3.3

Objective Verification of the MM5 over the Northeast U.S.: Comparison with the NCEP Eta and Impact of High Resolution

Brian A. Colle*[1], Jeffrey S. Tongue[2], and Joseph B. Olson[1]
[1]Institute for Terrestrial and Planetary Atmospheres, SUNY- Stony Brook, NY
[2] NOAA/NWSFO, Upton, NY

1. INTRODUCTION

Since September 1999, Stony Brook University in collaboration with the Upton, NY (New York City) NWSFO has been running the Penn State/NCAR Mesoscale Model (MM5) twice daily on 36, 12, and 4-km domains (Fig. 1). One of the goals of this effort is to complete a detailed long-term verification and inter-model comparison of the MM5 and operational NCEP Eta over the eastern two-thirds of the U.S. during the cool and warm seasons. As a result, this study expands on the MM5 verification studies over the central and western U.S. (Manning and Davis 1997; Mass et al. 2002; White et al. 1999). In addition, although there is a clear trend towards high resolution with mesoscale models, there have only been a few long-term studies evaluating the benefits and weaknesses of enhanced resolution (e.g., Mass et al. 2002). By analyzing a large number of model forecasts, this study addresses the following important questions: (1) How do the MM5 and Eta verification results vary across the country for the cool and warm seasons? (2) What are the effects of using different NCEP initializations and model physics on the forecasts? (3) What is the impact of increased spatial resolution around the coastal zone and urban corridor of the Northeast U.S.?

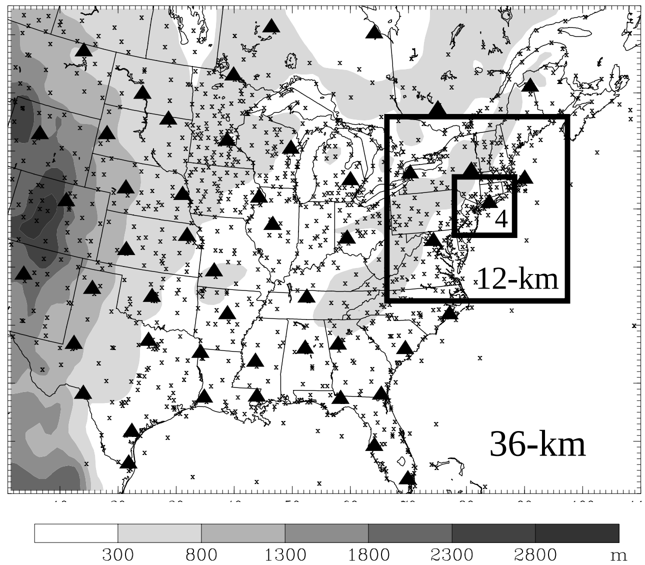

Figure 1. Location of the 36-, 12-, and 4-km MM5 domains. Terrain from the 36 km domain is shaded every 500 m using the inset key. The surface and upper-air stations used in this study are plotted using a 'x' and '▲', respectively.

2. DATASETS and METHODS

From September 1999 to August 2001 SUNY-Stony Brook (SUNYSB) integrated version 2.12 of the MM5 in real-time. Since August 2001 version 3.4 of the MM5 has been used, which has allowed the soil moisture to be initialized using the Eta grids and updated during the simulation. The 12- and 4-km domains are placed over the Northeast U.S. using a one-way nest interface with 33 full vertical sigma levels. The MM5 is initialized using the Eta model (currently at 12-km grid spacing) interpolated to the NCEP-221 grid (40-km horizontal resolution, 25 mb vertical levels). The SUNYSB MM5 is run for 60 h for the 36/12 km domains, and 36 h for the 4-km domain (see http://atmos.msrc.sunysb.edu/html/alt_mm5.cgi for details). The MM5 uses the MRF PBL, simple ice microphysics, and Grell convective parameterization. For the 2000-2001 cool season, a separate MM5 run was completed twice daily using the NCEP Aviation model for initial and boundary conditions. For the summers of 2000-2001 an additional Eta-MM5 simulation was completed using the Kain-Fritsch convective parameterization on the 36- and 12-km grids.

A long-term verification dataset has been collected at SUNYSB using all conventional observations including: North American SAO (Surface Airways Observing) sites, fixed buoys, coastal marine (CMAN) stations, and North American upper-air sites (Fig. 1). After collecting the observations a series of quality-control procedures were used to remove egregious errors. First, each observation was tested with a gross-error check, followed by a temporal consistency check (looking for excessive hour by hour changes). Next, observations were run through a spatial consistency check to insure that each observed parameter was not radically different from values observed at nearby stations at approximately the same elevation. For the MM5v2.12 verification the 40-m MM5 wind speeds were reduced to 10-m using a logarithmic profile, while for v3.4 the 10-m winds were verified directly from the MRF PBL. Wind direction forecast / observation pairs are excluded from the statistics when the observed wind speeds are less than 4 knots (2.05 m s^{-1}), since wind direction is poorly observed at such low wind speeds. For the MM5 v2.12 verification the 40-m MM5 temperatures were "reduced" to the observation elevation using the standard (6.5 ^{o}C/km) lapse rate, and then averaged with the model ground/water temperature to provide the MM5's prediction of 2-m temperature. For MM5v3.4 the 2-m temperatures were output directly from the model. Our study uses similar interpolation and statistical approaches as those MM5 verification studies over the western U.S. (see Mass et al. 2002 for details), in which the model data at the grid points are bilinearly interpolated to the observations sites. The Eta was verified using the post-processed Eta 104 grids (80 km grid spacing). Although this resolution is much coarser than the native Eta grid, it still allows a good evaluation and comparison of the large-scale fields with the MM5.

*Corresponding author address: Dr. Brian A. Colle, Marine Sciences Research Center, Stony Brook University/SUNY, NY 11794-5000. email: bcolle@notes.cc.sunysb.edu.

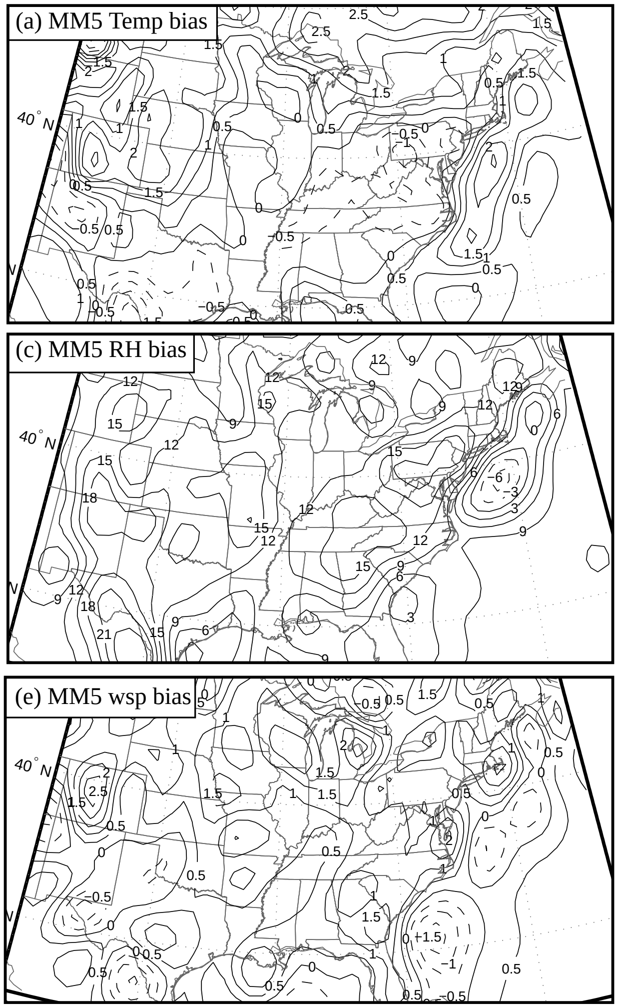

Figure 2. Surface 2001-2002 cool season temperature biases for the (a) MM5 and (b) Eta (every 0.5 ^{o}C). (c) and (d) Same as (a) and (b) except for relative humidity (every 3%). (e) and (f) Same as (a) and (b) except for windspeed (every 0.5 m s^{-1}).

3. VERIFICATION OF MM5 and ETA

3.1 2001-2002 cool season biases

Figure 2 shows the surface verification (12-48 h) from December 2001through March 2002 for the 36-km MM5 and the Eta. The MM5 results are similar to Colle et a. (2001) for the winters of 1999-2001. The MM5 is 1-2 ^{o}C too cool over much of the southeastern U.S., while a 1-3 ^{o}C warm bias exists over the Great Lakes, northern Plains, much of Canada, and near the Gulf Stream (Figs. 2a). The verification of the MM5 2-m temperature rather than the 40 m / surface average results in a 30-50% weaker warm bias over water (not shown), so the averaging approach is not recommended in those regions. In contrast, the Eta has a large (2-4 ^{o}C) cool bias over the Rockies and much of Canada (Fig. 2b), while a slight warm bias exists over the southern U.S. The MM5 moist bias over the eastern U.S. is nearly 2-3 times as large as the Eta (Figs. 2c,d), while the Eta has a slight dry bias over the southern Plains. The Eta and MM5 10-m winds are 1-2 m s^{-1} too strong over the Eastern U.S. and Canada (Fig. 2e), while the Eta winds are 1-2 m s^{-1} too weak in the lee of the Rockies and the northern Plains. (Fig. 2f).

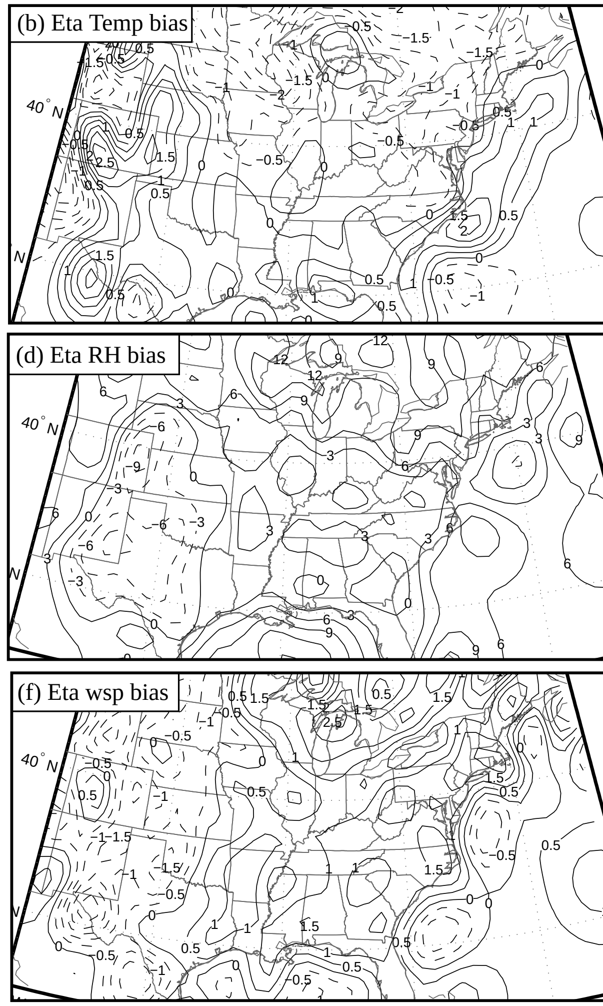

Figure 2 continued.

3.2 Sea breezes

Colle et al. (2001) showed only a small improvement in temperature and wind forecasts with increasing resolution over the 4-km domain region surrounding Long Island, and equally small improvements were also found during the warm season on average (not shown). The local NWS forecasters have suggested that MM5's largest benefit at high resolution has been for sea breeze events. Sea breeze evolution in this region is complicated by the sharply-curved mainland coastline and Long Island.

Increased horizontal resolution often results in more realistic structures with the sea breeze over Long Island, but does this realism translate into greater forecast skill for many different events? To address this question, sea breezes during the 2000-2001 warm season were objectively identified on Long Island using hourly surface observations, and the MM5 surface winds and temperatures were verified. Since a sea breeze is favored when there is a large temperature difference between land and water with relatively weak flow opposing the sea breeze, we implemented the following criteria to screen for events on Long Island: a 6 ^{o}C average temperature difference between Islip, NY (ISP on Fig. 3) and buoy 025 offshore during the early afternoon (12-3 PM EDT) and the average wind speed for all Long Island stations is less than 10 kts during the morning hours (8-11 AM EDT). These criteria were chosen based on their ability to select events when manually checked against regional surface analyses. This resulted in 32 observed events for the combined 2000-2001 warm seasons, with 6 events in May, 16 in June, 4 in July, 6 in August. There is an early warm season maximum of these events given the relatively cool coastal waters (10-15 ^{o}C) during May-June.

Figure 3 shows the spatial distribution of MAEs for the 32 events for all stations within 4-km domain during the afternoon period (12-4 PM EDT) using the short-term (16-20 h) 0000 UTC forecasts. From 36 to 12-km grid spacing (Fig. 3a), there is a reduction in MAE over most of the coastal sections of the New York Bight, with the largest (10-15 deg) improvement over Long Island and coastal New Jersey. In contrast, further inland more stations actually had degraded wind forecasts from 36- to 12-km grid spacing. From 12 to 4 km (Fig. 3b), there were only modest (0-10 deg) reductions in MAE across eastern Long Island, while over much of the rest of the domain there is little or no improvement.

Although these results are somewhat encouraging for high resolution forecasts of the sea breeze, there are also some distinct wind and temperature biases for these events. Using the combined 12-24 h and 24-36 h forecasts for 1200-0000 UTC, the 4-km MM5 the wind direction biases rapidly switch from 5-10^{o} positive (model wind vector rotated anticyclonically relative to the observed) to 10-20^{o} negative (model winds too southeasterly) by late afternoon (not shown). All resolutions develop a significant cool bias by 1800 UTC on Long Island (not shown). The cool bias steadily improves significantly from 36 to 4 km; however, the increasing cool bias during the day even at high resolution suggests that the on-shore cooling associated with the sea breeze is too strong. For the 32 sea breeze events at ISP, the 4-km MM5 on average was early 50%, on time 38%, and late 16%. The mean timing error was -0.79 h, which is significant at the 95% level using a two-sided t-test. The early MM5 sea breeze bias is consistent with the cool bias along the coast later in the afternoon.

3.3 Northeast U.S. Precipitation

The MM5 precipitation at 36,12, and 4 km grid spacing was verified at the Cooperative observer and NWS rain gauges over the Northeast U.S. (see Mass et al. 2002 for methods). Colle et al. (2001) showed that during the cool season the 12-km MM5 produces too much precipitation over the Appalachian windward slopes, especially downwind of Lake Erie and Ontario. In contrast, there is excessive precipitation shadowing in the lee of the barrier.

During the 2000-2001 cool season the MM5 precipitation forecasts initialized with the Eta (Eta-MM5) were compared with the MM5 forecasts initialized with the AVN (AVN-MM5). For the heavy precipitation thresholds, the 12-km grid spacing had noticeable more skill than the 36-km for both the Eta-MM5 and the AVN-MM5 (Fig. 4). This greater skill in the 12-km domain at

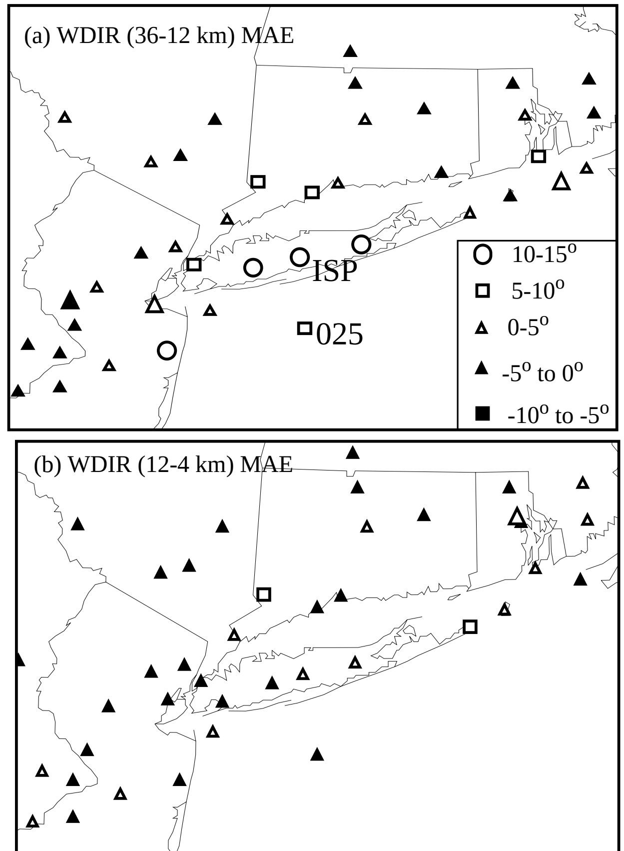

Figure 3. (a) Observing sites with improved (open symbols) and degraded (filled symbols) mean absolute wind direction errors (degrees) for the 16-20 h sea breeze forecasts (0000 UTC cycle only) as horizontal resolution is increased from (a) 36 to 12 km and (b) 12 to 4 km. As shown in the legend the size and type of the symbol is proportional to improvement or degradation as resolution is increased.

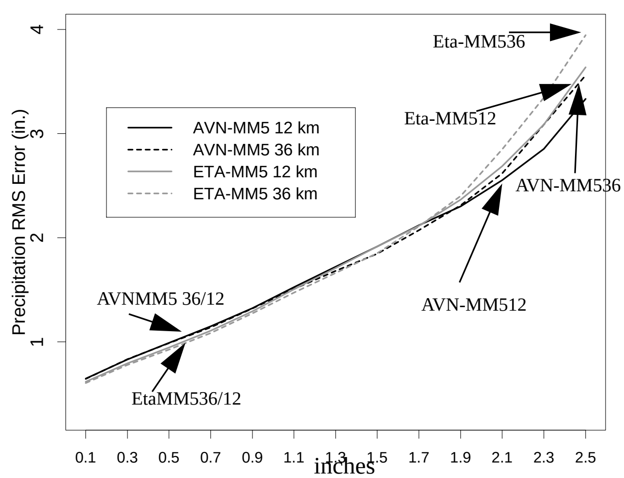

Figure 4. Precipitation RMS errors (12-36 h) during the 2000-2001 cool season for the 12-km domain region for MM5 forecasts initialized with the Eta (Eta-MM5) and the AVN (AVN-MM5).

larger thresholds was the result of the 12-km having less underprediction than the 36-km (12-km bias = 1.05 versus 0.80 in the 36-km).

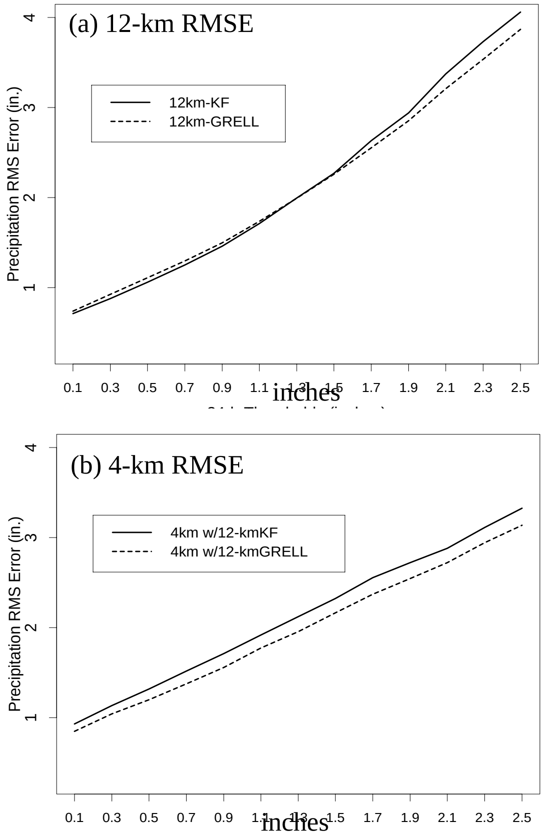

Figure 5. (a) Precipitation RMS errors (12-36 h) during the 2000-2001warm seasons at 12-km grid spacing for MM5 forecasts over the Northeast using the Kain-Fritsch versus Grell. (b) Same as (a) except for at 4-km grid spacing using no convective parameterization in this inner nest.

For the low thresholds (< .9 inches in 24 h), the Eta-MM5 has slightly lower RMS errors than the AVN-MM5. In contrast, for the heavy precipitation events the AVN-MM5 is significantly better than the Eta-MM5 (significant at the 95% level). In fact, the 36-km AVN-MM5 precipitation skill is comparable to the 12-km Eta-MM5, therefore illustrating that the benefits of high resolution can be erased if a more representative large-scale forecast can be obtained. As a result, an ensemble of 36-km MM5 forecasts may perform better than a single 12-km MM5 over the Northeast for many precipitation thresholds during the cool season.

During the summers of 2000-2001, after each MM5 forecast using the Kain-Fritsch (KF) convective parameterization was completed, a separate simulation using the Grell scheme in the 36-/12-km domains was integrated. Several problems were noted using the Kain-Fritsch scheme over the Northeast (Colle et al. 2001). The scheme tends to over-predict precipitation just inland of the southern New England coast along sea breeze boundaries (not shown), while over other areas there is general underprediction, especially for the heavy precipitation amounts.

Figure 5a shows the RMS error scores for the KF versus Grell convective scheme at 12-km grid spacing. At low thresholds, the KF has slightly better RMS error scores than the Grell, while for the heavy precipitation events the Grell scheme performs noticeably better (significant at the 95% level). Grell does better at larger thresholds since it appears to allows for more explicit precipitation than the KF. The KF triggers often with wide spread light amounts (60-70% total precipitation mass at 12-km grid spacing is from KF). Since the KF is more spatially active in the 12-km domain than the Grell, the KF tends to dry and warm mid-levels too much. This results is less explicit precipitation within the 4-km nest surrounding Long Island. For all thresholds using the Grell in the outer domains results in a better 4-km explicit QPF forecast than using the KF (Fig. 5b).

4. SUMMARY

This study illustrates some of the strengths and weaknesses of the MM5 and Eta across the Eastern U.S. The MM5 tends to be too cool and moist at low-levels during the cool season, and the results did not improve during the 2001-2002 winter using soil moisture initialization and variation throughout the simulation. The Eta temperature and moisture biases at the surface have evolved rapidly during the last few years as a result of increased resolution and implementation of a more sophisticated land-surface model. Unlike previous winters (Colle et al. 2001), the Eta now has a larger cool bias in Canada and over the Rockies, and a more significant weak wind bias over the Rockies.

This paper shows some of the benefits of sea breeze forecasting and heavy QPF using high resolution (36 to 12 -km grid spacing); however, there are limited benefits going from 12 to 4-km given feedbacks of the outer domain convective parameterizations on the explicit precipitation as well as surface temperature and wind biases that effect sea breeze evolution.

5. ACKNOWLEDGEMENTS

This research was supported by the Office of Naval Research (Grant No. N00014-00-1-0407) and UCAR/ COMET (No. S01-24242). Use of the MM5 was made possible by the Microscale and Mesoscale Meteorological Division of the National Center for Atmospheric Research (NCAR).

5. REFERENCES

Colle, B. A., C. F. Mass, and K. J. Westrick, 2000: MM5 precipitation verification over the Pacific Northwest during the 1997-1999 cool seasons. *Wea. Forecasting*, **15**, 730-744.

__________, J. B. Olson, and J. R. Tongue, 2001: Evaluation of high resolution MM5 and Eta forecasts over the Northeast U.S. Preprints, *9th Conf. on Mesoscale Processes*, Fort Lauderdale, FL, Amer. Meteor. Soc., 357-360.

Manning, K. W., and C.A. Davis, 1997: Verification and sensitivity experiments for the WISP94 MM5 forecasts. *Wea. Forecasting*, **12**, 719-735.

Mass, C. F., D. Ovens, K. Westrick., and B. A. Colle, 2002: Does increasing resolution produce better forecasts? The results of two years of real-time numerical weather prediction over the Pacific Northwest. *Bull. Amer. Meteor. Soc.*, **83**, 407-430.

White, G.B, J. Paegle, W.J. Steenburgh, and co-authors, 1999: Short-term forecast validation of six models. *Wea. Forecasting*, **14**, 84-108.