P4.10 **Evaluation of High Resolution MM5 and Eta Forecasts over the Northeast U.S.**

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

During the past several years real-time numerical weather prediction has spread rapidly from operational centers such as the National Centers for Environmental Prediction (NCEP) to universities, government agencies, and private industry (Mass and Kuo 1998). In order for these regional modeling efforts to be successful and help the development of new mesoscale models (e.g., WRF model), it is imperative to complete objective verification of the model forecasts. There have been a growing number of verification studies evaluating operational models from the NCEP and research mesoscale model forecasts (e.g., Colle et al. 1999; White et al. 1999; Mass et al. 2001, among others); however, there has been limited verification of these models along the densely populated region of the U.S. East Coast.

The goal of this present study is to complete the first long-term verification and inter-model comparison of the Penn State/NCAR Mesoscale Model (MM5V2.12) and operational Eta over the eastern two-thirds of the U.S. during the cool and warm seasons. As a result, this study expands on previous long-term verification studies of the MM5 over the central and western U.S. (Manning and Davis 1997; Mass et al. 2001; 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. 2001; Colle et al. 2000). 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? (2) How does the verification between the MM5 and Eta change from the cool to the warm season? (3) What is the impact of increased spatial resolution around the coastal zone, urban corridor and Appalachians of the Northeast U.S.?

2. VERIFICATION OF MM5 and ETA

Since September 1999, SUNY-Stony Brook (SUNYSB) in collaboration with the Upton, NY NWSFO has been running the MM5 in real-time twice-daily at 36-, 12-, and 4-km grid spacings (see http://atmos.msrc.sunysb.edu/html/alt_mm5.cgi for details and domain locations). 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 32-km Eta model (currently the 22-km Eta) interpolated to the NCEP-221 grid (40-km horizontal resolution, 25 mb vertical levels). The MM5 is run for 48 h for the 36/12 km domains, and 36 h for the 4-km domain. The MM5 uses the MRF PBL, simple ice microphysics, and Kain-Fritsch cumulus parameterization.

The real-time MM5 has realistically simulated some

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

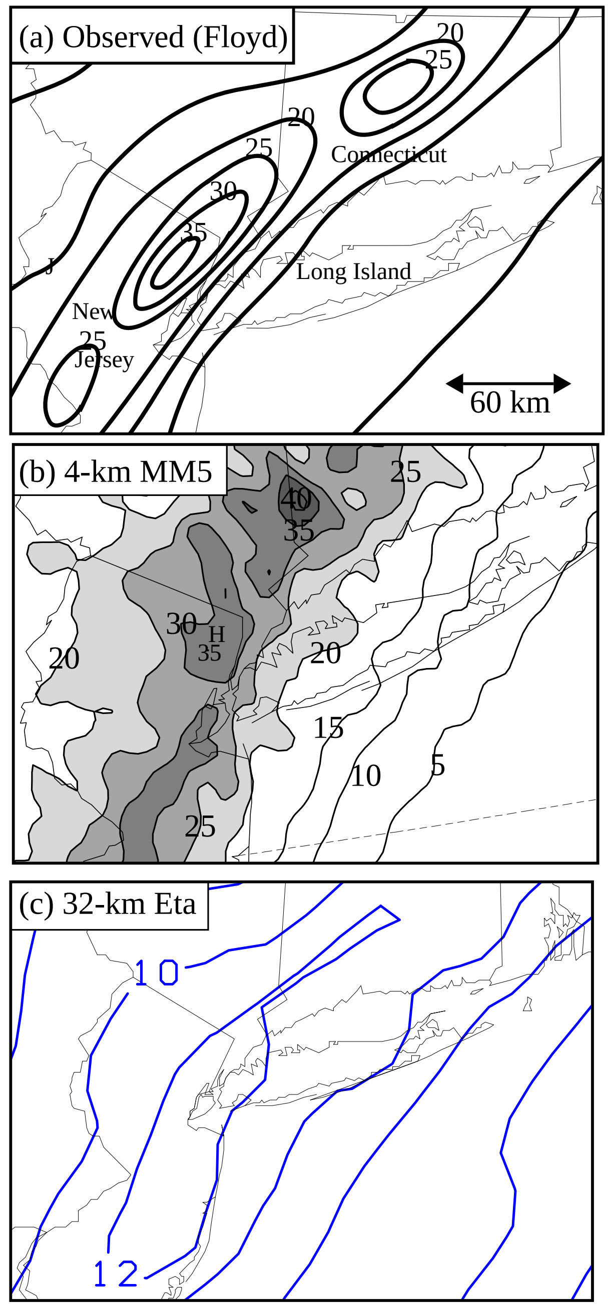

Figure 1. (a) Observed storm-total precipitation for tropical storm Floyd (contoured every 5 cm) derived using NWS and Cooperative observer rain gauges from 16-17 September 1999. (b) Same as (a) except for the 12-36 h forecast for a portion of the 4-km MM5 domain initialized at 0000 UTC 16 September 1999. (c) Same as (b) except for the 12-36 h forecast of the 32-km Eta contoured every 2 cm.

major East Coast storm events, such as tropical storm Floyd on 16-17 September 1999 (Fig. 1). During this event 25-40 cm of rain fell over a 12-24-h period from central New Jersey northeastward to Connecticut (Fig 1a). The NCEP Eta had a much weaker storm (5-10 mb too weak) as it approached Long Island (not shown), resulting in storm total of 10-14 cm (Fig. 1c). In contrast, the MM5, which used the Eta for initial and boundary conditions, had central pressures within 1-2 mb of observed along the East Coast (not shown), and heavy precipitation (20-35 cm) was predicted at 4-km resolution across northeast New Jersey (Fig. 1b). Even the 36-km MM5 generated 15-25 cm of precipitation in this region (not shown), which suggests that much of these Eta/MM5 differences result from differences in physics and/or numerics and not resolution.

Since November 1999 a long-term verification dataset has been collected at SUNYSB by bilinearly interpolating the model forecasts to the surface and rawinsonde sites. The 40-m MM5 winds were reduced to10-m using a logarithmic profile. The 40-m MM5 temperatures were "reduced" to the observation elevation using the standard (6.5 ^{o}C) lapse rate, and then averaged with the ground temperature to obtain a 2-m temperature. The NCEP-104 grids were used to verify the Eta for the same MM5 forecast days. Although the Eta grids have a coarse 80-km resolution, they still provide a baseline comparison with the MM5, and were the only long term Eta data available for the study period at SUNYSB.

Figure 2 shows the surface verification (12-36 h) from November 1999 through March 2000 for the 36-km MM5 and the 32-km Eta. Across the Eastern U.S. both models are 1-2 ^{o}C too cool over land and 1-5 ^{o}C too warm over the Great Lakes and Gulf Stream (Figs. 2a,b). Even the 40-m MM5 temperatures over the Gulf Stream are 0.5-1 ^{o}C warmer than the observed buoy temperatures (not shown). The MM5 has a slight surface warm bias in the lee of the Rockies, while the Eta has a large (2-4 ^{o}C) cool bias over the Rockies. The Eta moist bias along the East Coast is nearly twice as large as the MM5 (Figs. 2c,d), while the MM5 has a larger moist bias over west Texas. The Eta 10-m winds are 2-3 m s^{-1} too strong over the Eastern U.S. and Canada (Fig. 2e), while the MM5 winds are 1-2 m s^{-1} too strong in this region (Fig. 2f). This high windspeed bias is absent near the Rockies or above 900 mb across the Eastern U.S. (not shown).

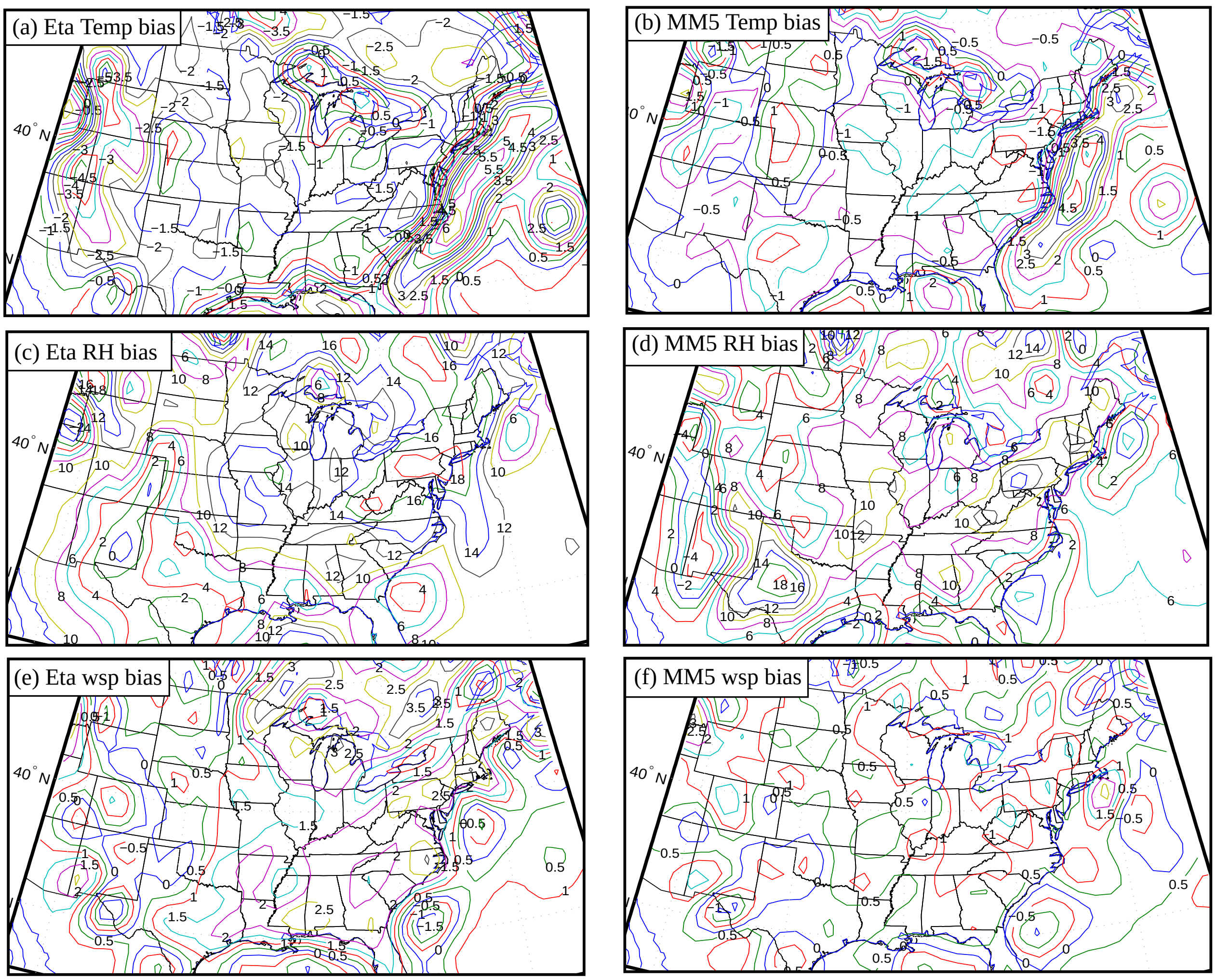

Figure 2. Surface cool season temperature bias for the (a) Eta and (b) MM5 (every 0.5 ^{o}C). (c) and (d) Same as (a) and (b) except for relative humidity (every 2%). (e) and (f) Same as (a) and (b) except for windspeed (every 0.5 m s^{-1}).

During the summer both the MM5 and Eta are too dry over the Eastern U.S. (5-10% in the Eta, 10-25% in the MM5) (not shown). This dry bias coincides with a surface 1-2 ^{o}C warm bias over land, which transitions with height to a cool bias between 900 and 700 mb (not shown). During the summer and winter around 200 mb both the MM5 and Eta have a ~1 ^{o}C warm anomaly, positive (moist) 10-20% relative humidity bias, and windspeeds 1-2 m s^{-1} less than observed.

The MM5 biases were also calculated for the 12-36 h 4-km forecasts over the coastal New York Bight region during the cool season (Fig. 3). At high resolution the biases are amplified for certain land-use categories. For example, the MM5 is 1-2 ^{o}C too cool around New York City and Philadelphia, PA (Fig. 3a), while only 0.5-1.0 ^{o}C too cool further inland and 1-2 ^{o}C too warm over the water. The relative humidities are also 8-14% too high (moist) near the urban areas and 3-7% too high for surrounding locations (Fig. 3b). The 4-km MM5 winds are 1-2 m s^{-1} too weak over the urban areas and 0.5-1 m s^{-1} too strong over the inland/coastal sites (Fig. 3c).

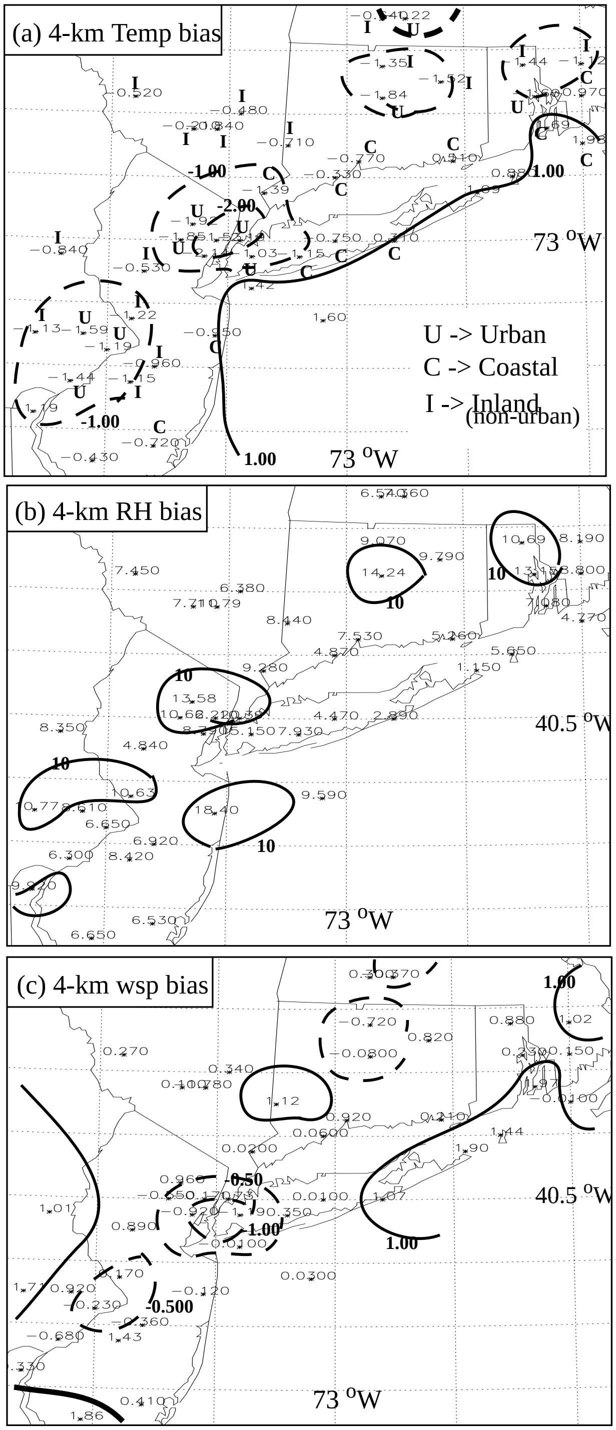

Figure 3. Cool season (November 1999 through March 2000) (a) temperature, (b) relative humidity, and (c) windspeed biases for the 12-36 h MM5 forecasts at 4-km resolution. The numbers indicate the biases at the individual stations, with temperature contoured every 1 ^{o}C (negative/cool bias dashed), relative humidity every 10%, and windspeed every 0.5 m s^{-1} (negative dashed). The coastal (C), urban (U), and inland (I) stations used for Fig. 4 are shown in (a).

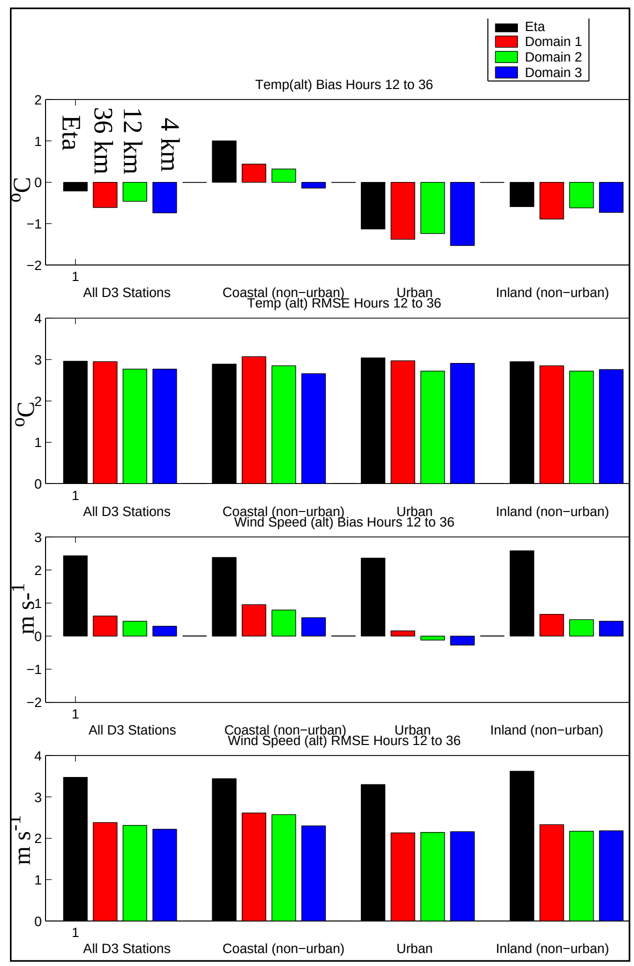

Figure 4. Cool season biases and RMS errors for temperature and windspeed from the 36, 12, and 4-km MM5 as well as the NCEP Eta for the urban, coastal, inland, and all stations within the 4-km MM5 domain. See Fig. 3a for station locations.

The surface stations within the 4-km domain were separated into coastal (C), urban (U), and inland (I) (see Fig. 3a) in order investigate how model skill changes for different locations and resolutions. Figure 4 shows the 12-36 h forecast biases and RMS errors for these categories for the 36,12, and 4-km resolutions of the MM5 as well as the NCEP Eta interpolated to a 80 km grid. For the coastal stations the warm temperature bias and associated RMS errors decrease from 36 to 4-km grid spacing since the 4-km has a more realistic coastline. However, the 4-km grid spacing has a more significant cold bias over the urban stations. As a result, when averaging all stations within the domain there is some improvement from 36 to 12 km but little additional skill between 12 and 4-km grid spacing. The 10-m Eta windspeeds are 2-3 m s^{-1} too strong at all sites, thus leading to large RMS errors. Meanwhile, because of the significant improvement in coastal windspeed biases between 12 and 4-km grid spacing in the MM5, there is some increased skill between 12 and 4-km on the domain average.

The MM5 precipitation at 36,12, and 4 km grid spacings was verified at Cooperative observer and NWS rain gauge sites during the 1999-2000 cool season (see Colle et al. 2000 for methods). Figure 5 shows the bias at the stations calculated by adding all the 12-km 12-36 h precipitation forecasts and dividing by the observed total. The 12-km MM5 produces too much precipitation along the windward slopes, especially downwind of Lake Erie and Ontario. In contrast, there is excessive precipitation shadowing in the lee of the Appalachians (a bias of < 110% likely represents underprediction since gauge undercatchment often exceeds 10% during the winter, Colle et al. 2000). These results are similar to the orographic region of the Pacific Northwest (Colle et al. 2000). However, with the more subtle topography over the Northeast U.S., the RMS errors do not decrease going from 36 to 12-km resolution when averaging all events (not shown). During the summer the Kain Fritsch scheme is too active at 12-km resolution, which significantly dries and warms mid-levels, resulting in significant underprediction in the 4-km resolution domain.

3. SUMMARY

This study illustrates some of the strengths and weaknesses of the MM5 and Eta across the Eastern U.S. Both models tend to be too cool and moist at low-levels during the cool season and too dry and warm during the summer. Some of these problems are enhanced in the SUNYSB MM5 since it used climatological values for soil moisture with no land surface model during this study. However, the Eta used a more sophisticated land surface model (e.g., continuously cycled soil moisture), yet the biases are similar and even worse for some variables (surface winds and wintertime low-level moisture).

This paper shows some of the benefits and deficiencies using high resolution over the Northeast U.S. For tropical storm Floyd the high resolution MM5 outperformed the operational Eta. However, during the cool season the 12-km MM5 tends to overpredict precipitation over the windward slopes and underpredicts in the lee. The 4-km MM5 resolves the urban and coastline regions better; however, the biases associated with these areas also become more pronounced. During the next few months the SUNYSB MM5 will switch to MM5V3.

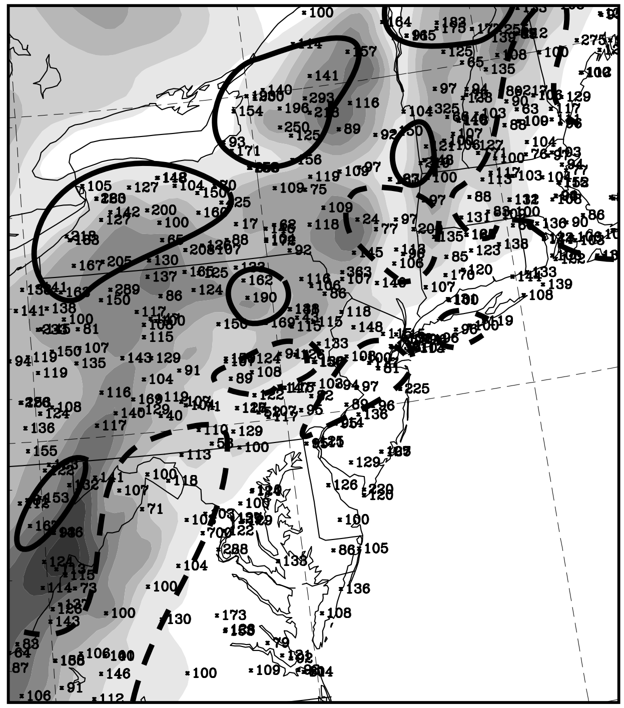

Figure 5. Bias scores (x 100) for the 12-km MM5 calculated by adding all the 12-36h model forecasts and dividing by the observed. The 110% and 150% lines are contoured with dashed and solid lines respectively. Terrain is shaded for reference.

4. ACKNOWLEDGEMENTS

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