1A.1 CHALLENGES WITH 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 2-meter temperature and dew point and 10-meter winds on a 5 km grid.

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, NAM forecasts are downscaled (Manikin, 2009) to serve as the first guess. The same downscaling technique will be applied to the Global Forecast System (GFS) to serve as the first guess for the upcoming Guam RTMA.

2. REPRESENTATIVE OBSERVATIONS

When attempting to construct a high-resolution analysis, there are always questions of what represents a representative analysis in regions of high data density. Fig. 1 shows all temperatures in the Phoenix, Arizona metropolitan area within a +/- 20 minute analysis time on a given morning in April 2009. These include METAR reports as well as many mesonet stations. Values range from the upper 40's to the middle 60's. In some locations, observations between two locations only a few kilometers apart vary up to 13°F. Deciding which observations are "valid" and represent legitimate mesoscale variability instead of error as part of a quality control system for the RTMA is a tricky process. Dealing with observations valid at different times within the 24 minute RTMA assimilation window with a first guess valid at the top of hour is also not a trivial issue. The analysis for the observations shown in Fig.1 is shown in Fig. 2. While it appears to generally capture the overall picture of cooler locations vs. warmer, it doesn't fully capture the fine-scale detail of the observations (assuming that all of the observations are valid).

Fig. 1. Temperature observations in the Phoenix, AZ metropolitan area centered around a time of 1200 UTC 27 April 2007. Units are degrees Fahrenheit.

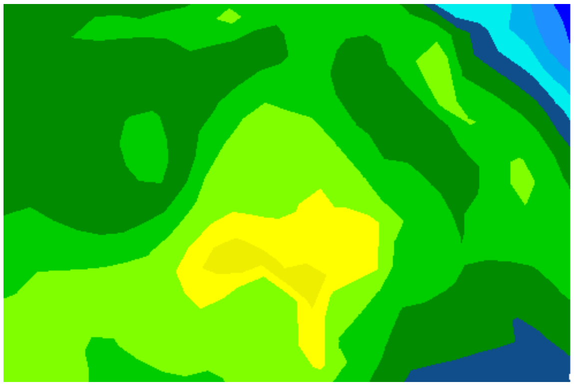

Fig. 2. RTMA 2-meter temperature analysis for the same valid time and area as in Fig.1, using the same color scheme.

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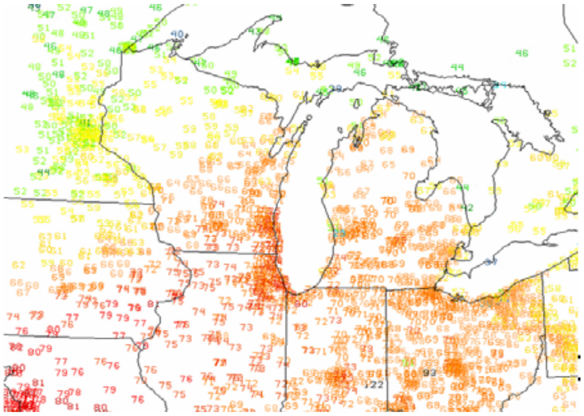
3. THE FIRST GUESS

The background field, or “first guess” for the CONUS RTMA is provided by a downscaled 1-hour RUC forecast. If the guess is significantly different from the observations, the RTMA may fail to draw properly for the data – the difference may be too large for the assimilation to overcome, or the quality control may even reject the observations This can be a major problem in situations in which the RUC is struggling. For example, the RUC had difficulty with snow cover and temperatures over snow cover during the spring of 2009. As a result, the first guess in these situations for the RTMA was often far too cold, with a major impact on the analysis. Fig. 3 shows the surface temperature observations for a March case, with Fig. 4 showing the RTMA 2-meter temperature analysis.



Fig, 3. Surface temperature observations for 2100 UTC 17 March 2009. Units are degrees F. The color code is the same used in Figs. 4 and 5.

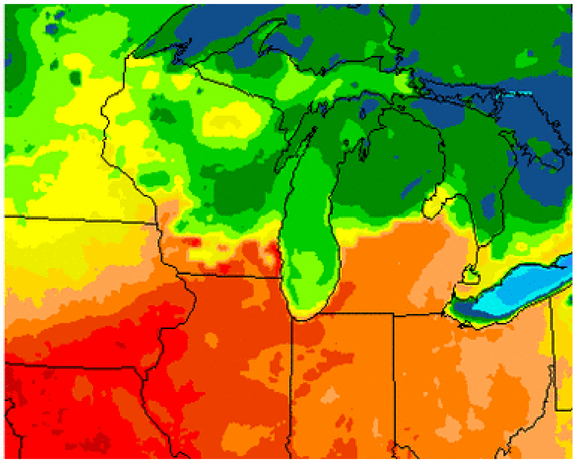


Fig. 4: RTMA 2-meter temperature analysis valid at 2100 UTC 17 March 2009.

The analysis is clearly far too cold over much of the northern half of the lower peninsula of Michigan and much of Wisconsin with errors even exceeding 30°F. The problem arises from a cold RUC first guess over these regions, shown in Fig. 5. 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. Prior to April 2009, no outside snow analysis was used by the model, but after cases such as these, a change was made to the model to use the NESDIS snow analysis once per day to eliminate snow cover where the model incorrectly believes it exists (See Section 8). The RUC however, still has an issue with temperatures being too cold over snowpack, particularly in daytime warm advection events.

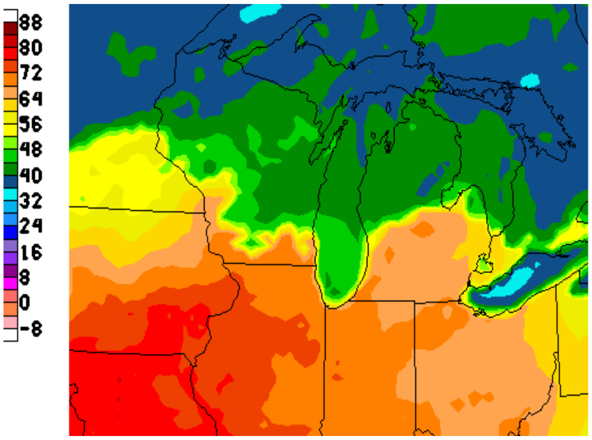


Fig. 5. 1-hour RUC forecast of 2-m temperature valid 2100 UTC 17 March 2009.

Another major first guess issue pertains to tropical systems. Landfalling hurricanes 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 was repeatedly observed during the late summer and early fall of 2008.

Fig. 6 shows observations available to the RTMA, taken a couple hours after Hurricane Gustav had made landfall along the southern Louisiana coast in September 2008. At this time, the center of storm was inland with maximum sustained winds of 80 knots. The RTMA analysis shown in Fig. 7 shows wind speeds nowhere close to the maximum, and it fails to even fully draw for the nearby observations in the 35-40 knot range west of

New Orleans, although the speeds over southeastern Louisiana look quite reasonable. The major contributor to this problem again is a weak RUC guess shown in Fig. 8. The model has an extremely weak wind field with the center of the storm still offshore. Given that landfall was in an area with few observations and therefore having a strong dependence on the first guess, it is not surprising that the RTMA fails to indicate any sort of strong wind field. It should be noted, though, that the RUC is not intended to be a short-range predictor of deep tropical systems and has no method of correctly initializing the strength or position of a tropical vortex like some other models (such as the Global Forecast System (GFS)) do. There is no intent here to indict the RUC for its background field – we merely point out issues related to usage of the first guess to assist in the analysis process.

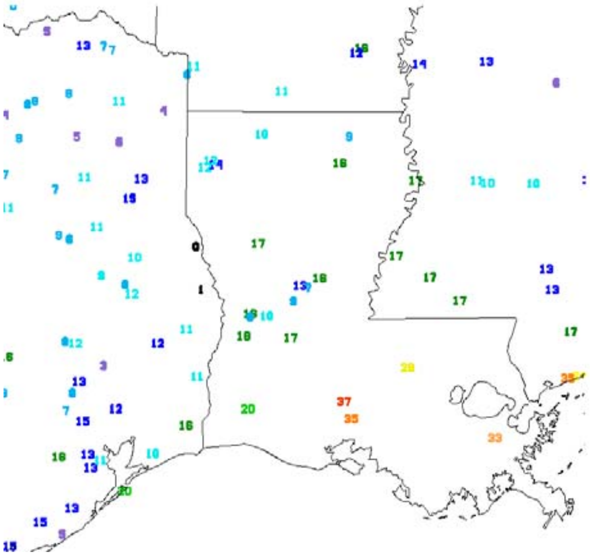


Fig. 6. Observed wind speed (knots) at 1800 UTC 1 September 2008. At this time, Hurricane Gustav is located over south-central Louisiana with maximum sustained winds of 80 kt. Color coding is not the same as in Figs. 7 and 8.

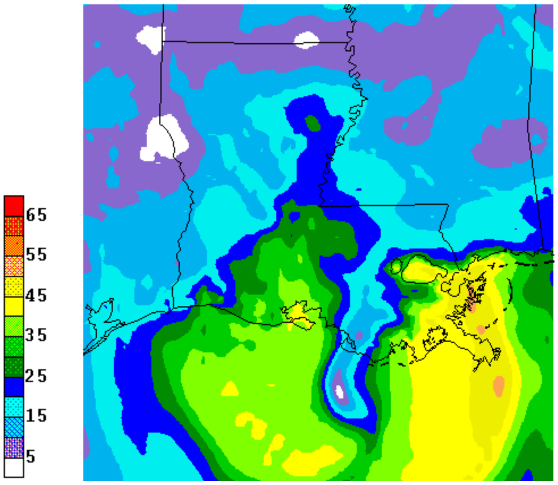


Fig.7. RTMA analysis of 10-meter wind speed in knots valid 1800 UTC 1 September 2008.

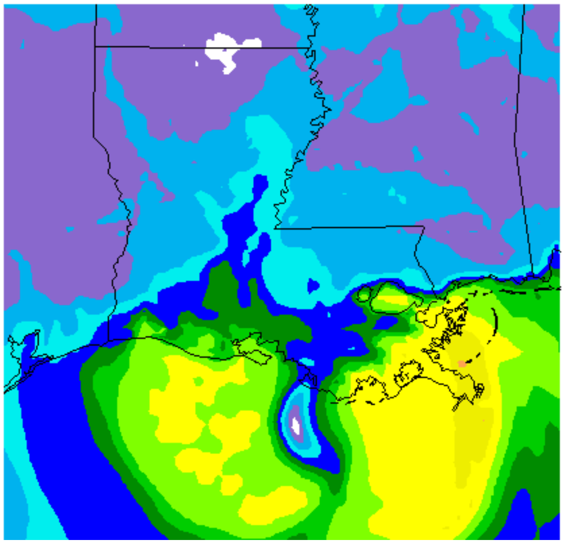


Fig. 8. Same as in Fig. 7, except for the 1-hour downscaled RUC forecast.

4. 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. 9 shows METAR wind speed observations over the mid-Atlantic region on a day with a strong pressure gradient that induced winds that caused some scattered damage and power outages. All of the METAR observations at this time were 14 knots or stronger.

Fig. 10, however, shows the mesonet observations, centered around the same hour, that were available to the RTMA. There are

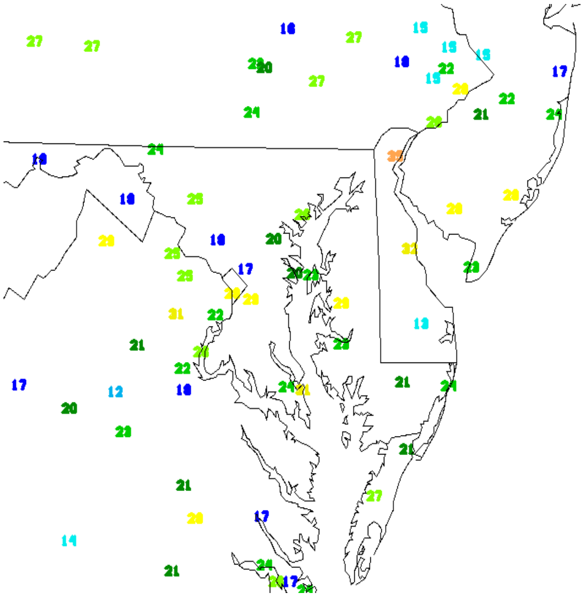


Fig. 9. METAR wind speed observations at 1800 UTC 31 December 2008.

many reports of wind speeds under 5 knots, particularly in the Washington, DC area and north-central Maryland and Virginia 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" stations after years of not including them due to quality control issues (Benjamin et al., 2007).

Fig. 11, however, shows a case in which mesonet winds did capture an area of stronger winds very well and were a significant enhancement to the METAR data. The remnants of Tropical Storm Erin unexpectedly strengthened during the night of 19 August 2007 over west-central Oklahoma. The Oklahoma Mesonet, whose wind speeds are shown in that figure, captured some of the stronger local winds quite nicely. This, however, was another case in which the RTMA was hindered by a weak first guess (not shown), and its analysis is shown in Fig. 12 with all wind speeds under 24 knots.

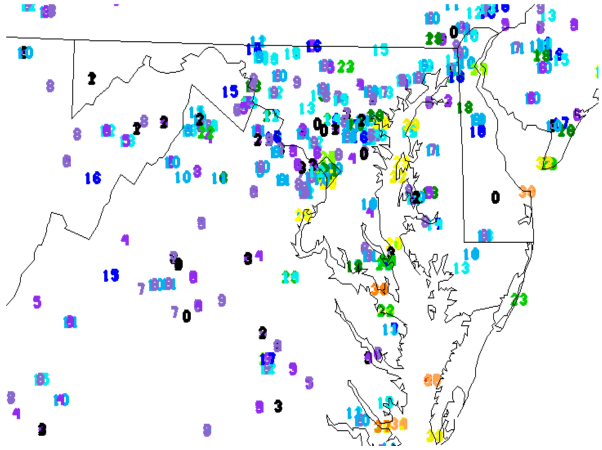


Fig. 10 Mesonet wind speed observations at times close to 1800 UTC 31 December 2008. All numbers in black have a value of 0, and all numbers in purple represent values less than 10 knots.

5. WIND COMPONENTS

It must be noted that the RTMA treats u and v wind components as separate observations and then analyzes stream function and velocity potential, using those to derive 10-meter wind speed. Some oddities are occasionally seen which reflect shortcomings in the manner in which the divergent and rotational components

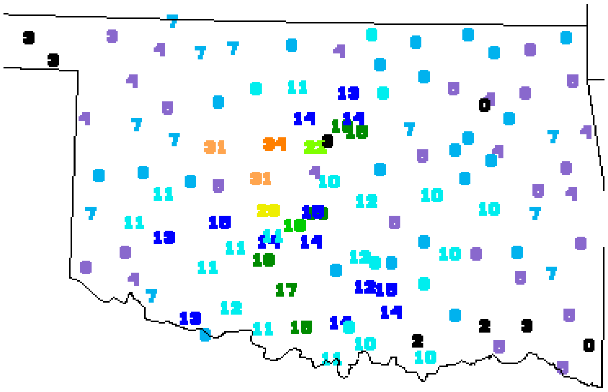


Fig. 11. Mesonet observations for Oklahoma at 0800 UTC 18 August 2007.

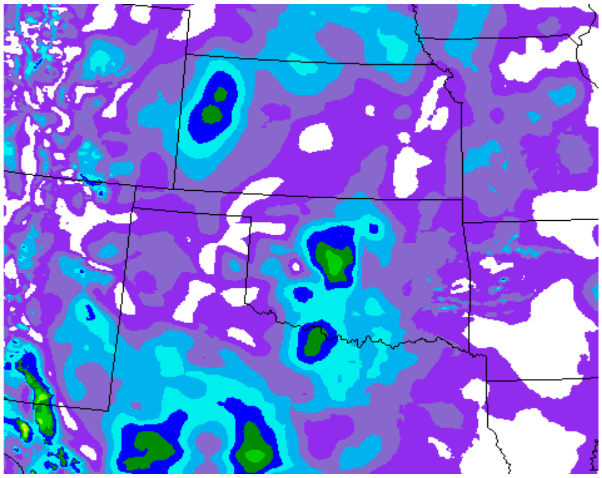


Fig. 12. RTMA 10-meter wind speed analysis valid 0800 UTC 18 August 2007. The color scale corresponds directly to Fig. 13.

are locally weighted in the assimilation. Fig. 13 shows observed wind speeds in the Missouri area for a fall 2008 case.

Fig. 14 shows the RTMA wind speed analysis for the same time. Most of the speeds are correctly quite light, but there are areas of faster speed near Kansas City and in northeastern Missouri as well. The guess is shown in Fig. 15 and suggests that the problem near Kansas City is due to a guess with a higher speed, but the guess is clearly not responsible for the other analysis maxima found further east.

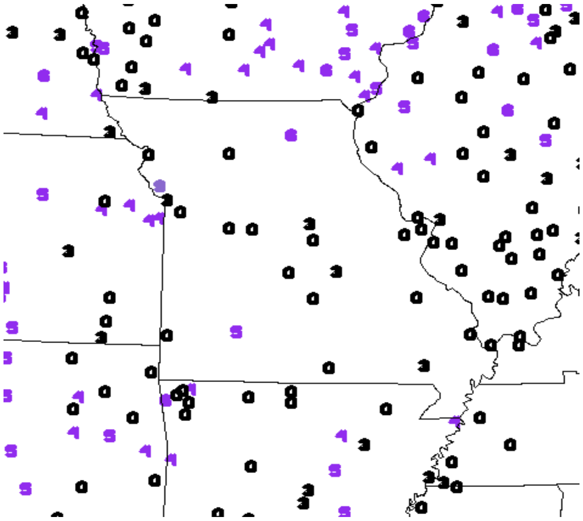


Fig. 13. Mesonet and METAR observations valid 1200 UTC 09 October 2008.

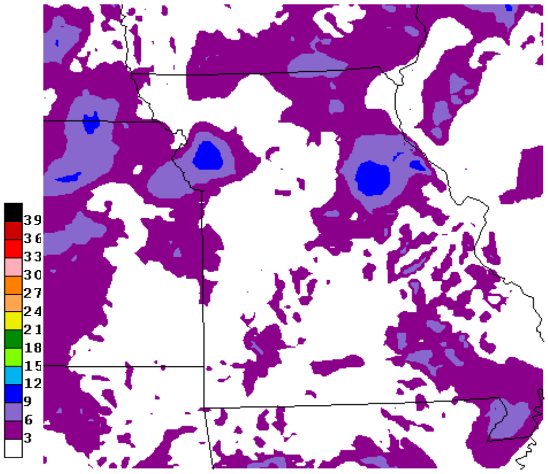


Fig. 14. RTMA 10-meter wind speed analysis valid 1200 UTC 09 October 2008.

The issue arises from the Columbia, MO observation (the 3 kt in central Missouri in Fig. 13). With the guess slightly off with the position of a boundary, the guess v component there is -3.32 knots, while the observation is +2.91 knots. An analysis increment between 5 and 6 knots is correctly added to the background in the vicinity of this observation (not shown).

The u guess is +1.24 knots, while the observed u is -0.06 knots, so an increment smaller than 1.24 knots would be expected in this area. With the relationship between stream function and velocity potential, the u and v increments impact each other. Fig, 16 shows the actual u increments added to the background, and although a reasonable value is found at the location of the observation, the increment is much larger in northeastern Missouri than the Columbia values would suggest.

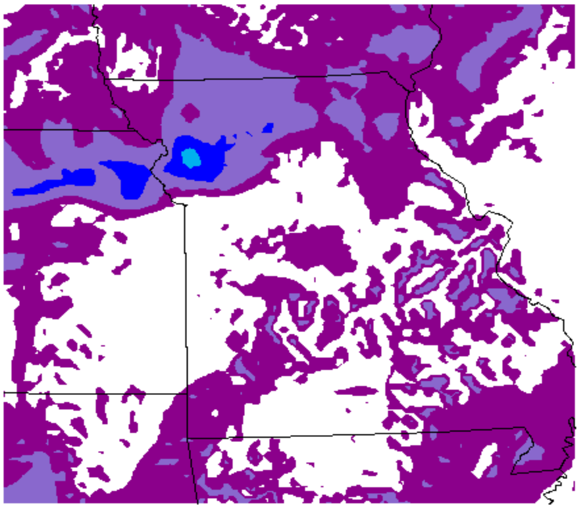


Fig. 15. Same as in Fig. 14, except for the 1-hour downscaled RUC forecast.

6. COASTLINE RESOLUTION

Another major challenge for the RTMA is assimilating land observations at grid points that the analysis believes are over water. This results from limitations of using a 5 km land/sea mask. Fig. 17 shows a temperature first guess over northern Ohio and the adjacent waters of Lake Erie. While the coastline is nicely represented by the gradient between the warmer land and colder water, some of the fine details of the shoreline are missed. And it is quite clear that the peninsula just north of Sandusky Bay is not resolved, as the guess shows a cold water temperature over the land. This creates a problem with certain observations shown in Fig. 18. The (land) station at the tip off that peninsula reports a temperature of 80°F, but the analysis believes that this is a water point. With the guess much colder than the observation, a large

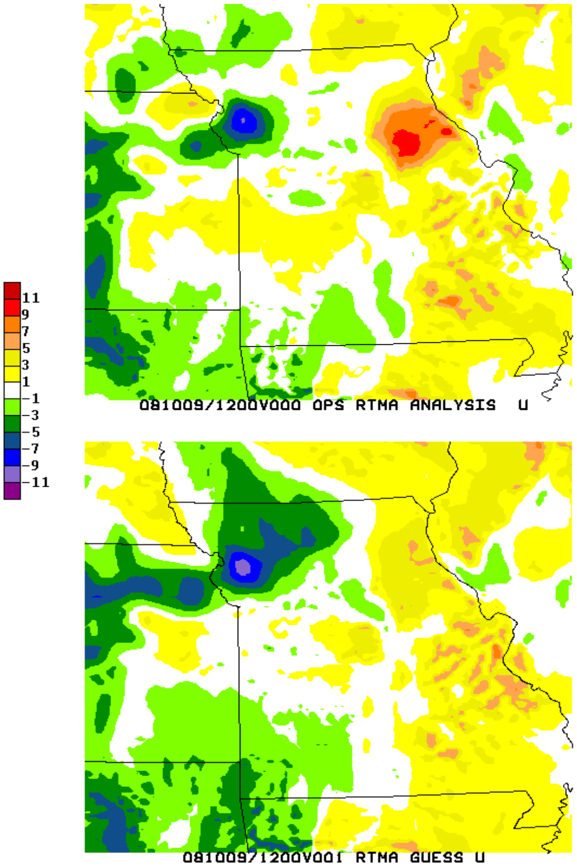


Fig. 16 RTMA analysis of u-wind components (kt) valid 1200 UTC 09 October 2008 (top) and 1-hr downscaled RUC forecast of the same (bottom).

positive increment is applied over the adjacent water area, leading to the analysis shown in Fig. 19 with seemingly too warm air over the western half of Lake Erie. It is also noted that, in situations such as this, the artificially sharpened terrain-following covariances along the coastline (false terrain boundaries induced at the coastline, designed to keep the influence of land observations near the shore over land and the influence of water observations close to the shore over water) produce the opposite effect desired, as the land observation will exclusively impact temperatures over the lake waters. In this situation, the water area is analyzed too warm, and the land area is analyzed too cold.

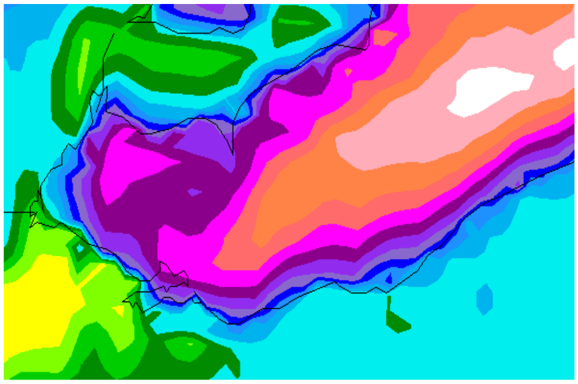


Fig. 17 1-hr RUC forecast of 2-meter temperature (degrees F) valid 0000 UTC 28 April 2009 downscaled to a 5 km grid. Scale shown in Fig. 18.

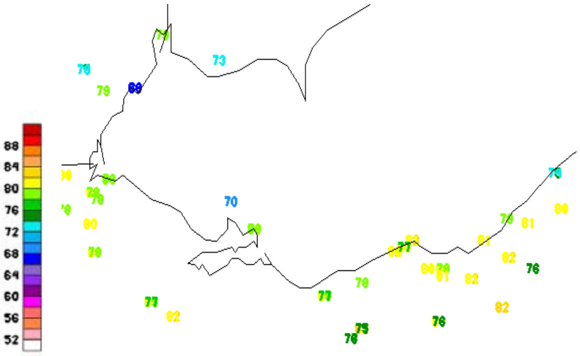


Fig. 18 2-meter temperature observations at times close to 0000 UTC 28 April 2009.

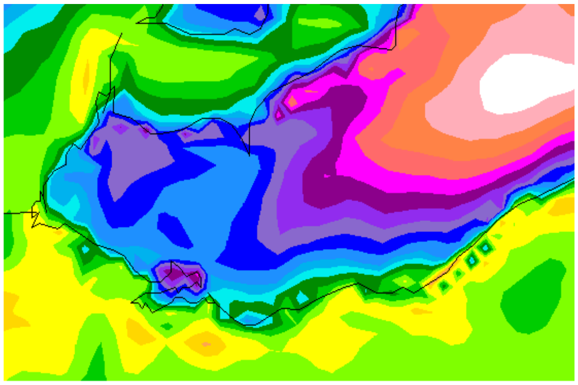


Fig. 19. Same as in Fig. 17, except the RTMA analysis.

7. DRYLINES

Drylines present a major challenge for the RTMA in trying to analyze the intense moisture gradient. Fig. 20 shows dew point observations in Texas and Oklahoma for a dryline event, with the boundary extending from north-central Oklahoma south through the Dallas-Fort Worth metroplex and then south to the Red River. 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.

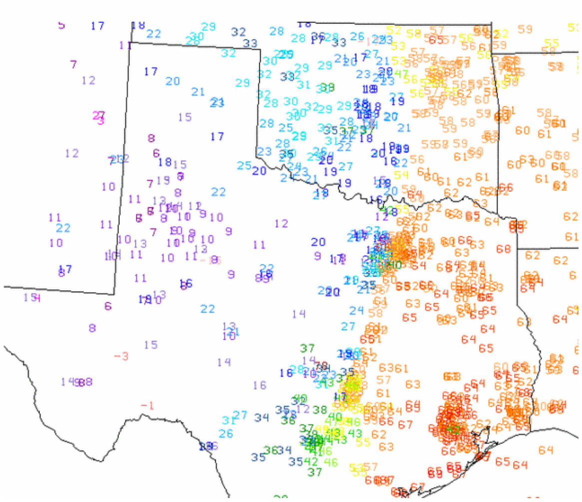


Fig. 20. Surface dew point observations (°F) valid at 2100 UTC 9 April 2009.

The RTMA dew point analysis is shown in Fig. 21. 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. 22), and while there are clearly a few bad observed values in Fig. 20, the analysis was found to reject 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) observation minus background 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.

8. ANISOTROPY

A major challenge for the RTMA is accounting for terrain when adding increments to the analysis. For example, an observation over higher terrain is probably not representative of conditions in a nearby valley, so it is desirable to have increments follow the terrain (anisotropy) instead of being smoothly applied to the surrounding area (isotropy). This, however, is not a simple issue, as forcing increments to follow terrain too strongly has led to odd "streaks" in both the increment and analyzed fields. An example is shown in Fig. 23 - this temperature increment (analysis – guess) field shows several east-west and north-south streaks over southern California. Even the actual temperature analysis, shown in Fig. 24, displays some evidence of the streaks.

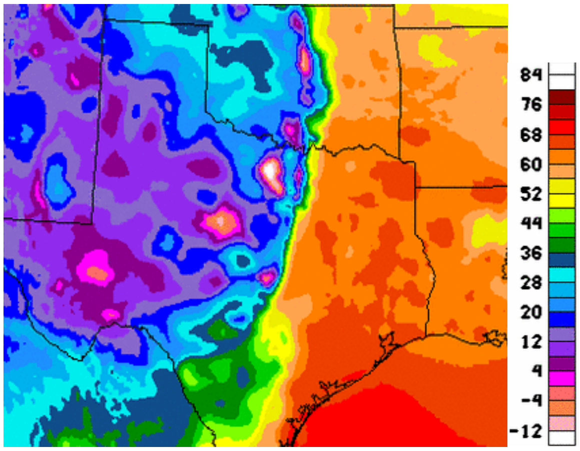


Fig. 21. RTMA 2-meter dew point analysis valid at 2100 UTC 9 April 2009.

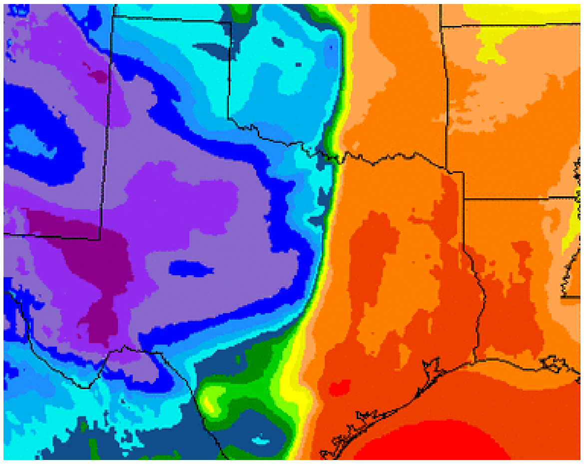


Fig. 22. 1-hour downscaled RUC forecast of 2-m dew point valid 2100 UTC 9 April 2009.

9. DEALING WITH THE CHALLENGES

This paper has explained several significant challenges faced when trying to develop a real-time mesoscale analysis product. This section attempts to explain what has been done and might be done to deal with these issues.

As has been shown, the RTMA is heavily dependent upon the RUC for its first guess, and any significant RUC improvements can greatly improve the RTMA. For example, as mentioned in Section 3, the RUC now removes snowpack at some points each day where the model incorrectly believes it exists. This has greatly improved the first guess on many spring days when the model has previously kept the

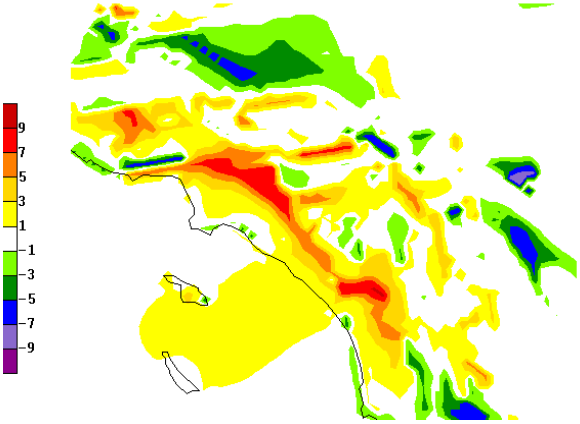


Fig. 23. RTMA Analysis – Guess temperature field over southern CA valid 08z 20 February 2009.

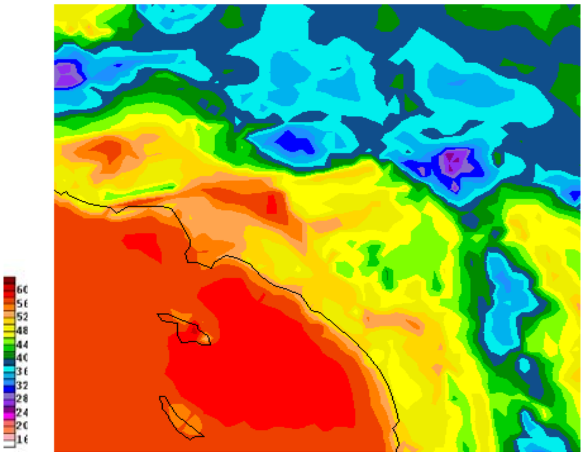


Fig. 24.: RTMA 2-meter temperature analysis valid at 0800 UTC 20 February 2009.

temperatures too cold. Fig. 25 shows the RTMA analysis shown in Fig. 4, re-run with the “new” version of the RUC providing the guess. Major improvement over Michigan and especially Wisconsin is quite evident.

The issue of analyzing winds with tropical systems is not easily solved. It is not reasonable to expect the RUC to provide an accurate position or wind field from a tropical system making landfall. The best hope may be to use the Hurricane Weather Research and Forecasting Model (HWRF, Tallapragada et al., 2008)) as a first guess. Fig. 26 shows a short-range HWRF low-level wind speed forecast valid at the same time as Fig. 7. A far superior initial wind field would be obtained by this guess, but blending this nest with the rest of the RTMA grid will likely not be a trivial process.

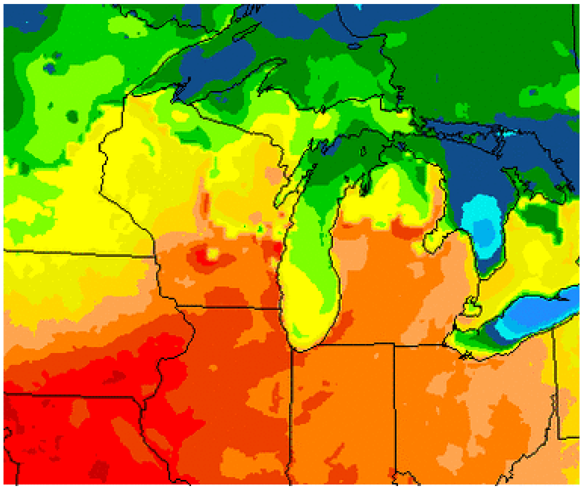


Fig. 25. RTMA 2-m temperature analysis for the same time as in Fig. 4, except produced using a version of the RUC with updated snow cover as the first guess.

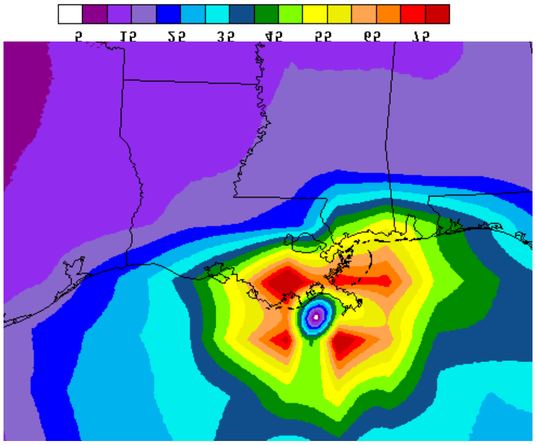


Fig. 26. 6-hour forecast of 35-meter wind speed (kt) from the HWRF valid 1800 UTC 1 September 2008.

For mesonet wind speed observations, the RTMA uses both a static and dynamic reject list. The static list verifies all approved stations for wind speed, while the dynamic list is constantly changing and tells the analysis to reject wind observations at stations where the quality control process has repeatedly rejected the data in recent days. Fig. 27 shows the RUC guess, and Fig. 28 shows the RTMA analysis for the case shown in Figs. 9 and 10. It is clear that the analysis successfully uses much of the good data in this region while not using the observations that are clearly questionable. There are, however, a few locations at which it appears likely that the low speeds of some mesonet wind data hurt the analysis, including southern Delaware, Maryland’s eastern shore, and the Shenandoah Valley of Virginia. The quality control of mesonet wind data will require more work – changes to the dynamic rejection mechanism are being tested, and variational quality control for the RTMA is planned.

Situations like the one discussed in Figs. 11 and 12 will continue to provide problems for the RTMA. The processes which caused a weakening inland tropical storm to intensify are not at all well-understood, so it is not realistic to expect any model to accurately represent the process. And the RUC would have the same difficulties as the RTMA in trying to get those observations through the quality control process. It is hard to envision any scenario in which a first guess for that event would have captured the strong wind speeds; trying to find a balance between making sure that real mesoscale detail such as this is captured by the analysis and keeping bad data out will be an ongoing process for many years ahead.

Improving the wind analysis in situations such as the one discussed in figures 13 through 16 requires mainly the correct specification of the amplitudes for the covariance models for stream function and velocity potential. This is a challenge that is being addressed by looking at various background error statistics for these variables. For the case discussed here, a sensitivity study to these amplitudes showed good results when the divergent component of the assimilation was boosted by decreasing the ratio of the observation error to the velocity potential background error. It is also believed that the assimilation of wind speed and direction in place of the u and v-components may in the future allow for the more convenient specification of the observation errors.

Avoiding problems with the analysis believing that a land station is over water and vice versa may be possible with future efforts. First, plans exist to change the RTMA to 2.5 km resolution over the CONUS which will immediately give a better representation of the coastline in the guess and analysis. But there will still be issues with data on small islands or on peninsulas which are not resolved even by going to 2.5 km. It may be necessary to keep a list of stations where such discrepancies exist to have its observations treated specially or have some other sort of different treatment.

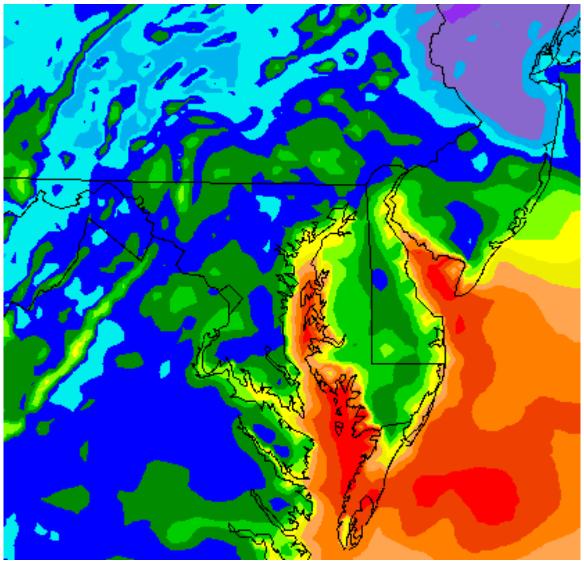


Fig. 27. 1-hour RUC forecast of 10-meter wnd speed valid 1800 UTC 31 December 2008.

Drylines will likely continue to provide a major challenge to the RTMA. Any feature with an incredibly tight gradient can pose such risks, as large increments may be incorrectly imposed over too big of an area. Recent code changes 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. But there is much work to be done in dealing with applying increments along the dryline itself. 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.

The streaks issue shown in Section 7 can be greatly improved by relaxing the anisotropy. Fig. 29 shows the case from Fig. 23, run with new parameters. The new forecast is a clear improvement, but there is a balance between removing undesired features and removing the ability of the code to follow the terrain with the application of the increments.

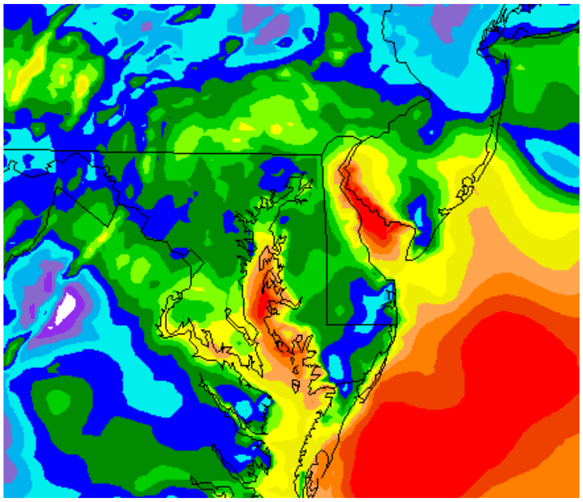


Fig. 28. RTMA 10-meter wind speed analysis (kt) valid 1800 UTC 31 December 2008.

10. 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 and David Novak, formerly of the Eastern Region Headquarters (now with NCEP's Hydrometeorological Prediction Center) have been particularly tireless in their 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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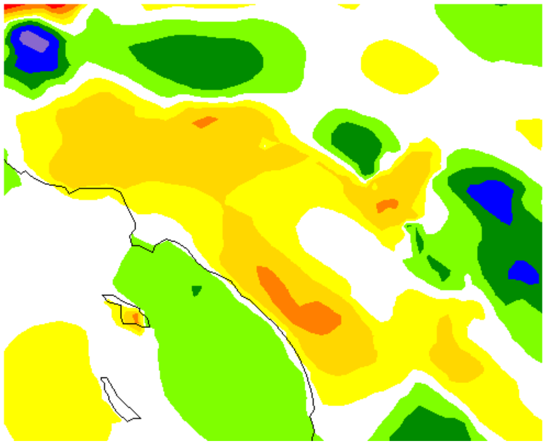

Fig. 29. Same as in Fig. 23, except for an RTMA analysis made using relaxed anisotropy.

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