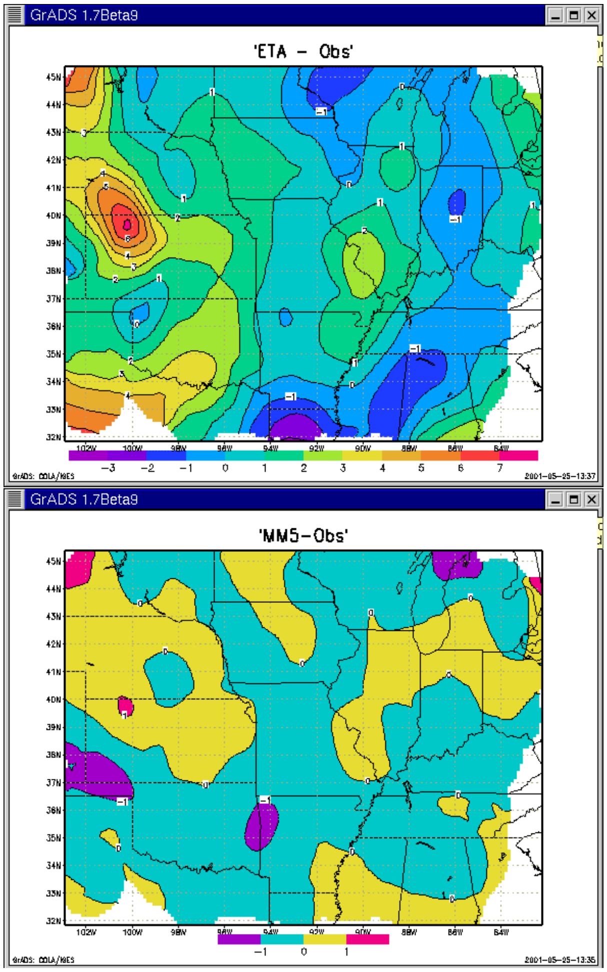

Fig. 2. Difference (^{o}C) between lowest sigma-level temperature and observed 2 m temperature from MM5 initialization at 12 UTC 24 May 2001 for 1) initialization with Eta analysis only and b) initialization with Eta analysis, surface observations and sounding.

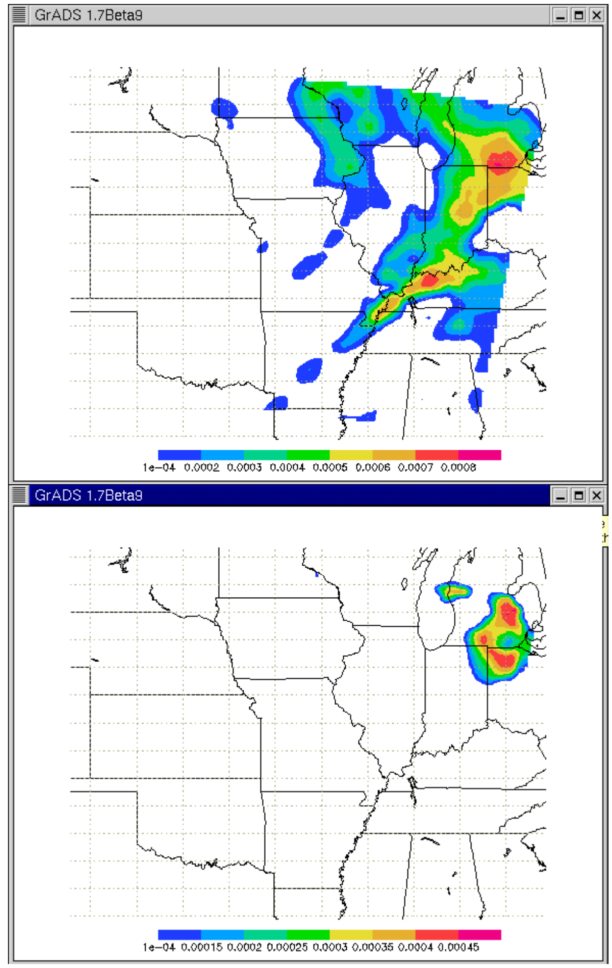

Fig. 3. Cloud liquid water content (kg/kg) at (a) initialization (12 UTC 24 May 2001) and (b) 30 minutes after initialization.

there were occasional cases where erroneously warm temperatures in the Eta initialization spawned convection that was not observed and was not seen in simulations that incorporated observations. Similar inconsistencies in the Eta analysis were found by Otte (2000).

There are several reasons why the Eta initialization may be different from observations. First, there are errors associated with interpolating the 80 km Eta grid to 30 and 10 km grids. We use bilinear interpolation to infer values, which assumes that the extreme values must occur at the original grid points. Additionally, the 80 km grid is smoothed operationally, which tends to remove any high-resolution features that may be found within the 80 km grid. (see http://www.emc.ncep.noaa.gov/mmb/tips/tip.aug99.html). To combat these resolution problems, we assimilate surface and upper air rawinsonde observations into the initialization grids using WSI data decoding logic and the MM5 data injection program little_r.

Lack of initialization data for some fields also contributes to an inconsistent, or dynamically unbalanced, analysis. For example, when cloud liquid water (CLW) data is absent, MM5 is initialized with clear sky conditions over the entire model domain. In areas where significant cloud cover is actually present, the assumption of clear skies can result in significant warming (for daytime initializations) or cooling (for nighttime initializations) that is not observed.

To account for cloud cover at the initialization time, we initialize the cloud water field with values from the 40 km Eta grids. While we don't have any statistical verification for this approach, subjective analysis has revealed improved forecasts in some cases. However,

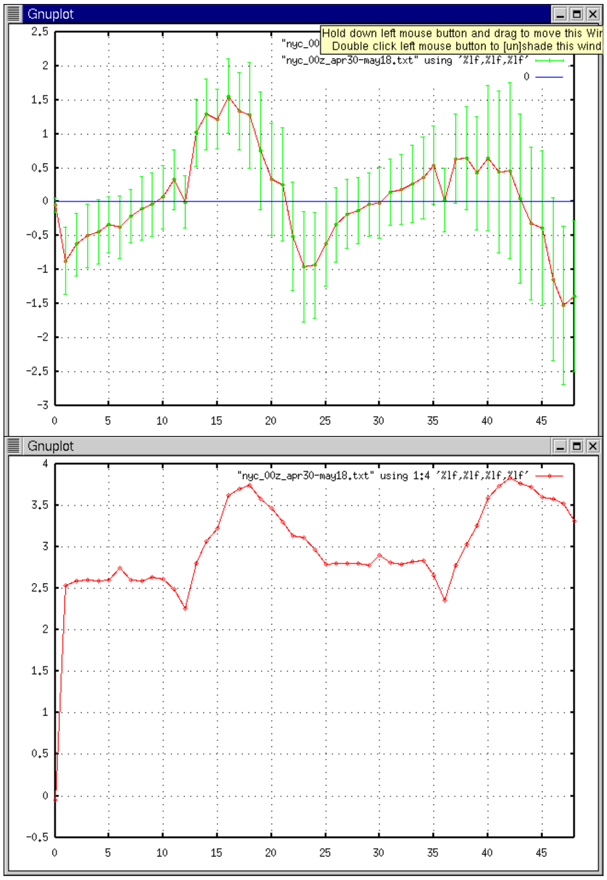

Fig. 4. a) Mean error in surface temperature (^{o}C) verses forecast hour for daily runs initialized at 12 UTC between 30 April and 18 May 2001 for the 30 km domain in Fig. 1. Error bars indicate the range of 1 standard deviation. b) Root-mean-squared error (^{o}C) for the same period as in (a).

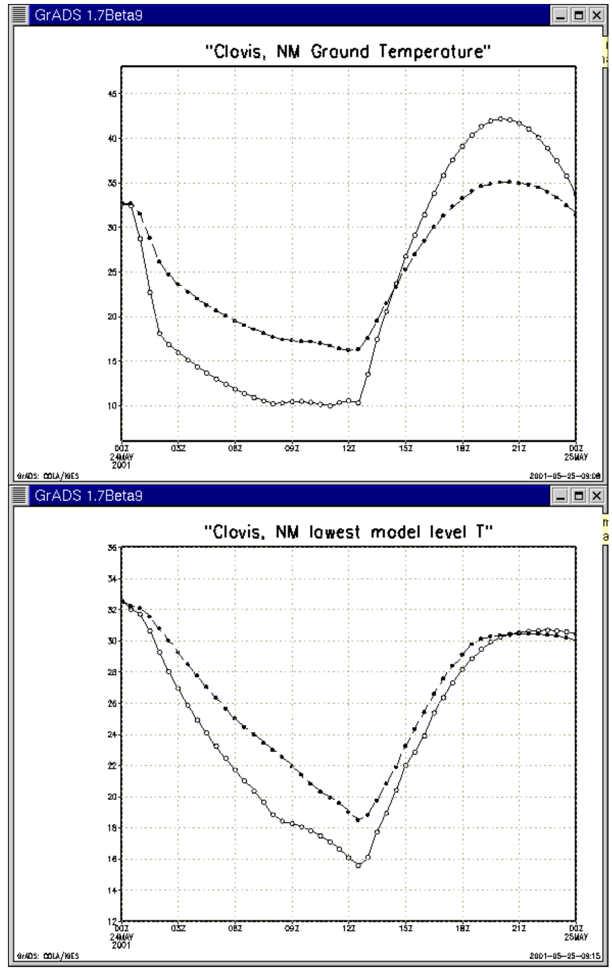

Fig. 5. a) Skin temperature (^{o}C) verses forecast hour for a simulation using the OSU LSM (solid line) and without LSM (dashed line). (b) Same as (a) but for lowest half sigma-level temperature.

even when CLW is initialized properly, significant amounts of CLW often evaporate within 30 minutes of initialization (see Fig. 3 for an example). We suspect that this evaporation of CLW is due to the lack of corresponding adjustments of the mass field (McGinley and Smart, 2001). We are currently examining ways to provide a more balanced initialization in order to minimize the evaporation of CLW.

4. Statistical Analysis

We have built a system to statistically monitor MM5 real-time runs in near real-time. Fig. 4a is a plot of bias in surface temperature verses forecast hour for daily runs initialized at 12 UTC between 30 April 2001 and 18 May 2001 for the 30 km domain of a New York City centered run (domain 2 in Fig. 1). The bias is generated by interpolating model data to station locations within domain 2, and averaging the differences between model forecast 2 meter temperatures and the corresponding observations at each forecast hour. The model surface temperatures are computed from the temperatures of the earth's skin and the lowest half-sigma level (using similarity theory). The observations are from reports in the METAR, SYNOP, SHIP, BUOY, and CMAN formats received from standard NWS data circuits. In addition to the mean bias, the range of plus or minus one standard deviation are plotted as error bars. It can be seen that there is a tendency for surface temperatures to be forecast too warm between 10 UTC and 21 UTC (5 am to 4 pm LST) and too cool between 22 UTC and 9 UTC (5 pm to 4 am LST). Fig. 4b shows the root-mean-square error, also averaged over the 30 km grid, for the same period. Clearly, the root-mean-square error is largest during the daylight hours, with the peak at 18 UTC on both the first and second forecast days.

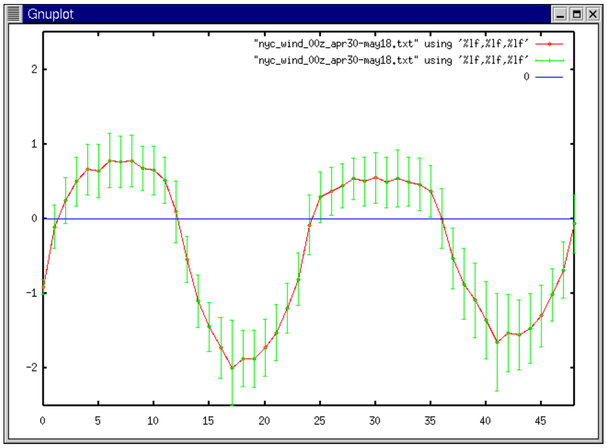

Fig. 6. Same as 5a, except for wind speed (m/s).

As mentioned before, the OSU LSM was turned on for these runs. It should also be noted that the period in question was an exceptionally dry period over the northeastern United States. The skin temperature fluctuates very rapidly when using the LSM in dry soil conditions. We have no observational data to verify the skin temperatures output by the LSM, so we have no reason to believe that they are in error. However, since large variations in skin temperature can occur when using the LSM, it is important to assure that calculations of near-surface fields are applied appropriately.

To demonstrate this point, Fig. 5 shows skin temperature from two MM5 simulations, one using the OSU LSM and the other using the 5-layer MRF soil model for an eastern New Mexico location for a 24 hour run initialized 00UTC 24 May. This example shows that the LSM has a significant effect on forecast skin temperature, with the LSM cooling the skin temperature by 6 ^{o}C at night and warming the skin temperature by 7^{o}C during the day. However, the lowest half-sigma level temperature (Fig. 5b) is much less sensitive to the LSM, especially during daylight hours. In light of these results, we are investigating ways to improve our methodology for calculating 2m temperature.

We have found significant biases in 10 m wind speed (Fig. 6). The 10 m winds are calculated using similarity theory, however, 10 m winds are almost always between 0 and +0.6 m/s of the lowest sigma level winds. Clearly, wind speeds are overforecast at night and underforecast during the daytime. We are using the MRF PBL scheme in our operational runs, and we suspect that low-level wind biases are strongly tied to the PBL schemes. We have found better prediction of wind speed using the Blackadar PBL, although the MRF scheme produces superior results in prediction of low-level temperatures when coupled with the LSM.

5. Results

Operational runs of the MM5 over numerous areas of the US have revealed many strengths and weaknesses of a real-time forecast system. It has been necessary to refine a first-guess initialization with surface and upper-air observations. The OSU LSM model has proven to be very useful, and to improve skin and low-level temperatures, especially in regions of anomalously high or low moisture. However, due to the large fluctuations in skin temperature when using the LSM, it is very important to use appropriate physics in calculating surface fields such as 2 m temperature. In cases of dry soil, we've found an overestimation of daytime 2m temperatures and an underestimation of nighttime 2m temperatures. One cause of these biases may be inadequacies in our calculation of 2m temperatures (similarity theory). Further, significant biases in wind speed were found, with winds being forecast too low during the daylight hours and too high during the night. As of yet, we have not been able to explain or suggest a solution for these biases.

Acknowledgements. We have been very happy with the performance, robustness and reliability of the MM5 as the core of WSI's modeling system. We would like to thank NCAR, as well as the MM5 community for developing, maintaining, and supporting the MM5 model. We would also like to thank NCEP for publicly providing gridded data from its numerical prediction models.

6. References

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