J7.3 RECENT UPGRADES TO AND ONGOING CHALLENGS FOR THE REAL-TIME MESOSCALE ANALYSIS (RTMA)

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1. INTRODUCTION

In the fall of 2006, the Real-Time Mesoscale Analysis (RTMA) system (de Pondeca et al., 2007) was implemented at the National Centers for Environmental Prediction with the goal of providing a current national gridded verification system. In particular, it serves to verify the high-resolution predictions in the National Digital Forecast Database for which there is not a sufficient density of observations for a grid point verification. The current RTMA configuration consists of the Environmental Modeling Center's (EMC) Stage II National Precipitation Analysis, a NESDIS-based cloud analysis product, and EMC's two-dimensional variational analysis (Wu et al., 2002) of surface and near-surface variables. This paper will focus on these analyses of near-surface weather conditions.

While the dense surface observational network provides plenty of data for the RTMA, it must still incorporate a 3-dimensional atmospheric/land-surface model to introduce some consistency with land-water contrasts, terrain elevation, boundary layer structure, and local effects. The Rapid Update Cycle (RUC) serves as the first guess for the CONUS RTMA, with the one-hour forecast from the model downscaled to 5 km (Benjamin et al., 2007). For the Hawaiian, Alaskan, and Puerto Rican RTMA domains (with analyses at 2.5 km resolution), NAM forecasts are downscaled (Manikin, 2009) to serve as the first guess. The same downscaling technique is now applied to the Global Forecast System (GFS) to serve as the first guess (Chuang 2011) for the new Guam RTMA. A full description of the RTMA can be found in de Pondeca et al. (2011).

2. SEPTEMBER 2010 UPGRADE

A significant upgrade to the CONUS RTMA was made on 28 September 2010. The important components of the implementation are described in the subsequent three subsections.

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2A. RESOLUTION UPGRADE

The 5 km resolution is insufficient to resolve much of the terrain in the western U.S., and the RTMA analyses have suffered accordingly in this part of the country. Computer resources have finally allowed the CONUS analyses to be run with a resolution of 2.5 km, and these are now being produced. The 5 km analyses are still available while users transition to the new files. An example of the improvement gained by increasing the resolution is shown in Fig. 1. The 2.5 km temperature field shows much greater detail over the higher terrain of Colorado.

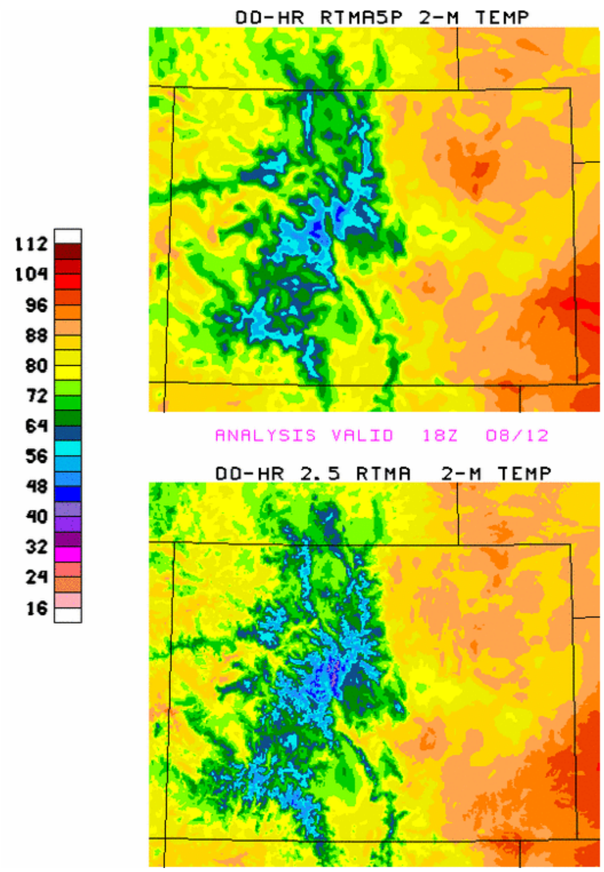


Fig. 1. RTMA 2-m temperature analyses (°F) valid 1800 UTC 12 August 2010 over Colorado at 5 km resolution (top) and 2.5 km (bottom).

Another example is shown in Fig. 2, with the 5 and 2.5 km analyses compared over southern California and the adjacent southwest states.

The detail over the higher peaks of the Sierra Mountains and the adjacent valleys in the 2.5 analysis is again a major improvement over the lower resolution. The Colorado River basin in northern Arizona also shows up much better in the 2.5 analysis.

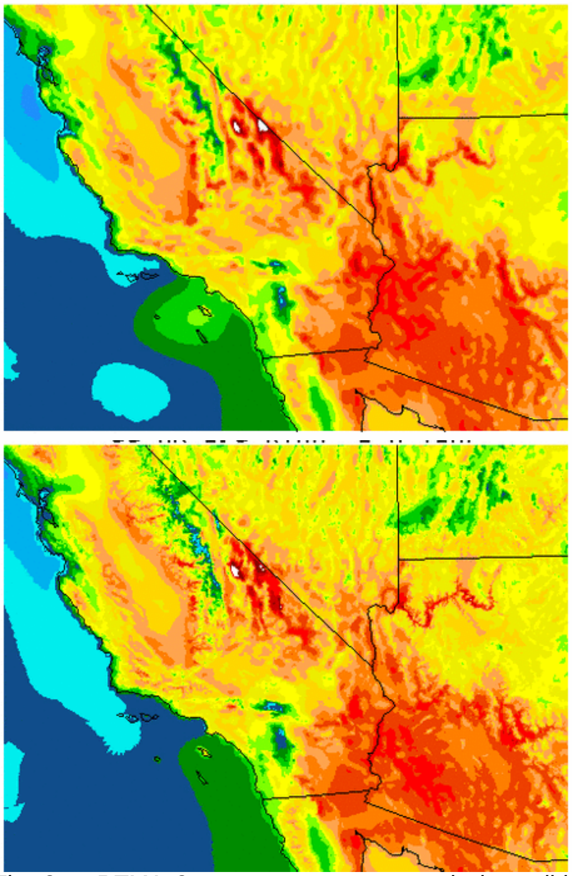


Fig. 2. RTMA 2-meter temperature analysis valid 1800 UTC 30 September 2010 with horizontal resolution of 5 km (top) and 2.5 km (bottom).

Various local geographical features are better resolved at 2.5 km, and the resulting analyses for these areas are much improved. One such feature is the peninsula extending out from the Ohio shoreline near Sandusky. Fig. 3 shows that the 5 km analysis fails to resolve most of this land area and treats it like the cooler lake, while the 2.5 analysis captures it quite well.

2B. FGAT

The original version of the RTMA used a time observation window of +/- 12 minutes. The concept of “First Guess at the Appropriate Time” (FGAT) has been constructed to use data more representative of the given hour for which the analysis is made; for example, it can be difficult to accurately assimilate an observation made at

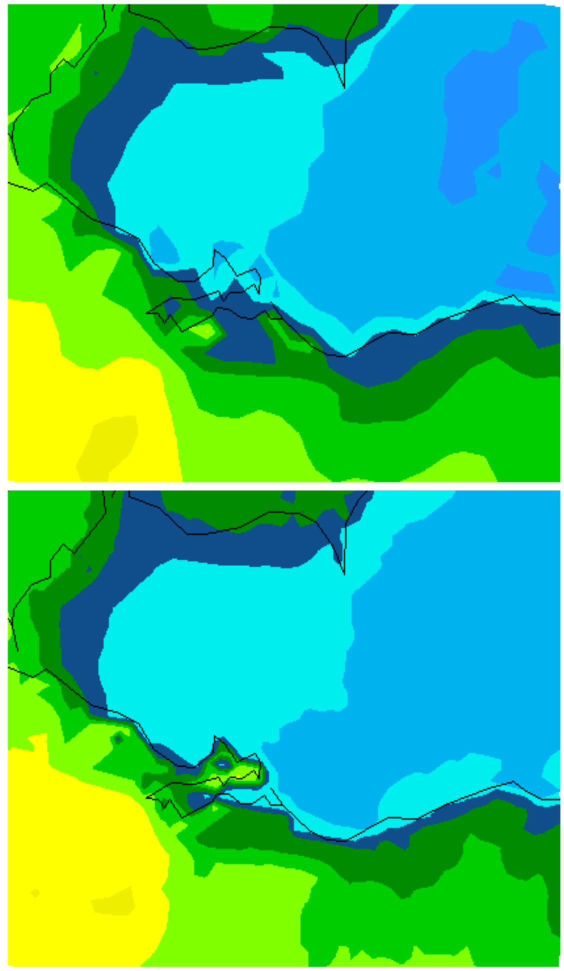


Fig. 3. RTMA 2-meter temperature analysis valid 2100 UTC 14 September 2010 along the shoreline of northern Ohio with horizontal resolution of 5 km (top) and 2.5 km (bottom).

35 minutes past 1500 UTC using a first guess valid at 1600 UTC. As part of the recent upgrade, the RTMA now uses the FGAT concept. In this scheme, the observation increment is computed for the exact report time with a first guess constructed by interpolating several first guess fields valid at different times within the assimilation time window. FGAT helps prevent unrealistically large observation minus background increments that can result when the observation time is far away from the analysis time. The FGAT has a positive feedback mechanism in that improved increments lead to better analyses and dynamic reject lists which lead to more improved analyses down the line. This has also allowed the assimilation time window to be expanded to +/- 30 minutes for all conventional observation types. Satellite-derived WindSat and ASCAT

data are now being used with a time window of -3h / +1h.

An example of an improved forecast likely due to FGAT is shown in Figures 4 and 5. A mesonet site over central Utah is reporting several varying dew points (not shown) within the time window, with at least some of the values quite erroneous, leading to the 5 km analysis having a dry bullseye feature. The FGAT is likely helping to improve the guess in that area by helping the site in question to be included on the dynamic reject list, allowing the analysis code to reject the questionable observation at this hour. The 2.5 km analysis with FGAT (and also increased resolution and a longer time window for observations), shown in Fig. 5, looks significantly better.

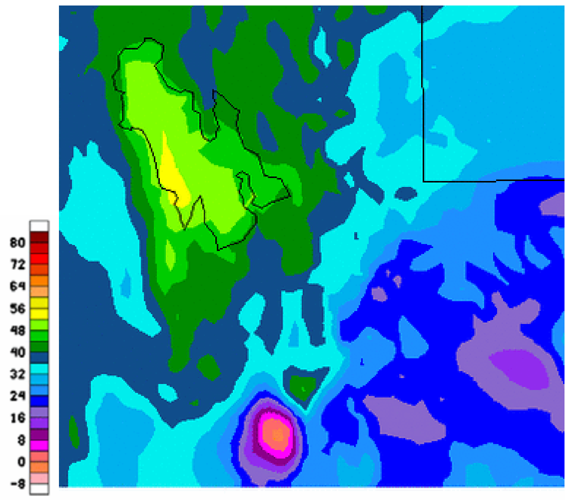


Fig. 4. 2-m dew point analysis (°F) over Utah from the 5 km RTMA valid 1800 UTC 12 August 2010.

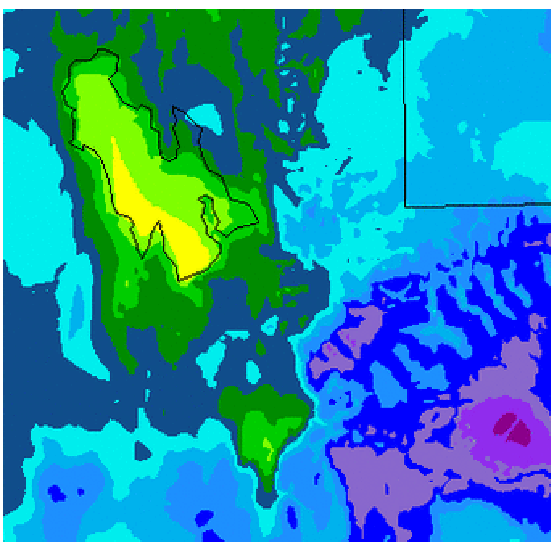


Fig. 5. Same as in Fig. 4, except for the 2.5 km RTMA.

2C. BIAS CORRECTION

As noted in Manikin and Pondeca (2009), RTMA analyses can suffer when the first guess in a particular region is particularly egregious. This is especially true in regions where snow is on the ground or the RUC believes that snow is on the ground. The RUC cycles its own snow, meaning that predicted precipitation falling as snow accumulates in the model, and the model must then melt it in future cycles. The model has a mechanism in place to eliminate erroneous model snow cover, but if the RUC fails to clear snow cover that no longer exists in reality, the resultant first guess can be far too cold. The analysis code in these cases often determines that the valid observations deviate too much from the guess, and only small increments at best are applied. And even if the RUC has an accurate snow cover, a cold temperature bias may still exist in the model.

Bias correction, however, can help with these cases, and this was added to the 2.5 km RTMA for temperature in the 2010 upgrade. A sequential bias correction algorithm is applied to the background temperature with a decaying average used to update the bias. Fig. 6 shows a RUC snow cover analysis over the northeast, Fig. 7 shows the observed temperatures in this region, and Fig. 8 shows the first guess temperature from the RUC without any correction.

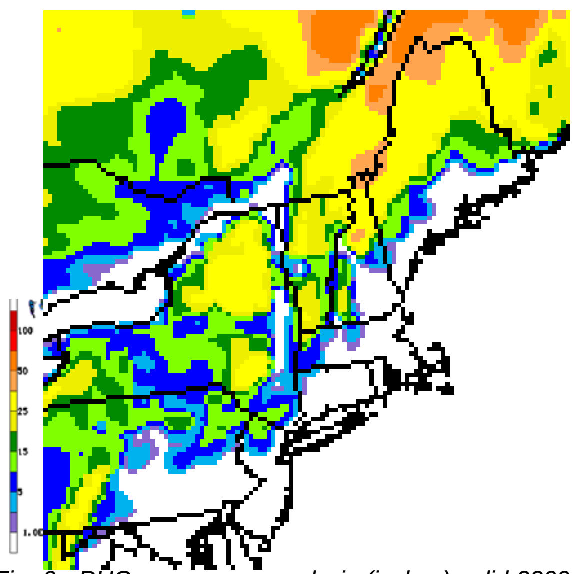


Fig. 6. RUC snow cover analysis (inches) valid 2200 UTC 11 March 2010.

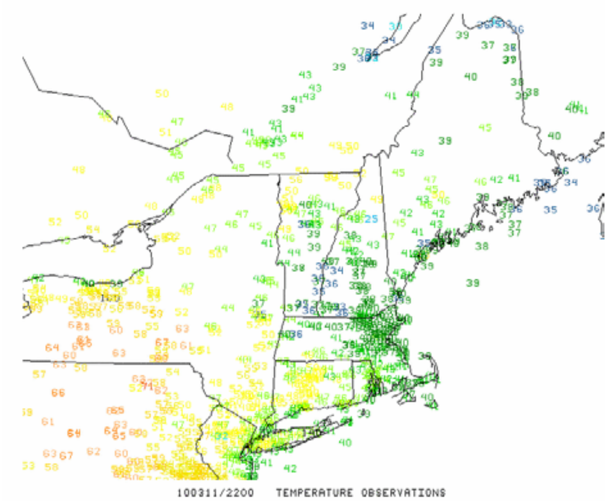


Fig. 7. Observed surface temperatures valid 2200 UTC 11 March 2010.

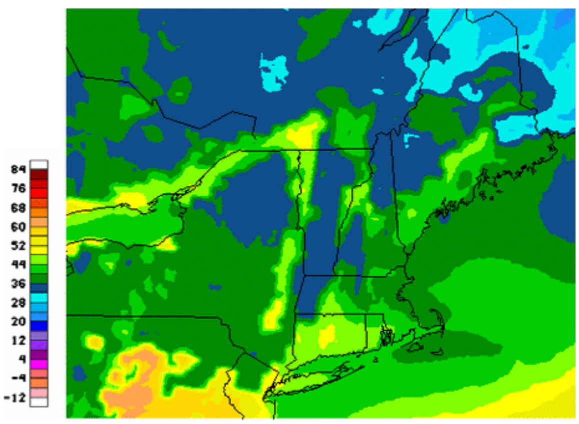


Fig. 8. RTMA 5 km 2-meter temperature guess valid 2200 UTC 11 March 2010.

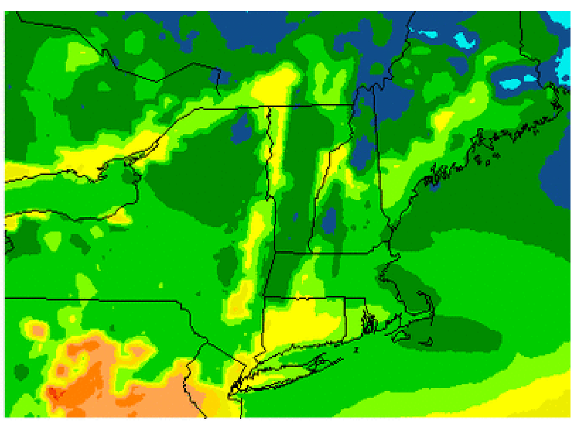


Fig. 9. Same as in Fig. 8, except with bias correction.

The guess is clearly far too cold over much of New York, northern Pennsylvania, and parts of New England, with errors even exceeding 25°F in a few locations. The impact of bias correction is shown in Fig. 9 with an improved first guess in these regions (note that the operational 5 km RTMA does not yet use the bias correction as of January 2011; the plot is from a test version). The impact of this bias correction is shown in Figures 10 and 11. The original analysis is burdened by the colder guess, and even though the observations steer the values in the proper direction, the temperatures are still too cold over much of western and northern New York, northern Pennsylvania, Vermont, and northern New Hampshire and Maine. The analysis made with the bias-corrected guess is correctly warmer in all of these areas.

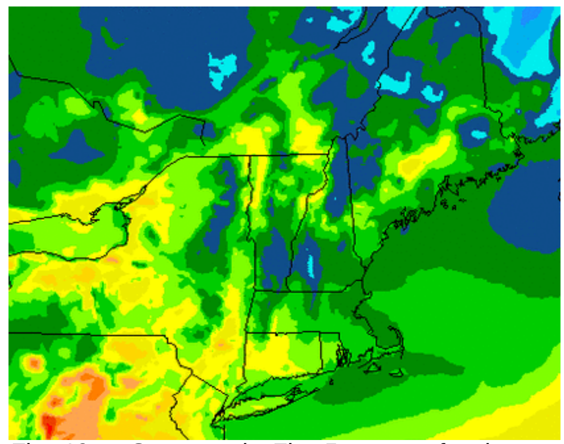


Fig. 10. Same as in Fig. 5, except for the actual analysis from the 5 kim RTMA.

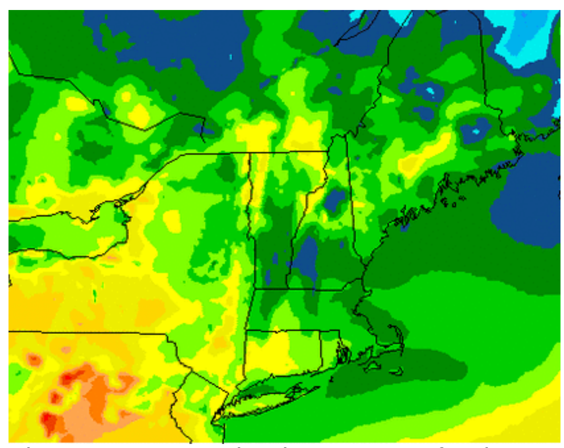


Fig. 11. Same as in Fig. 7, except for the actual analysis with bias correction.

3. ONGOING CHALLENGES

The past sections describe several recent improvements added to the RTMA to deal with the many challenges associated with generating a high-resolution real-time analysis. The next sections discuss ongoing challenges for which solutions are still being developed and tested to be included in future upgrades.

3A. TROPICAL SYSTEMS

Another major first guess issue pertains to tropical systems. Hurricanes making landfall with the accompanying intense wind field passing through the coastal waters provide the type of high-impact event for which an accurate, detailed analysis of the wind field is very desirable, but the RTMA has struggled in such events. The first guess again can create an insurmountable deficit for the analysis to overcome. This has been repeatedly observed during each tropical season.

Fig. 12 shows the RTMA 10-meter wind speed analysis at a time when Hurricane Earl was passing just east of the North Carolina coast in September 2010. The National Hurricane Center assigned a sustained wind speed of 90 knots with this storm, but the analysis shows a maximum speed of 50-55 knots, and it fails to capture the common structure of a hurricane. With limited observations off of the coast, the analysis is dependent upon a good first guess, but the speeds in the guess (not shown) are far too weak. And even where there are observations capturing the stronger winds, they are likely to deviate so far from the guess that the quality control might unfortunately reject them.

The solution to this issue is to bring in a first guess from NCEP's Hurricane Weather and Forecasting (HWRF, Gopalakrishnan et al., 2010) model in events with tropical systems and blend it with the standard RTMA guess. Fig. 13 shows the analysis generated after using this blending for the Earl case, and the result is an analysis with wind speeds much closer to those likely associated with the storm as well as a structure of the wind field resembling a classic hurricane. This capability for the first guess will be added to the RTMA during 2011.

3B. MESONET WINDS

Mesonet winds are an incredibly valuable data source, but there are some quality control issues that provide a challenge for the RTMA. Fig. 14 shows METAR wind speed observations over the midwest region on a day with a strong pressure gradient that induced winds that caused widespread damage and power outages. Across the main area of interest covering Michigan, Illinois, Indiana, western Ohio, and central Wisconsin, all of the available METAR

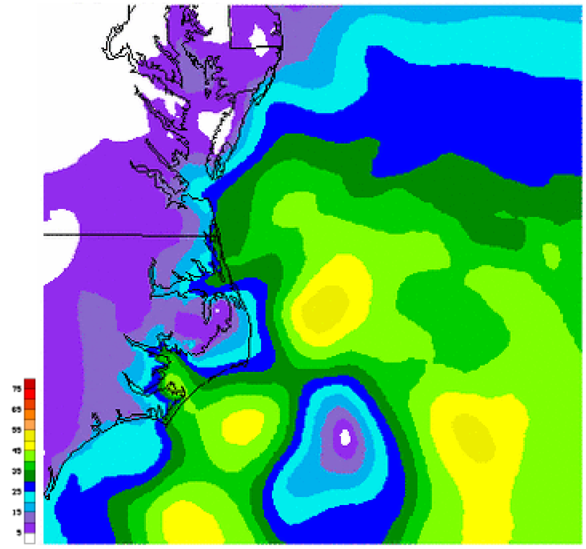


Fig. 12. RTMA 5 km analysis of 10-meter wind speed (knots) valid 0800 UTC 3 September 2010.

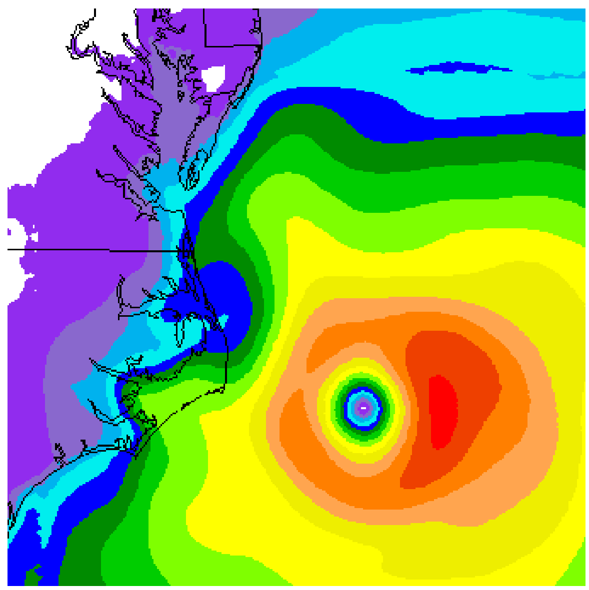


Fig. 13. Same as in Fig. 12, except with the blended HWRF first guess.

stations reported 14 knots or stronger at 1900 UTC.

Fig. 15, however, shows the mesonet observations, centered around the same hour, that were available to the RTMA. There are many reports of wind speeds under 5 knots, across the area of interest and plenty of values under 10 knots (purple) throughout the domain. There are even a few 0 values scattered throughout the region. The mesonet winds have a known low bias, and the RUC assimilates them now with a list of "approved"

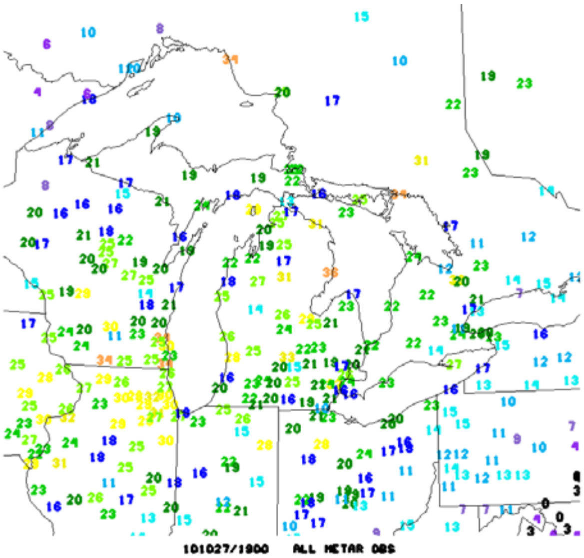


Fig. 14. METAR wind speed observations (°F) at 1900 UTC 27 October 2010.

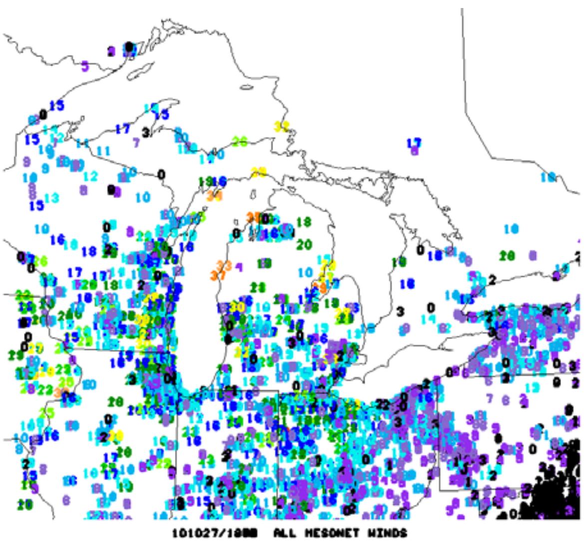


Fig. 15. Mesonet wind speed observations at times close to 1900 UTC 27 October 2010. All numbers in black have a value of 0, and all numbers in purple represent values less than 10 knots.

stations after years of not including them due to quality control issues (Benjamin et al., 2007).

Fig. 16 shows the RTMA wind speed analysis for this time, and the impact of the mesonet wind observations is quite dramatic, with several "blotches" of low wind speed in Indiana, Michigan, Wisconsin, Ohio, and Illinois.

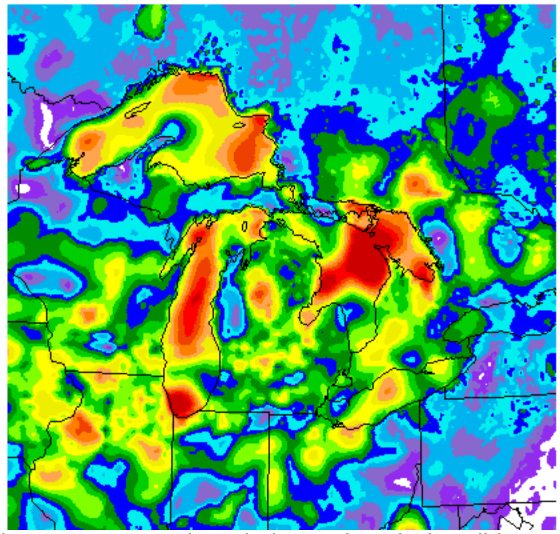
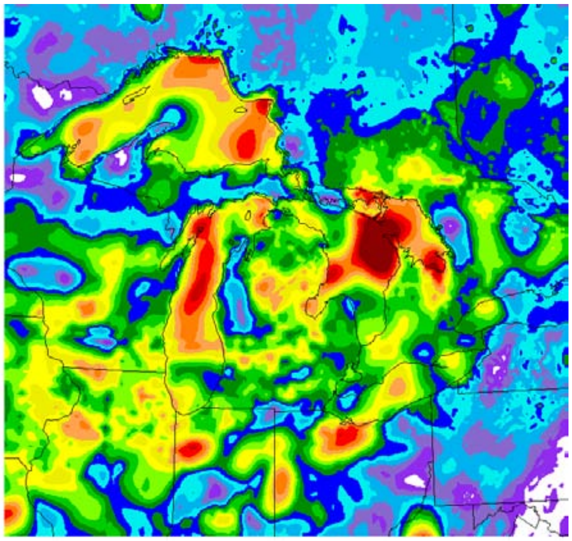


Fig. 16. RTMA 5 km wind speed analysis valid 1900 UTC 27 October 2010.

Dealing with the low wind speed bias of the mesonets is not simple. The static dynamic and reject lists help significantly, but they do not solve all of the issues. It was suggested to have the quality control reject an observation for which the wind speed is less than the guess when the guess speed exceeds 15 knots. Fig. 17 shows the result of a run made using this concept. There is some promise in the result – speeds appear to be improved over parts of northern Indiana, northern Ohio, and central Michigan. Some of the wind speeds over the lakes, however, are decreased, and that is not likely a good result. The added strong maxima in northern Indiana and Ohio are dubious, and the erroneous minima over Wisconsin, Michigan, and northern Indiana are not changed. Much work is needed before this code can be added to the RTMA.

Finally, the result from the 2.5 km version is shown in Fig. 18. The 2.5 version benefits from the FGAT, which leads to better dynamic reject lists, and it also has longer correlation lengths and gives more weight to the guess. In this analysis, there is significant improvement over Wisconsin, northern Indiana, and western Michigan. On the other hand, the speeds over the Great Lakes are greatly reduced, and this again is not likely a good result. The larger correlation lengths appear to reduce the impact of the low mesonet wind speed bias but also reduce some of the desired maxima.



Fig, 17. Same as in Fig. 16, except for the experiment in which observations are rejected if they are less than the first guess at a location where the speed in the guess exceeds 15 knots.

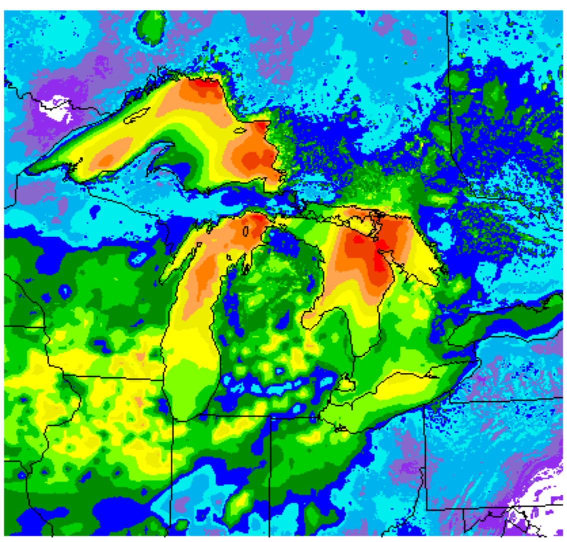


Fig. 18. Same as in Fig, 16, except for the 2.5 km version of the RTMA.

3C. BAD OBSERVATIONS

Many steps have been taken in recent years to help the RTMA eliminate the use of "bad" observations which can lead to spurious features in the analyses. The static and dynamic reject lists significantly improve the ability of the system to throw away bad data, but this issue remains a significant challenge.

Consider the METAR and mesonet observations over western New York shown in Fig. 19. No observation shows a wind speed greater than 10 knots, except for the Oswego County Airport (FZY) in Fulton, located just

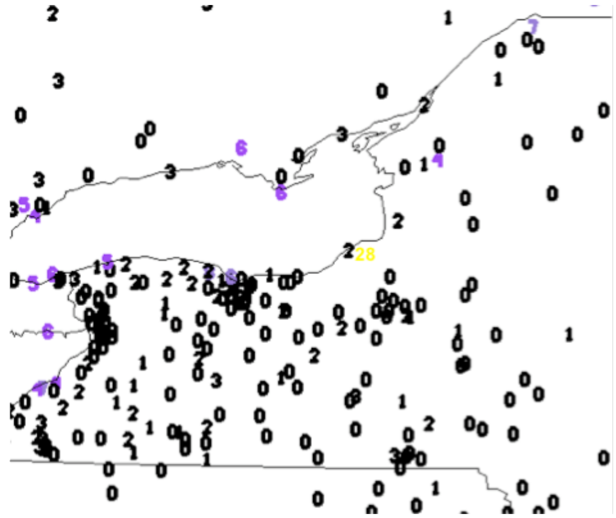


Fig. 19. Surface wind speed observations (kt) over western New York at 1200 UTC 26 September 2010.

inland from the southeast corner of Lake Ontario, showing 28 knots.

Based on the other data in the region, and the fact that FZY does not show a wind speed nearly that strong at any other hour (not shown), it is likely that the data is not valid. The 5 km RTMA, however, does assimilate it, and Fig. 20 shows a bullseye of fast wind speed in that area.

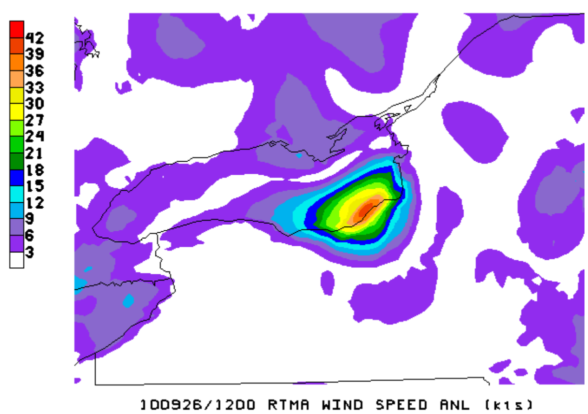


Fig. 20. RTMA 5 km analysis of wind speed (kt) valid 1200 UTC 1200 UTC 26 September 2010.

The analyzed maximum speed of approximately 40 knots is much stronger than the observation. The likely cause of this is overfitting. Fig. 21 shows the first guess for the analysis. The guess is stronger in areas just west of FZY out over the water, and the large increment is applied to already larger values there.

Dealing with bad observations is tricky. In this case, a METAR provided the erroneous report,

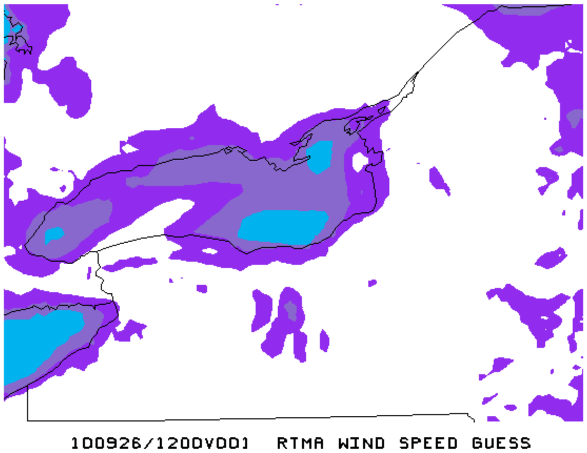


Fig. 21. Same as in Fig. 20, except for the first guess for the analysis shown in Fig. 20.

and METAR data is generally assumed to be valid, so the gross error check is reduced for this data type. Perhaps the increments should be reduced when a METAR observation is that far off of the first guess. Having a buddy-check in which an observation is checked against nearby values might have helped here too. These two things are part of a non-linear quality control code which is currently being developed for the RTMA.

3D. DRYLINES

Drylines present a major challenge for the RTMA in trying to analyze the intense moisture gradient. Fig. 22 shows dew point observations in Texas and Oklahoma for a dryline event, with the boundary extending from south-central Kansas south to just west of the Dallas-Fort Worth metroplex and then south to the Rio Grande near Del Rio. The dew point varies up to 50°F within a few miles across the dryline in certain areas. It must immediately be noted that the RTMA does not analyze dew point directly; specific humidity is the moisture variable.

The RTMA dew point analysis is shown in Fig. 24. The overall position and handling of the gradient are quite good, but there are several pronounced areas of erroneously low dew points analyzed just west of the boundary with some values well below 0. This is not an issue with the guess (shown in Fig. 23), and while there are clearly a few bad observed values in Fig. 22, the analysis was found to reject most of them, so this is also not the source of the problem. The issue is that if the guess is slightly off with the position and/or magnitude of the gradient, very large negative (positive) analysis increments can develop. These get applied to neighboring points in addition to the location of the observation, and even if the initial guess there was accurate, the value at that point gets significantly reduced (increased) anyhow.

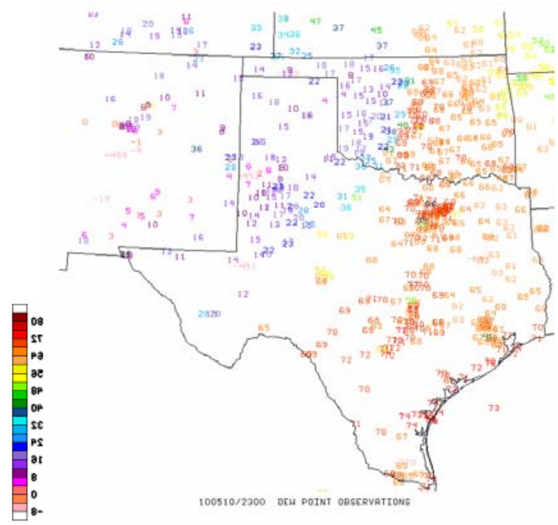


Fig. 22. Surface dew point observations (°F) valid at 2300 UTC 10 May 2010

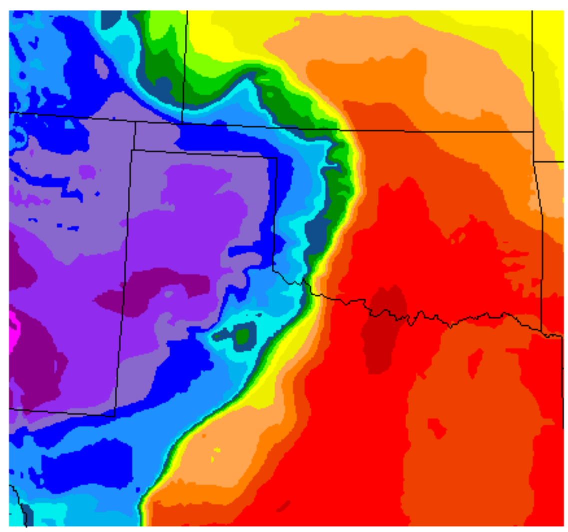


Fig. 23. First guess of 2-meter dew point for the 5 km RTMA valid 2300 UTC 10 May 2010.

Drylines will likely continue to provide a major challenge to the RTMA. Any feature with a very tight gradient can pose such risks, as large increments may be incorrectly imposed over a large area. Code changes in recent years impose restrictions on negative moisture increments being applied to already dry values, and this has helped, particularly in the dew point analyses in the very dry air west of the boundary.

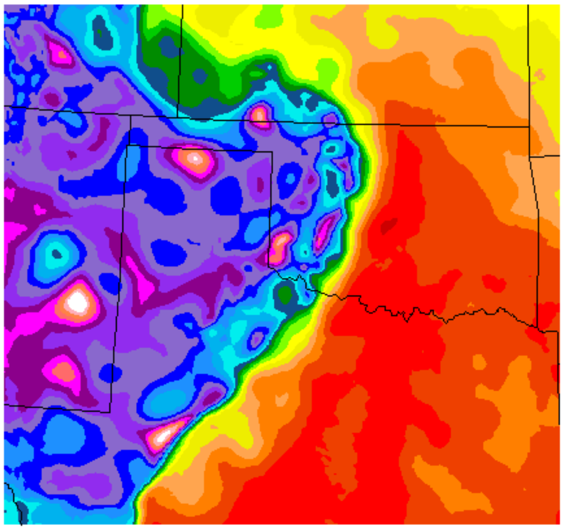


Fig. 24. 5 km RTMA analysis of 2-meter dew point valid 2300 UTC 10 May 2010.

But there is much work to be done in dealing with applying increments along the dryline itself. Future plans include analyzing dew point directly to avoid the intermediate step of the specific humidity analysis. An idea for the future is to constrain the covariances, and thus the analysis increments, to follow the contour lines of the first guess dew point field to some extent.

4. ACKNOWLEDGEMENTS

The authors thank the many users and evaluators of the RTMA who have helped and continue to help identify cases in which there are issues with the analysis. Dave Myrick of the National Weather Service's Western Region Headquarters has been particularly tireless in his efforts. We also thank Bill Callahan of AWS Convergence Technologies, Inc. for permission to use the mesonet data in figures in this paper to greatly enhance verification.

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