Comparison of the Real-time MM5 and WRF over the Northeastern United States

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1. INTRODUCTION

Since September 1999, Stony Brook University in collaboration with several National Weather Service Forecast Offices (NWSFOs) has been running the Penn State/NCAR Mesoscale Model (MM5) on 36, 12, and 4-km domains (Fig. 1). The primary objective of this project has been to improve operational weather forecasting over the Northeast U.S. using high resolution and ensemble modeling as well as verification approaches. This effort began by completing twice-daily deterministic forecasts down to 4-km grid spacing, in order to determine the MM5 biases (Colle et al. 2003a,b) and to evaluate whether the model can realistically produce various mesoscale phenomena, such as the sea breeze (Novak and Colle 2005a) and mesoscale precipitation banding within extratropical cyclones (Novak and Colle 2005b).

In May 2003 Stony Brook began running an 18-member MM5 ensemble operationally down to 12-km grid spacing over the Northeast U.S. for the 0000 UTC cycle (http://fractus.msrc.sunysb.edu/mm5rt). There are 12 physics members and 7 different initialization condition (IC) members. The physics members are setup in a 3 by 4 matrix of three boundary layer parameterizations (MRF, Blackadar, and Eta) and four convective parameterizations (Grell, Kain-Fritsch, new Kain-Fritsch, and Betts-Miller). The NCEP Eta, GFS, and Eta-bred members are used for the MM5 IC members. The Eta bred ICs used in the ensemble are the Eta members from the 2100 UTC cycle of the Short-Range Ensemble Forecast System (SREFS) of the Eta, in which there are 2 positive perturbations, 2 negative, and a control. Jones et al. (2005) quantitatively evaluates the ensemble and compares the results with the deterministic MM5 and NCEP Eta models.

The Weather Research and Forecasting (WRF) model v2.0 was implemented in real-time during the summer of 2004. The goal of this paper is to compare some basic verification statistics between the MM5 and WRF during the warm and cool seasons over the Northeast U.S. in order to determine whether the WRF results are at least comparable with the MM5 on average. This paper focuses on surface verification. Novak and Colle (2005b) highlights comparisons of WRF and MM5 for a nor-easter event occurring on 25 December 2002.

2. MODELS AND METHODS

The real-time MM5 and WRF were configured using the same 36, 12, and 4-km domains (Fig. 1), and the physical parameterizations were set as close as possible to each other. Namely, both models used the new Kain-Fritsch in winter 2004-2005 and a version of Grell (WRF used Grell-Devenyi) in summer 2004, RRTM/Dudhia radiation, simple ice, and a version of the MRF PBL. The MM5 utilized the v3.6 MRF, with modifications for surface fluxes using the TOGA

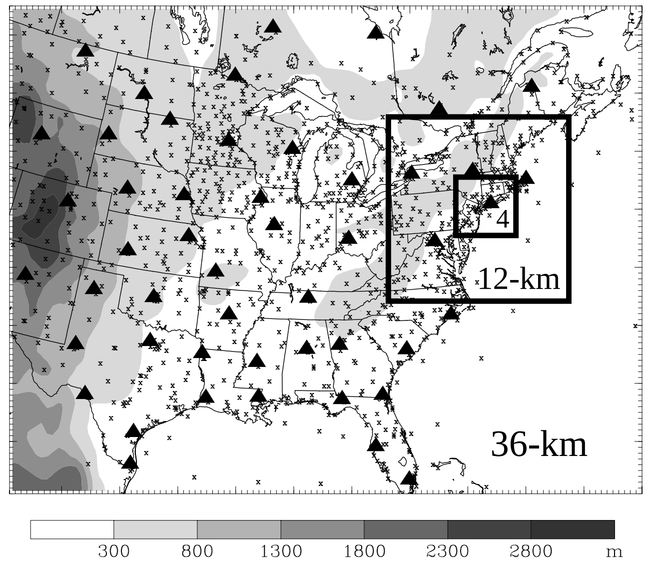

Figure 1. Location of the 36-, 12-, and 4-km MM5 and WRF domains. Terrain from the 36 km domain is shaded every 500 m using the inset key. The surface and upper-air stations used in this study are plotted using a ‘x’ and triangles, respectively.

COARE heat flux algorithm (Chen et al. 2005), while the WRF used the updated MRF (YSU PBL).

Both the MM5 and WRF were “cold-started” using the same NCEP operational model outputs, which includes the Eta 221 grids (32-km grid spacing) for the initial conditions and the 3-hourly 104 grids (80-km) for boundary conditions. The 12- and 4-km domains were placed over the Northeast U.S. using a one-way nest interface with 33 full vertical sigma levels. Both the MM5 and WRF were run for 48-h for the 36/12 km domains, and 36 h for the 4-km domain.

A long-term verification dataset has been collected using all conventional observations (Fig. 1), but this study evaluates only the 12-km domain. After collecting the observations a series of quality-control procedures were used to remove egregious errors. For this preliminary work, the conventional interpolation and statistical approaches were used (Colle et al. 2003a), in which the model data at the grid points were bilinearly interpolated to the observations sites. This point verification identifies model biases and makes qualitative comparisons, but it can not evaluate the ability of WRF to produce better/worse mesoscale structures than MM5. For the MM5 and WRF domain-average comparisons, the same 0000 UTC forecasts and observations within the 12-km domain were used.

3. SURFACE VERIFICATION OF MM5 and WRF

During the warm season (June-Sept), the 12-km MM5 and 12-km WRF have some similar biases (Fig. 2), which is consistent with using similar physics. Both

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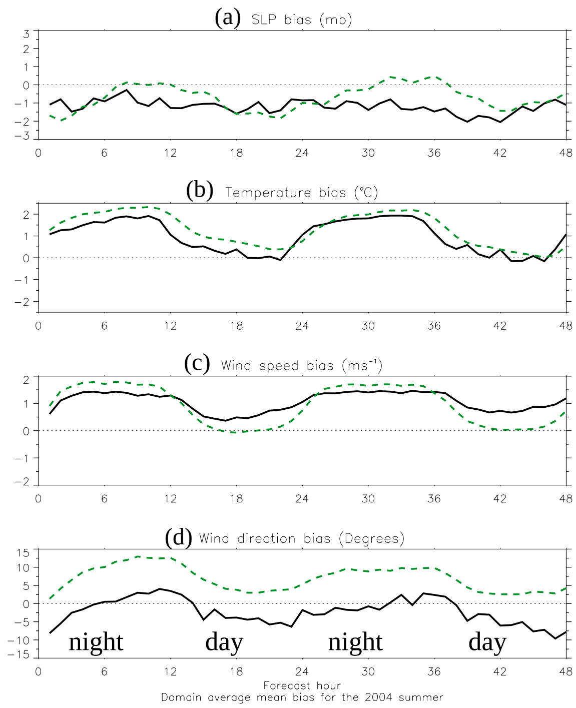

Figure 2. Surface warm season (June-Sept 2004) biases versus forecast hour for the 12-km MM5 (green dashed) and 12-km WRF (solid) showing (a) sea-level pressure, (b) temperature, (c) wind speed, and (d) wind direction. All forecasts were started at 0000 UTC, so the night and day periods are labelled.

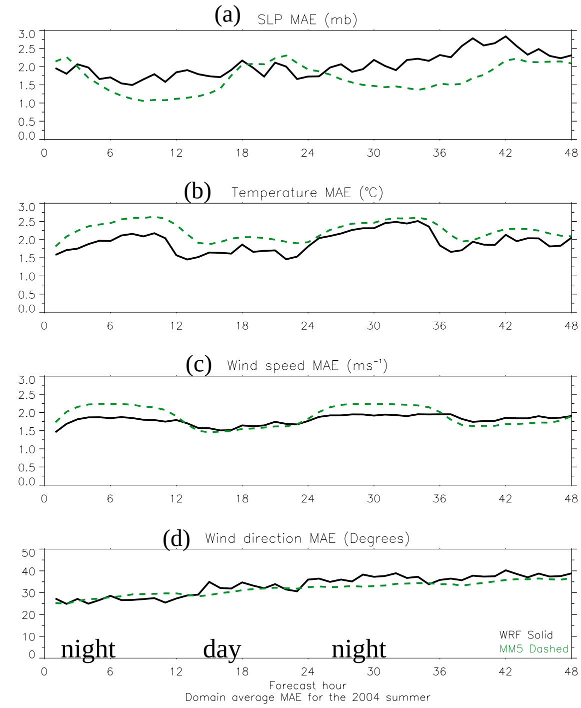

Figure 3. Same as Fig. 2 but for mean absolute error during the 2004 warm season.

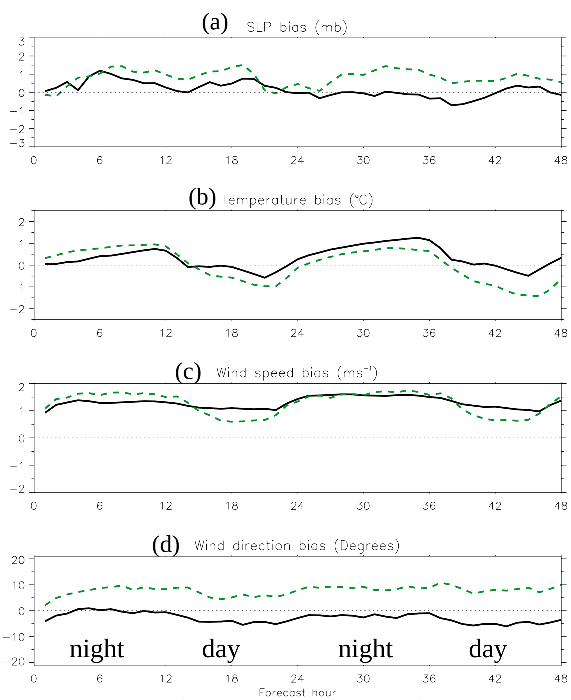

Figure 4. Surface cool season (Nov. 2004- Mar 2005) biases versus forecast hour for the 12-km MM5 (green dashed) and 12-km WRF (solid) showing (a) sea-level pressure, (b) temperature, (c) wind speed, and (d) wind direction. All forecasts were started at 0000 UTC, so the night and day periods are labelled

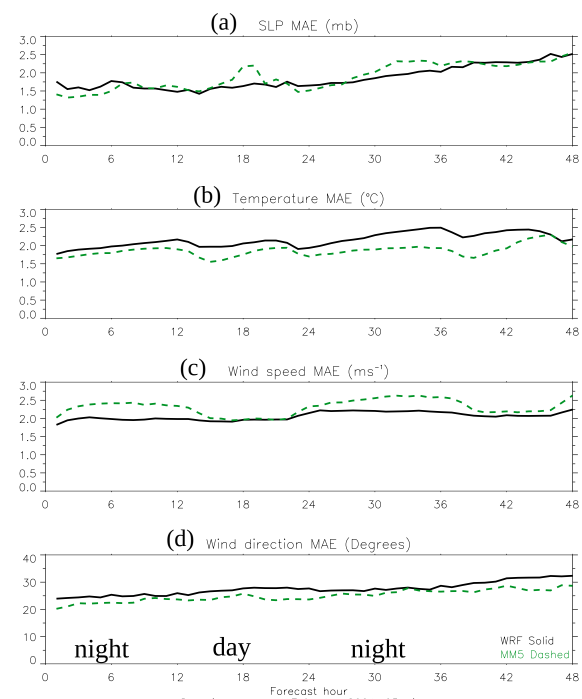

Figure 5. Same as Fig. 2 but for mean absolute error during the 2004-2005 cool season.

models have a warm (1-2 ^{o}C) and high wind speed (1-2 m s^{-1}) bias at night (0-12 h and 24-36 h on Figs. 2b,c); however, the WRF mean errors are slightly less than MM5 for these two variables. During the day the temperature and wind speed biases are diminished, with no wind speed bias in the WRF. The WRF has a persistent negative sea-level pressure (slp) bias during the full forecast period, while the MM5 has a 1-2 mb negative bias during the early evening. The MM5 wind direction biases are 10-15^{o} positive (model wind vector rotated anticyclonically relative to the observed) during the night, while there is little bias in the WRF.

Figure 3 shows the mean absolute errors (MAEs) during the warm season. The MM5 has a lower (better) MAE slp forecast than WRF during the late night and early morning (Fig. 3a), while both models are comparable during the afternoon. The WRF has a temperature MAE that is ~0.5 ^{o}C less than MM5 (Fig. 3b), especially during the first 24 h of the forecast. The WRF also has a slightly better wind speed forecast than MM5 at night (Fig. 3c). Even though the MM5 has a larger wind direction bias, the MM5 has slightly lower wind direction MAEs after hour 24. We have observed more wind direction variability in the WRF at 12-km grid spacing than MM5, perhaps because of WRF's smaller horizontal diffusion, so this combined with point verification may be producing larger WRF wind errors. The slightly better results in WRF for temperature and wind speed are likely the result of improvements made to the YSU PBL over the older MRF in MM5.

During the cool season (Nov-Mar), the MM5 has a positive 0.5-1.5 mb slp bias (Fig. 4a), while the bias in WRF is smaller.The nightime warm bias in both models is smaller than the warm season, with the MM5 developing a weak cool bias during the day. Unlike the cool season, both the MM5 and WRF also maintain a slight high wind speed bias during the day (Fig. 4c). The MM5 also has a positive wind direction bias.

The winter MAEs for sea-level pressure are comparable between MM5 and WRF (Fig. 5a), while the MM5 has slightly lower MAEs for temperature and wind direction. The WRF wind speed MAEs are lower than MM5 at night, while both models have similar wind speed MAE during the afternoon.

Several stations were evaluated individually over the Atlantic Ocean and the Northeast. For example, Fig. 6 shows a time series or errors at hour 24 for buoy 40025 just to the south of Long Island (cf. Fig. 1) from 1 Dec 2004 to 31 Mar 2005. For the MM5 temperature, the default v3.6 MM5 MRF is plotted (MRF_old) as well as the modified surface flux algorithm over water in the CTL-MRF (Chen et al. 2005). The MM5 forecasts initialized with the GFS are also shown for comparison for sea-level pressure. The wind speed errors are similar between the MM5 and WRF (Fig. 6a), but there are larger 2-m temperature differences between the MM5 and WRF (Fig. 6b). In particular, the WRF has periods with large (3-5 ^{o}C) warm errors, especially in late January 2005, which was an active cyclone period along the East Coast. This warm bias over water has been documented in the MRF over the eastern Atlantic (Colle et al. 2003a). The default MRF in MM5 v3.6 also has a 1-3 ^{o}C warm bias, but the best 2-m temperature forecast is for the modified CTL-MRF. These warm biases are not as prevalent during the warm season (not shown), but the winter results suggest that the surface heat fluxes in the default YSU and MRF schemes over water need to be improved, perhaps using the TOGA-COARE algorithm. The WRF also has slightly deeper sea-level pressures than the MM5 (Fig. 6c), which is shown by the reduction in positive slp error spikes, although some of this problem is removed in the MM5 by simply using the GFS.

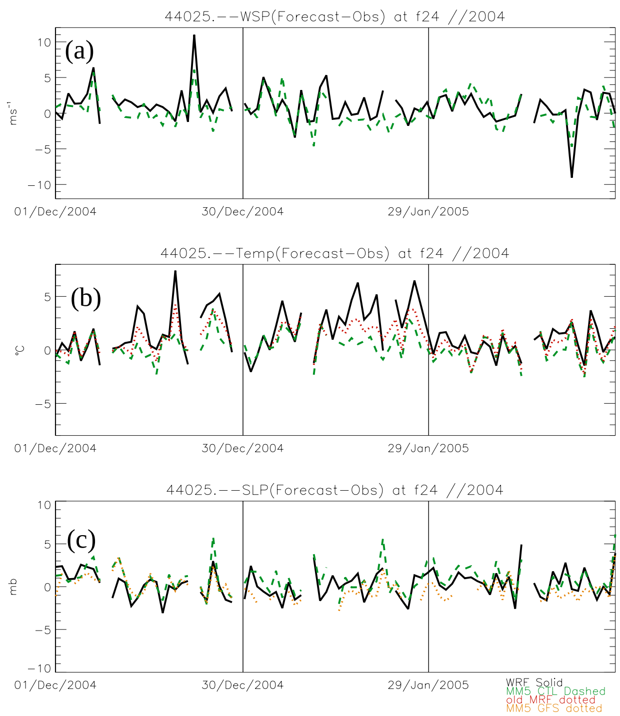

Figure 6. WRF (solid) and MM5 (dashed) errors at hour 24 (forecast-obs) for buoy 44025 just south of Long Island between 1 Dec 2004 and 28 Feb 2005 showing (a) wind speed, (b) temperature, and (c) slp. The MM5 using the default v3.6 MRF is red dashed and MM5 using the GFS is orange dashed.

4. REAL-TIME ENSEMBLE WRF

A 6-member WRF ensemble has been constructed in order to evaluate more physics in the WRF, and the results are posted daily on the ensemble web site above. Two WRF members use GFS for initial and boundary data combined with the YSU and Eta (Mellor-Yamada) PBLs and new KF, while the other four members use the NCEP Eta as well as KF-new, Grell, YSU PBL, and Eta PBL. Figure 7 shows a 48-h slp and 925-mb temperature forecast from 0000 UTC 23 May 2005. For this cyclone event there is large uncertainty in cyclone position and strength using different initial conditions and physics.

5. SUMMARY

This paper has presented some surface verification for MM5 and WRF during the 2004 warm season and

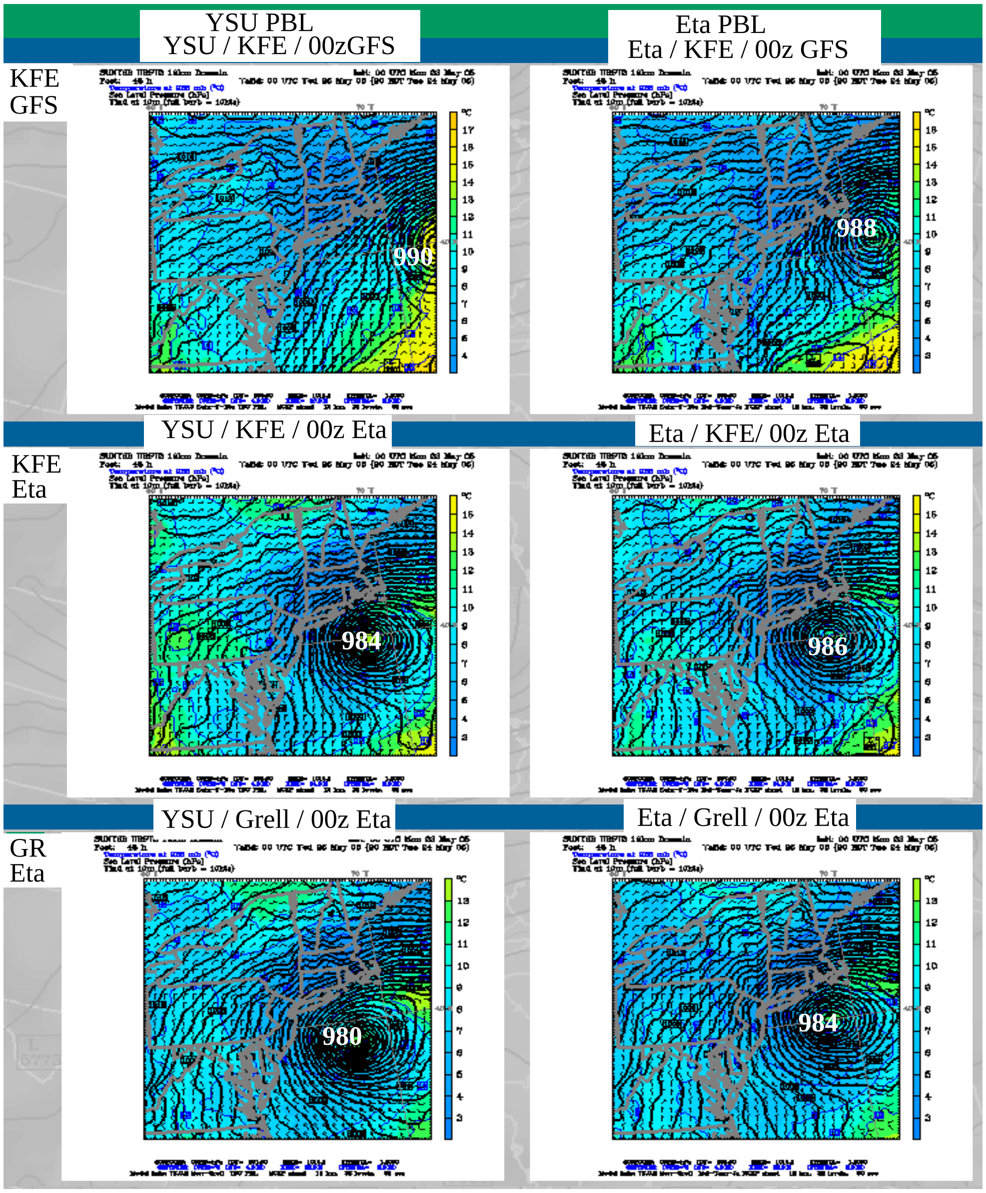

Figure 7. The 6-member WRF ensemble for 0000 UTC 23 May at hour 48 showing slp and 925-mb temperature
The WRF and MM5 ensemble can be viewed at: http://fractus.msrc.sunysb.edu/mm5rte/

2004-2005 cool seasons. Using similar physics as MM5, the WRF results are generally comparable to MM5, which is encouraging for real-time operations; however, there are some WRF biases larger than MM5, such as the surface warm bias over water during the cool season. A 6-member WRF ensemble has been constructed to better evaluate the modeling system.

6. ACKNOWLEDGEMENTS

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