# Evaluation of real-time high-resolution MM5 predictions over the Great Lakes Region

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## 1. Introduction

This paper presents validations of MM5 predictions for the 2002-2003 winter season (December – February) and 2003 summer season (June – August). The MM5 model has been run twice daily in real time since the beginning of summer 2002 in the Eastern Area Modeling Consortium (EAMC) in East Lansing, Michigan. The results were validated against both surface and upper air observations in the states neighboring the Great Lakes and the verifications were performed not only for variables that are traditionally included in forecasting validations, such as precipitation and surface temperature, but for properties that are important for air pollution and fire weather, such as mixed layer heights, inversion strengths, moisture content in the lower atmosphere, and lake-land breezes.

## 2. Model Configuration and Data for evaluation

MM5 is run with two-way nested grids initialized at 0000 and 1200 UTC using the NCEP's operational Eta model output. It is configured with four domains. The outer domain has a horizontal grid spacing of 36 km and covers the continental United States and the adjacent coastal waters as well as part of southern Canada. The middle domain, with 12-km grid spacing, encompasses north-central/northeast U. S. Nested within the 12-km resolution domain are two domains with 4-km grid spacing: the eastern 4-km domain covers the New England area, while the western 4-km domain encompasses the Great Lakes and the neighboring states. In the vertical, 35 unevenly spaced sigma levels are employed with vertical grid spacing stretched from approximately 10 meters above surface to 1500 m at the model top near 12 km. The model physics employed for the operational predictions includes the cloud radiation scheme (Dudhia 1989), the mixed phase cloud microphysics (Reisner et al. 1998), the Kain-Fritsch cumulus parameterization (Kain and Fritsch 1990), the Eta model boundary layer parameterization (Janjic, 1990) and the simple multi-layer soil model.

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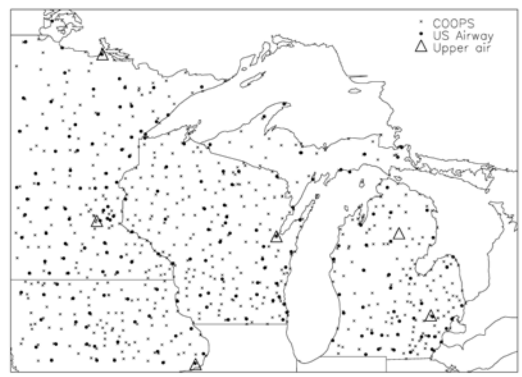
The validation of MM5 predictions is limited to the western 4-km domain over the Great Lakes region (Fig. 1). Data used for the evaluation are hourly observations from approximately 193 US Airway stations, daily summaries from 669 COOP sites, and 6 twice daily upper air sounding sites (Fig. 1).

The MM5 results at grid points are interpolated to the irregularly spaced observational sites using a Cressman-type interpolation scheme (Cressman 1959).




## 3. Results

### *a. Near surface properties*

Figure 2 shows time series of predicted and observed domain-mean and standard deviation of near surface variables, including daily maximum and minimum temperature, daily averaged temperature, specific humidity, and wind speed for summer. The forecasted daily maximum temperature values are consistently lower than the observed and minimum temperatures are always higher. Consequently, the amplitudes of the diurnal temperature cycles are smaller in the model forecasts, but the daily mean temperatures show good agreement with the observations because of the cancellation of the errors in the predicted daytime and nighttime temperature. The smaller forecasted diurnal cycles are consistent with a wet bias of 1-2 g $kg^{-1}$ near the model surface. Little bias is found in the forecasts of near-surface wind speeds. The cold and wet biases have been attributed in the past to an inadequate specification of soil moisture in the model, which is also likely to be the dominant factor here because the summer of 2003 is known to have been unusually dry in the upper Midwest and Northeast and the soil moisture values in the model, specified based on land-use categories, would not be representative for the general dry conditions.

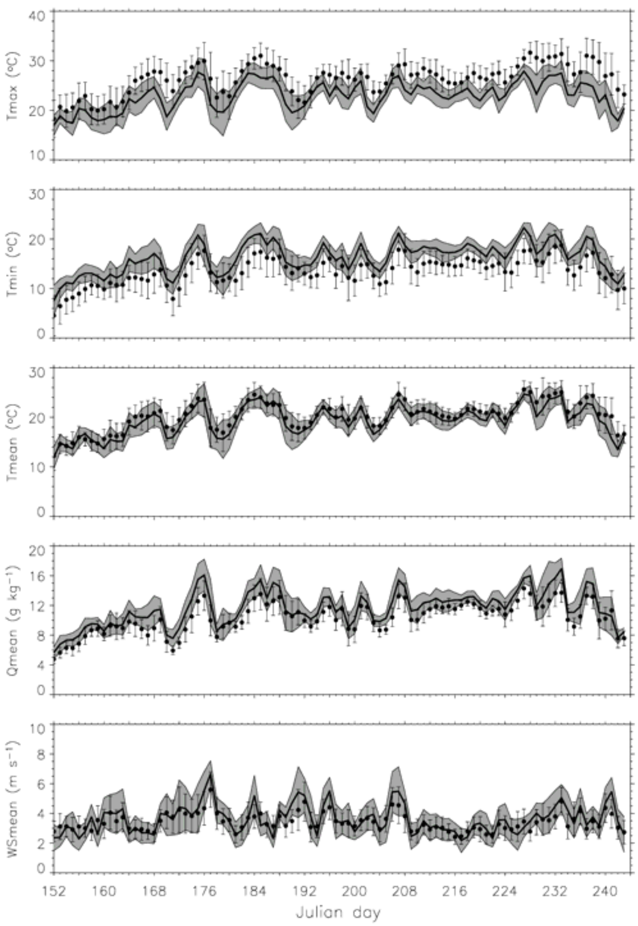



Fig. 2. Time series of observed and forecasted domain-mean values and standard deviations of daily maximum temperature, minimum temperature, daily mean temperature, specific humidity, and wind speed for summer season. The predicted and observed domain mean values and standard deviations are represented by the line, shading and open circles, bars, respectively.

### *b. Precipitation*

The model consistently over-predicted precipitation amounts for all months and the over-prediction is much worse in the 12-km results than the 4-km results (Fig. 3). The monthly total precipitation amount predicted with the 4-km grid spacing is 1.3 to 2 times higher than the observed, compared to 2-4 times higher in the 12-km predictions. Time series of domain-accumulated daily total precipitation are compared with the observed values and the comparisons are shown in Fig. 4 for the summer season. The forecasts appear to track the day-to-day changes of the observed precipitation reasonably well. The forecasted precipitation amounts were always higher than the observed except for a few days in the summer. The 12-km and the 4-km forecasts tend to closely track each other with the 12-km forecasted precipitation amount being persistently higher. The large error in the monthly total precipitation in June resulted primarily from the large over-forecasting of the most heavy precipitation event in the summer that occurred on 23-26 June (Julian Day 174-177). The over-prediction in domain-total precipitation is found to be a result of larger area coverage and/or substantially larger amount at some locations in the forecasts.

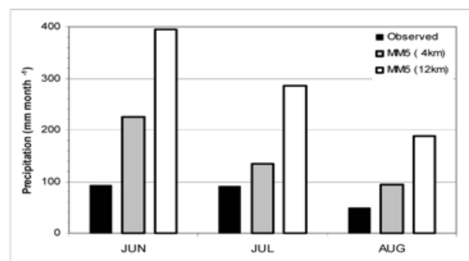
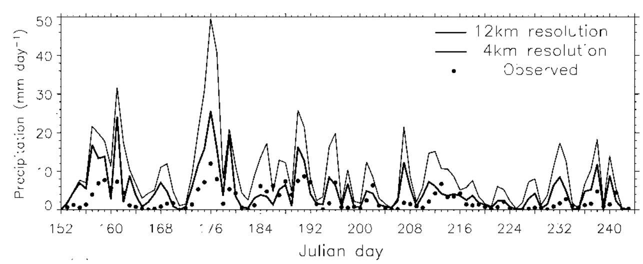



Fig. 3. Observed and forecasted monthly domain total precipitation for summer months.




### *c. Vertical structures*

Predicted vertical profiles of potential temperature, specific humidity, and wind are compared to the corresponding mean vertical profiles available twice per day at 0000 and 1200 UTC at the six sounding sites in the domain and the results for Detroit, MI are shown in Fig. 5. For the mean temperature, the predicted values are lower than the observed, especially in the lowest 1500 m, which corresponded to the average depth of the boundary layer. The values of the cold bias in the lower atmosphere are 2-3 $^{o}$C.

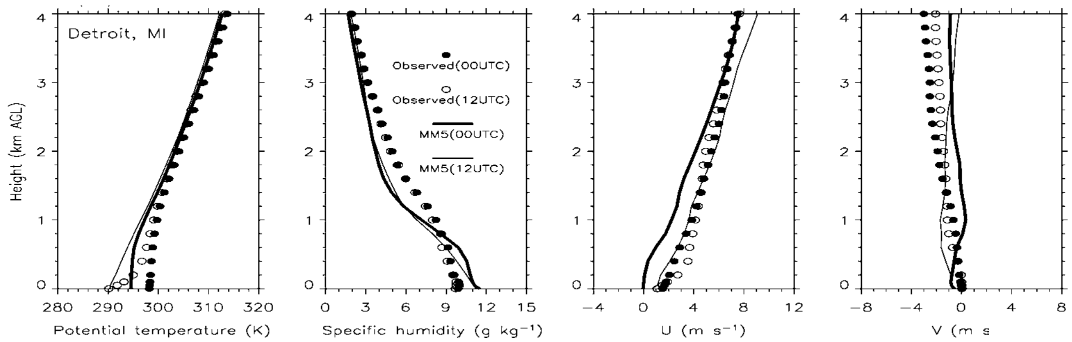



Fig. 5. Observed and forecasted mean vertical profiles of potential temperature, specific humidity, and u and v components of horizontal winds at 0000 and 1200 UTC at Detroit, Michigan for summer.

The predicted surface-based inversion at 1200 UTC appears to be much weaker than observed, becoming somewhat stronger than observed during winter. The predicted specific humidity profiles are wetter by 0.5 – 1.5 g $kg^{-1}$ in the boundary layer, and drier above the boundary layer. The errors in the two wind components, however, tend to cancel each other to produce total wind speeds that are in good agreement with the observed wind speeds.

The modeled mixed layer depths were compared to the observations at all six upper air sounding sites in the validation domain. The mixed layer depths are determined as the base of the elevated inversion using predicted and observed potential temperature profiles at 0000 UTC for the summer season and the results are shown in Fig. 6 for three sites. The predicted mixed layer depths exhibit no noticeable differences among the locations, consistent with the observations. However, at all locations, the predicted afternoon mixed layer depths are substantially lower than the observed. This under-prediction is consistent with results from earlier studies (Berg and Zhong 2004, among others) showing that the MM5 predicted mixed layer depths are very sensitive to boundary layer turbulence parameterization schemes. These previous studies focusing on a few cases concluded that boundary layer parameterization schemes in which turbulent mixing is determined based upon the predicted turbulent kinetic energy (TKE), such as the Eta boundary layer scheme employed by the current real-time predictive system, tend to under-predict mixed layer depths.

Another important boundary layer property affecting atmospheric near-surface dispersion is the surface-based radiation inversion at night. Not only is nocturnal inversion a key meteorological factor in air pollution, but also it has great impact on agriculture and aviation because of its role in the buildup of cold air pools in lower lying terrain and the formation of fog and frost. The MM5

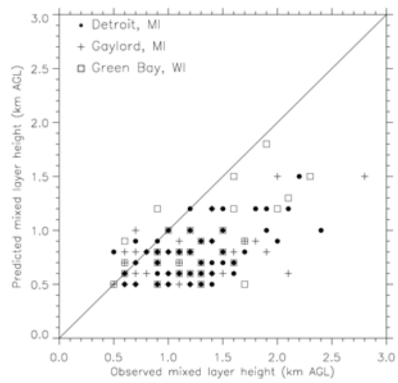



Fig. 6. Observed and forecasted mixed layer heights at 0000 UTC over Detroit and Gaylord, MI and Green Bay, WI for the summer season.

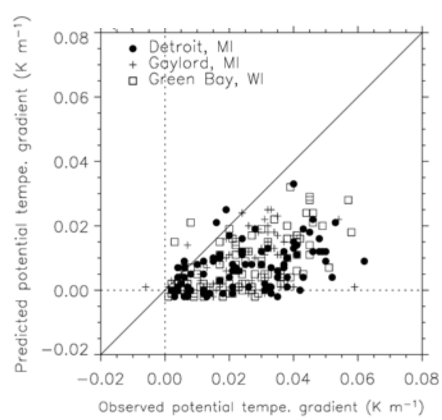



Fig. 7. Observed and forecasted 1200 UTC potential temperature gradients in the lowest 200m over Detroit and Gaylord, MI and Green Bay, WI for the summer season

predicted inversion strengths in early morning were evaluated using the 1200 UTC soundings and the results are shown in Fig. 7. The inversion strengths were determined by the potential temperature gradients between 10 and 200 m above ground. The sounding profiles were interpolated linearly to these levels before the gradients were computed. The data points from the three sites are mixed together, indicating small spatial variation of morning inversion strengths in both the forecasts and the observations. Except for a few data points, the predicted inversion strengths are much weaker than the observed. It is interesting to note that in the summer while the observed values are all positive, indicating an increase of potential temperature with height in the lowest 200 m, there are roughly 20% of the predicted values that are below zero. These negative values represent a decrease of potential temperature with height, suggesting that a mixed layer had already developed and grown to 200 m by 1200 UTC. An examination of individual potential temperature profiles corresponding to those negative data points confirmed that a mixed layer had indeed developed in the MM5 forecasts by 1200 UTC (0700 EST) just one to two hours after sunrise which occurred at 0458 EST on 1 June and 0556 EST on 31 August. The earlier development of a mixed layer in the forecasts is consistent with the fact that the predicted nocturnal inversion is significantly weaker than the observed, and consequently, less solar heating is required to break up the inversion before a mixed layer starts to grow. The head start of the mixed layer growth in early morning, however, failed to produce either a deeper afternoon mixed layer or a warmer convective boundary layer, suggesting that either the surface sensible heat flux in the model is lower than the observed or the flux divergence in the boundary layer may be too high. Unfortunately, no energy flux data are available to verify this hypothesis.

## 4. Summary and Conclusions

The model exhibited a cold bias of 1-3 $^{o}$C in the predicted daily maximum temperature and a warm bias of approximately 1 $^{o}$C in the minimum. The amplitudes of the diurnal oscillation of the predicted temperature are considerably smaller, but the predicted daily mean temperatures are in good agreement with the observation. The cold bias is not confined to near surface, but occurs in the entire boundary layer. The cold bias may be explained by a wetter predicted boundary layer that, in turn, can be attributed to an inadequate specification of soil moisture based on climatological value.

The model results have a substantially higher chance to produce precipitation when it is absent in the observation at a particular location than to miss an observed event. It appears that the over-prediction results primarily from more wide spread area coverage in the model results.

The predicted afternoon mixed layer depths are considerably lower than the observed. The predicted inversion strengths in early morning are significantly weaker than the observed inversion in the summer. The weaker surface-based inversion in the summer leads to a more rapid breakup of the inversion followed by an earlier development of a mixed layer in the morning forecasts. The forecasted head start of the mixed layer growth in the morning, however, fails to produce a deeper mixed layer in the afternoon, suggesting that either the surface sensible heat flux in the model may be too small, or there is too much flux divergence across the boundary layer. Given these relatively large errors in the modeled mixed layer development and nocturnal inversion strengths, extra cautions need to be taken when these properties are used in applications such as air pollution forecasting.

Finally, there is little difference between the 12-km and 4-km results in almost all the properties except for precipitation for which the decrease of grid spacing from 12 km to 4 km significantly reduced the bias of over-prediction in all categories.

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