

15A.2 RECENT IMPROVEMENTS TO THE REAL-TIME MESOSCALE ANALYSIS

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1. INTRODUCTION

In the spring of 2006, the Real-Time Mesoscale Analysis (RTMA) system 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 (NDFD) 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 (de Pondeca et al., 2007) analysis of surface and near-surface variables.

This paper focuses on the latter product, the hourly 5 km CONUS gridded analyses of surface pressure, 2-meter temperature and dew point, and 10-meter u and v wind components, along with estimates of the analysis uncertainty associated with each field. These analyses are made using the NCEP Grid-point Statistical Interpolation (GSI) analysis system (Wu et al., 2002). 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). RTMA products are also generated for Hawaii, Alaska, and Puerto Rico, with downscaled NAM forecasts (Manikin, 2009) providing the first guess. This paper discusses an upgrade to the CONUS code implemented in the fall of 2008; these changes were not implemented into the RTMAs for the other regions, so only the CONUS will be the focus of this paper.

2. FALL 2008 UPGRADE

A set of changes was implemented into the operational CONUS RTMA on 9 December 2008. The package included 1) a change to the assimilation variable from virtual to sensible temperature, 2) an improved quality control system for moisture, 3) introducing superior

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mesonet wind use and reject lists 4) replacing the Cressman-based analysis error estimates with ones derived from a Lanczos computation, and 5) adding requirements to make the background error covariances follow the terrain more closely. Each of these changes will be examined in its own section.

3. SENSIBLE vs. VIRTUAL TEMPERATURE

The default EMC variational analysis scheme uses virtual temperature as the analysis variable, with the observations being a combination of virtual temperature and sensible temperature. Fields of sensible temperature "analysis" are derived from the separate analysis of virtual temperature and moisture. Following months of RTMA evaluation, however, it was concluded that some of the inexplicable increments seen in the temperature field were a direct consequence of the coupling between temperature and moisture implied in the used of virtual temperature as the analysis variable. The December 2008 upgrade introduced a change which has led to significant improvements in the temperature fields: the analysis variable became sensible temperature, and the observations are all assimilated in the form of sensible temperature.

4. MOISTURE QUALITY CONTROL

Another change included in the fall 2008 change package was a change to the quality control of moisture observations, intended to deal with the very dry air often found behind drylines in the plains. Fig. 1 shows a case in which the RTMA has a strange dew point "couplet" over the Texas panhandle on the low moisture side of a pronounced dryline. In this situation, the problem was that a negative specific humidity increment was added to an already extremely low value, leading to a negative specific humidity value. Using this negative value while converting specific humidity to dew point causes the strange couplet. The code change prevents negative increments from being added to extremely low first guess moisture values, and the analysis made with the revised code is shown in Fig. 2 and is a clear improvement over the original.

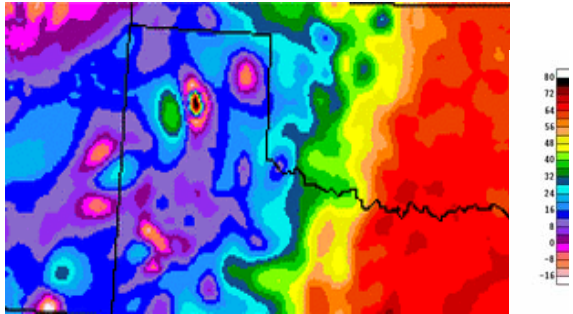


Fig. 1. RTMA analysis of dew point (°F) valid 2100 UTC 1 May 2008.

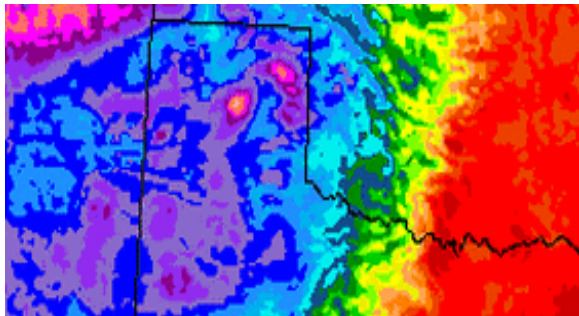


Fig. 2. Same as in Fig. 1, except using the RTMA code with the restriction to adding negative increments to already low moisture values. Note: the analysis in Fig. 2 used a less smooth background than the one shown in Fig. 1, but that is irrelevant to the feature discussed.

The impact of this change is not only seen in dryline events. Fig. 3 shows an analysis of dew points across the mid-Atlantic region. An odd ring of very low values with an inner ring of high values is seen very close to the border between Virginia and West Virginia. Some of the mesonet data available to this analysis is shown in Fig. 4. The guess (not shown) was quite dry, and when the code processed the very low specific humidity value associated with the -2 dew point observation seen in eastern West Virginia, a large negative increment was added to the already low value, giving a negative value of specific humidity (seen in Fig. 5). This had the same unrealistic impact on the conversion to dew point as seen in the Texas case. This West Virginia case was rerun with the new code to prevent the development of the negative specific humidity values, and Fig. 6 shows the same large improvement that was seen in the Texas case.

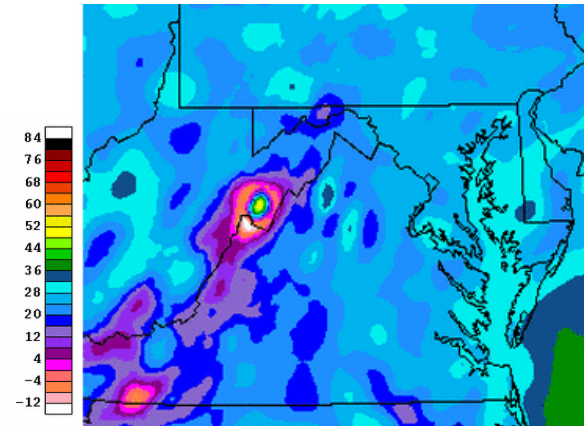


Fig. 3. RTMA analysis of 2-meter dew point (°F) valid 2100 UTC 30 October 2008.

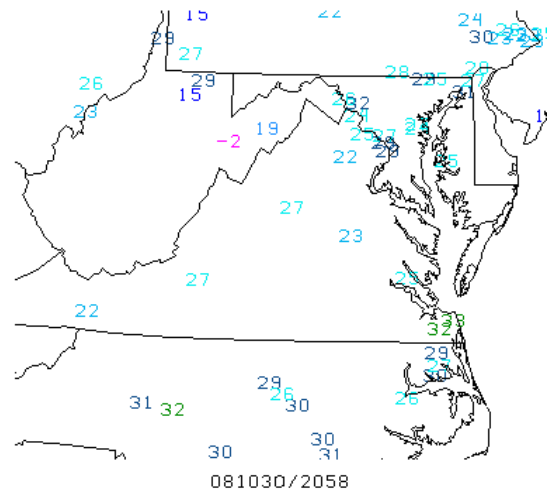


Fig. 4. Mesonet dew point observations (°F) valid 2058 UTC 30 October 2008.

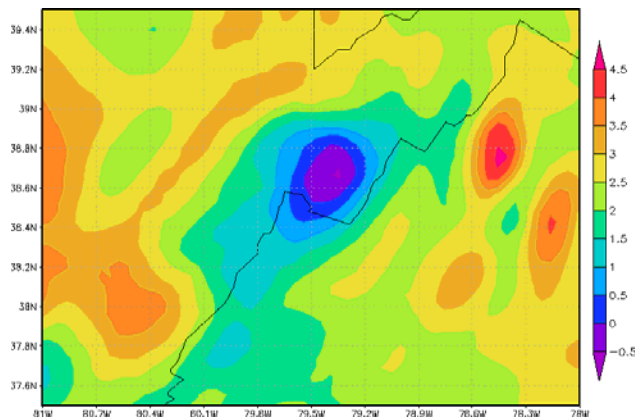


Fig. 5 RTMA analysis of 2-meter specific humidity (g/kg) valid 2100 UTC 30 October 2008.

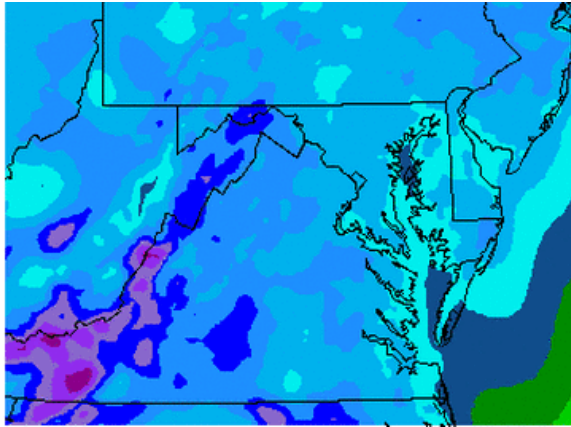


Fig.6. Same as in Fig. 3, except made using the newest version of the RTMA code.

5. MESONET DATA REJECT LISTS

The December 2008 update of the operational RTMA contained important improvements to the quality control (QC) of observations. For mesonet winds, the list of approved providers was updated, and a new list of approved stations was added. Both lists come from the Global Division System (GSD) of the Earth System Research Laboratory (ESRL) and are based on long-time statistics of differences between the reported winds and the model equivalents from the Rapid Update Cycle (RUC). In addition, the RTMA began to use lists of sub-standard observations for each parameter that are periodically collected from the Weather Forecast Offices (WFOs). Besides flagging observations that are obviously bad, the WFOs' lists are instrumental in flagging observations that only a local forecaster can know to be non-representative of the local conditions. They are a tremendous complement to the RTMA's automated quality control which includes the gross-error check that flags observations that differ too much from the first guess and the dynamic blacklists generated from the past hours' gross-error checks.

The use of mesonet winds in the RTMA presents a great challenge, owing to the slow biases that these observations often exhibit. Siting issues with the instruments are in many instances to blame (Benjamin et al., 2007). Figure 7 shows the full set of stations reporting winds for a December 2008 case. There were 12734 stations available; 10308 (80.95%) of these were mesonets. Fig. 8 shows which of these observations were rejected through usage of the GSD and WFO lists – the data was

rejected at 6602 (64%) of the stations. The numbers from this case are very representative of any analysis time.

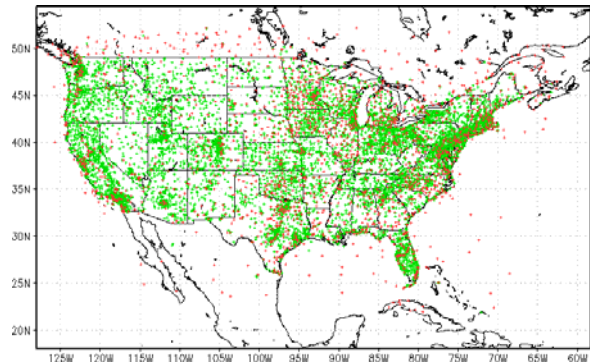


Fig. 7. Wind reports available for the 1800 UTC 31 December 2008 analysis. Green dots indicate mesonets, and red shows all other station types.

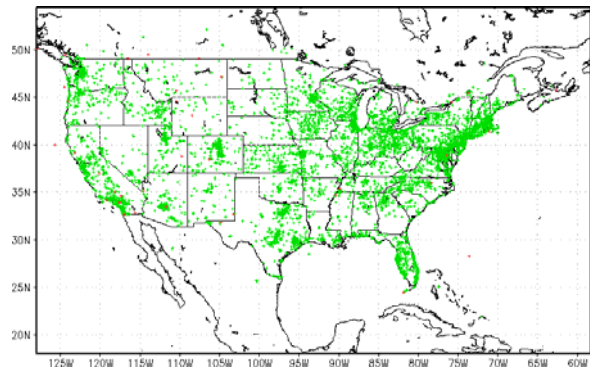


Fig. 8. All mesonet wind reports rejected through the GSD and WFO lists for the 1800 UTC 31 December 2008 RTMA.

The impact of the QC for mesonet winds is illustrated by the 1800 UTC 31 December 2008 analysis in the mid-Atlantic. A deepening coastal storm brought strong winds to the region, accompanied by fairly widespread reports of damage and power outages. As shown in Fig. 9, all METAR winds available to the RTMA in this region showed values of 14 knots or stronger. Figure 10 shows all mesonet observations available to the analysis, and the low speed bias is quite evident. Figure 11 displays the downscaled RUC first guess, and Fig. 12 shows the analysis that uses the full QC process to eliminate bad mesonet observations, while Fig. 13 shows a test analysis made without using the GSD list of approved mesonet providers or the WFO reject lists. All of the observations shown in Fig. 8 are used for the test (Fig. 13), and the differences between this analysis and the control

(Fig. 12) are remarkable. The absence of quality control leads to unrealistically slow wind speeds in the analysis across the mid-Atlantic region. While not perfect, the use of the above QC leads to much improved results. The area of weaker (less than 3 knots) winds just east of the Blue Ridge in Virginia, however, shows that there is still room for improvement.

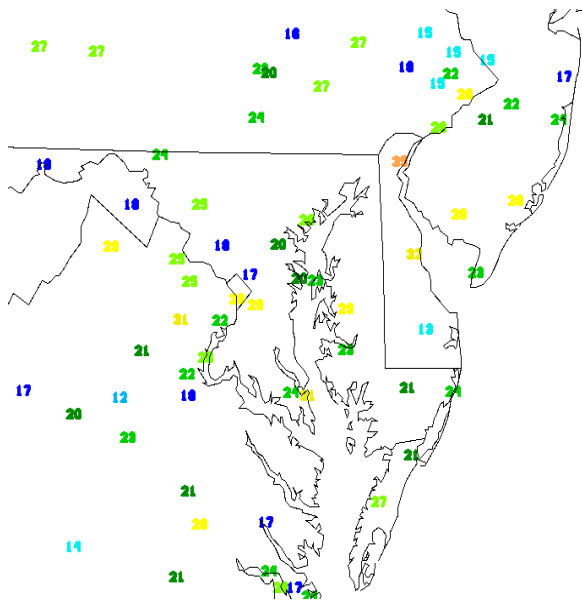


Fig. 9. METAR wind speed observations in knots at 1800 UTC 31 December 2008.

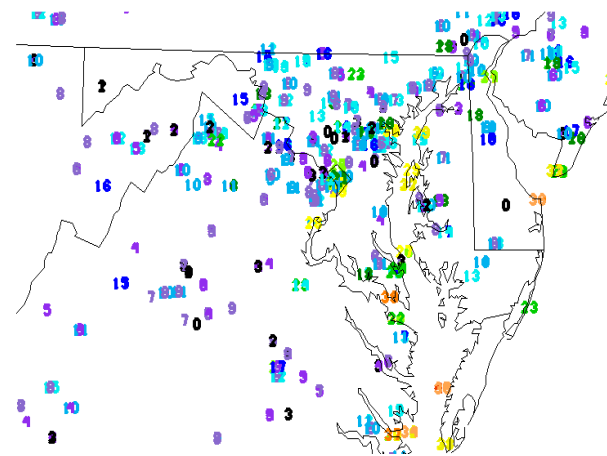


Fig. 10. Mesonet wind speed observations in knots at times close to 1800 UTC 31 December 2008. All numbers in black have a value of 0, and all numbers in purple represent values less than 10 knots.

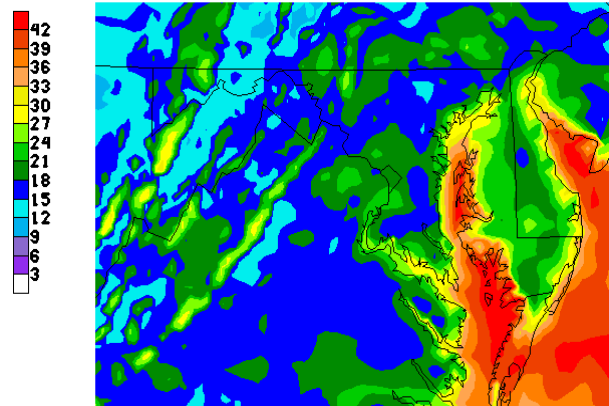


Fig. 11. Downscaled 1-hr RUC forecast of 10-meter wind speed (kt) valid 1800 UTC 31 December 2008.

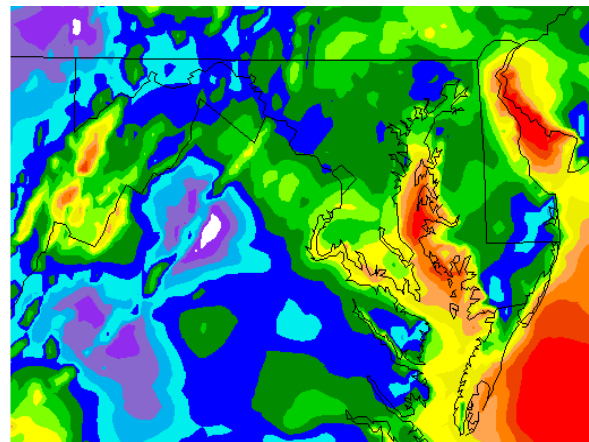


Fig. 12. RTMA analysis of 10-meter wind speed (kt), generated using full mesonet wind quality control, valid 1800 UTC 31 December 2008.

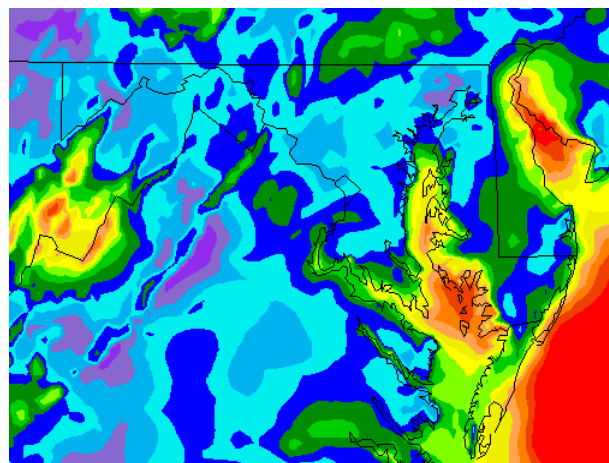


Fig. 13. Same as in Fig. 12, except with no list of approved mesonet data used in the analysis.

6. ANALYSIS ERROR ESTIMATES

Along with the analysis, the RTMA also computes an estimate of the analysis uncertainty for each parameter. For now, that estimate is thought of as being the analysis error from the GSI. A more complete measure of the analysis uncertainty should in the future incorporate contributions from the systematic errors in both the first guess and the observations.

In order to compute the analysis error of the GSI-2DVar, one must deal with the matrix of second derivatives of the cost function with respect to the control vector, also known as the Hessian matrix. The analysis error is equal to the square roots of the diagonal elements of the inverse of the Hessian. In its first implementation, the RTMA used a very crude estimate of the inverse-Hessian at each observation location, and applied a simple Cressman analysis to derive a gridded field of analysis errors. Not surprisingly, the analysis error estimated in this manner often did not reflect the underlying covariances well - its contours indiscriminately cutting across contour lines of constant topography. Although this feature could have been improved by refining the Cressman analysis to include dependence on terrain elevation in the weighting function, improving on the rather poor assumptions that lead to the point estimates of the inverse-Hessian proved rather difficult. Fortunately, however, it was later recognized that a more accurate estimate of the analysis error of the GSI could be accomplished with the help of some of the by-products of the GSI-minimization procedure - namely, the gradient vectors and step sizes along the descent directions. The method is an adaptation of the Lanczos method described by Fisher and Courtier (1995), which uses the above by-products to reconstruct a reduced-rank version of the Hessian matrix. This method was part of the upgrade and provides the best possible estimate of the analysis error from first-principles. In particular, the error shapes are estimated very well. A subjective calibration of the error amplitudes is, however, needed, owing to the reduced dimensionality of the space of calculation.

For temperature, Fig. 14 shows the old, Cressman-based estimate of the analysis error over a portion of Utah as well as observations used for the analysis (X) and the underlying terrain. Figure 15 shows the estimate using the new, Lanczos method. These figures clearly

show the superiority of the Lanczos method. Compared with Fig. 14, Fig. 15 shows structures that are more consistent with (i) the underlying topography used to build the covariances, and (ii) the observation locations. As expected, both figures show that the analysis error coincides with the background error in data void areas and generally has reduced values where observations are available.

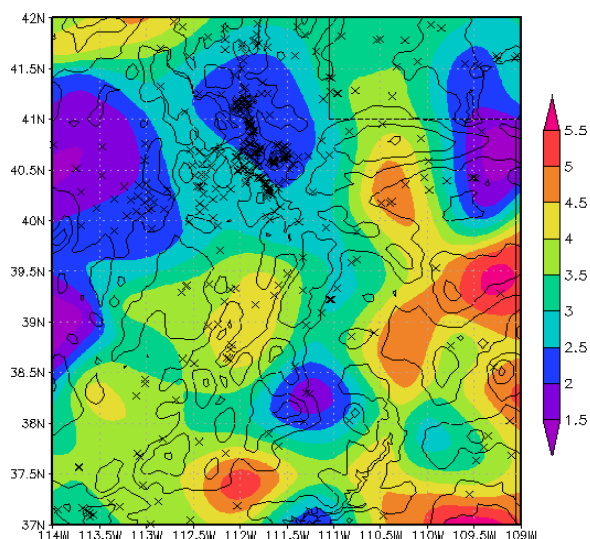


Fig. 14. Analysis error ($^{\circ}\text{F}$) valid 0800 UTC 20 February 2009, computed using the Cressman-based method (shaded contours) and terrain field (black contours). Observation locations are marked with 'X'.

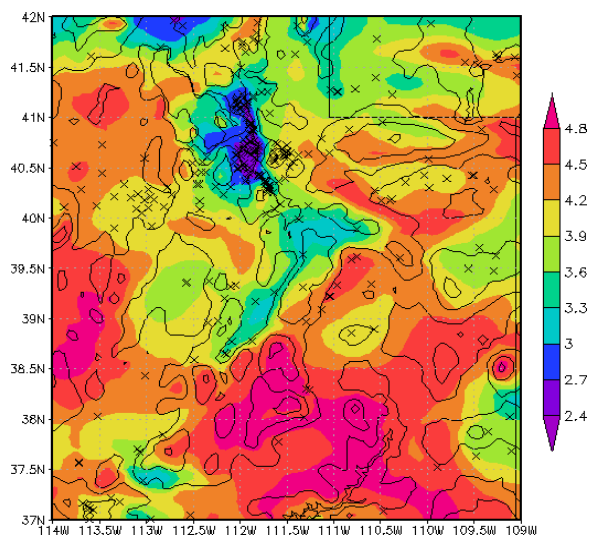


Fig. 15. Same as in Fig. 14, except with the analysis error computed using the Lanczos method. Note that the observations used here are not necessarily the same as those from Fig. 14 since different quality controls were applied.

7. TERRAIN-FOLLOWING COVARIANCES

A problem repeatedly noted by RTMA users was that the increments for the different variables were often too isotropic, crossing the terrain contours too much. We note that the RTMA background error covariances, which determine the manner in which the observation increments are spread to the adjacent grid points, are mapped to a smooth representation of the 5 km terrain. Adding a certain degree of smoothing is a requirement of the recursive filter formalism used to synthesize the covariances, especially over rapidly changing terrain. (Purser et al., 2005). As part of this change package, however, the smoothing of the terrain field used to build the background error covariances was reduced, allowing the analysis increments to follow the terrain field more closely. Figures 16 and 17 show a nice impact of the change over Utah. In Fig. 16, the temperature increment field is quite smooth with the contours not following the terrain field much. The increments with the reduced smoothing are shown in Fig. 17; the increment field here follows the terrain much more closely.

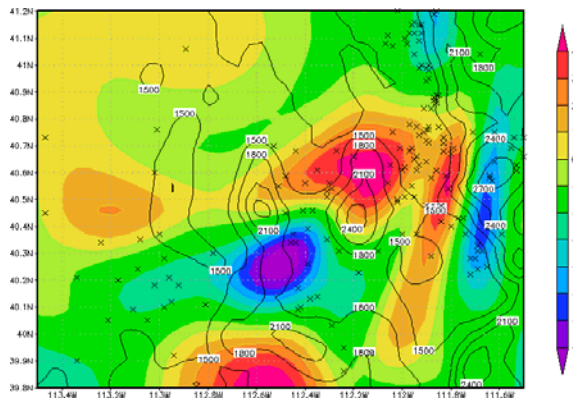


Fig. 16. RTMA temperature increments (analysis – guess, °F) in the vicinity of Salt Lake City, UT 0900 UTC 27 October 2007.

8. FUTURE WORK

It must be noted that this implementation was only made to the CONUS RTMA; the changes will hopefully be added to the RTMAs for Alaska, Hawaii, and Puerto Rico later in 2009. Other changes are being tested and are discussed in this section.

In order to widen the time window for the RTMA to use observations, an FGAT (first guess, appropriate time) method is being tested.

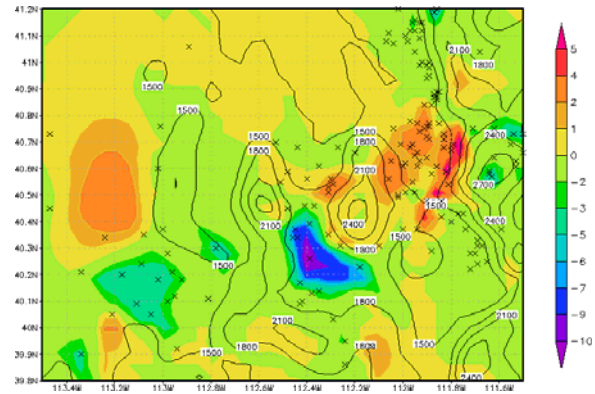


Fig. 17. Same as in Fig. 16, except with the terrain smoothing turned off.

The window is increased to +/- 30 minutes instead of +/- 12 minutes. With the wider window, a guess valid right at the analysis hour may not be representative for a time closer to 30 minutes before or after. The FGAT requires that a new first guess be created by performing a linear interpolation in space and time using the 1-hour downscaled RUC forecast from the previous hour and either the RTMA analysis from the previous hour or the 2-hour forecast from the previous RUC cycle.

Another issue to be addressed concerns providing a reasonable first guess in situations with landfalling tropical systems. As discussed in Manikin and Pondevca (2009), the RUC is not designed to accurately represent the strength of a major tropical system; the first guess and resulting RTMA analysis therefore usually exhibit a tremendous low wind speed bias in these events. There is a plan to test using the Hurricane WRF model to provide the wind field first guess for these events, but blending this nested grid with the RUC background will likely not be a trivial process.

Future improvements to the quality control process will include fine-tuning the dynamic reject list mechanism and the use of a variational QC. The former is especially important in continuing to gain all of the mesoscale detail provided by mesonet data while preventing bad data from causing unrealistic details.

It is hoped that the CONUS RTMA will be run at 2.5 km resolution later in 2009. This will help resolve lingering problems with unrepresentative analyses in regions of varying terrain, and it will hopefully reduce the number of land (water) coastal points incorrectly treated as water (land) points as discussed in Manikin and Pondevca (2009). A special treatment of stations on

unresolved peninsulas or small islands may be required.

Bias correction of the fields is also being tested. The guess is adjusted in areas where it varies from the observations for multiple consecutive hours. It has been tested in parallel on the temperature field for many months and will be added to the other fields soon.

Finally, an RTMA for the region around Guam will be developed. The first guess will be provided by a downscaled forecast from the Global Forecast System (GFS), since neither the RUC nor NAM domain covers this part of the world.

9. REFERENCES

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