IMPACT OF SAINT LOUIS UNIVERSITY-AMERENUE QUANTUM WEATHER PROJECT MESONET DATA ON WRF-ARW FORECASTS

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1. Introduction

QuantumWeather, a partnership between Saint Louis University and utility company AmerenUE, has been established to provide dedicated real-time forecasts of weather hazards impacting the AmerenUE electric power grid in eastern Missouri. Forecasts originating from the Department of Earth and Atmospheric Sciences at Saint Louis University aid informed decision-making on the part of the utility company with respect to issues such as workforce retention and prepositioning of resources prior to a potentially hazardous event. With the goal of improved localized forecasts, AmerenUE has funded the installation of an expanding surface mesonet across the state of Missouri consisting of over 60 stations as of June 2009. Up to 100 stations are currently planned for placement.

These stations are useful to forecasters at Saint Louis University for a couple reasons. First, the real-time acquisition of meteorological data across the AmerenUE service area enables the forecaster to better assess the current state of the atmosphere including detailed knowledge of the location of the surface freezing isotherm, identification of subtle features such as remnant outflow boundaries which may trigger further convection, and other features that are of concern to the forecast. Secondly, data acquired by the mesonet can be assimilated into mesoscale models such as the WRF-ARW Version 2.2 to refine the numerical forecast. Assimilation of additional data into a forecast cycle has been shown to improve forecast accuracy in numerous studies (e.g., Xu, et al. 2002; Yu, et al. 2007). Therefore, an effort to assimilate this data has been undertaken at Saint Louis University with the expectation that high-resolution model forecasts may be improved at minimal computational expense.

The QuantumWeather data assimilation process is built upon observation nudging techniques (Liu et al., 2005) in the Weather Research and Forecasting (WRF-ARW) mesoscale model. The purpose of this study is to develop the successful use of FDDA within the model framework (i.e., show a difference between non-FDDA model runs and obs nudging runs) using information gathered from the QuantumWeather mesonet. Further, it is necessary to verify the results of 12-24 hour forecasts resulting from non-FDDA and FDDA runs against observations and NCEP NAM-218 derived analyses. This study will focus on a qualitative evaluation of WRF-ARW forecasts.
2. Study Design

The WRF-ARW mesoscale model was run on 2 domains (9km-3km) for a 24 hour case (06Z 27 December 2008-06Z 28 December 2008). The outer domain covers the entire state of Missouri, while the inner domain focuses on northeastern and east-central Missouri, the heart of the AmerenUE service area (Figure 1). NCEP NAM-218 forecast data from the forecast valid 06Z 27 December 2008 was used for initial conditions and lateral boundary conditions were applied at 3 hour intervals (Figure 2).

Physics options used in this study and operations were optimized for the St. Louis region in a previous study at Saint Louis University. The microphysics option used is the Thompson, et al. scheme; Radiation schemes are rrtm for longwave and Goddard for shortwave and are called every 30 minutes; Planetary boundary layer physics is parameterized through use of the YSU scheme and is called every minute; and the Kain-Fritsch (new Eta) scheme is used to parameterize the effects of cumulus clouds on the model result every 2 minutes. These schemes are set for both domains. The time step used on the outer domain is 15 seconds. Use of the recommended 6*dx time step (54 seconds in this case) results in CFL violations, presumably due to higher mean flow associated with mesoscale and local scale weather features such as mesoscale convective systems (MCS).

Figure 1: The WRF-ARW configuration for the QuantumWeather project is shown above. In this study, only the outer two domains are used.

Figure 2: The setup for FDDA runs is shown above. Forty minute centered averages of mesonet data are created and applied every 20 minutes (the averaged file used at a particular time \([t = 0]\) is generated from all data received from \(t-20\)min to \(t+20\)min) for the first 3 hours. NAM 218 data is used for initial conditions and boundary conditions every 3 hours.
Data received from the QuantumWeather mesonet includes variables such as temperature, wind speed and direction, and relative humidity. This is important information to have because it allows for the calculation of $u$ and $v$ wind components and mixing ratio ($q$). In our study, 40 minute averages of temperature, $u$, $v$, and $q$ fields at each station are used to nudge the model state every 20 minutes for the first 3 hours of the run. Forty minute averages are generated to remove unrepresentative small-scale effects from assimilation. The nudging parameter is set to $G_n = 1 \times 10^{-3} \text{s}^{-1}$ for each variable with radius of influence on domain 1 of $R_1 = 90 \text{km}$ and on domain 2 of $R_2 = 60 \text{km}$. As of the time of this case, there had been 37 surface stations installed (Figure 3) and frequently updating (~40 observations per hour per station).

The key to the study is the denial of certain stations from assimilation. For example, each station is assigned to a specific group based upon geographical location within the full mesonet (e.g., north array, south array, etc.). These groups of stations are then alternately excluded from assimilation in an attempt to assess the impact of added stations in each general location.

![Figure 3: Red dots denote the 37 surface stations in QuantumWeather mesonet array as of late December, 2008. The four red tabs show the corners of the second domain in this study.](image)

### 3. Case Description

The period 0600 UTC 27 December 2008 through 0600 UTC 28 December 2008 was chosen for study because of the presence of a cold front and low pressure system in addition to severe convective storms within the model domains. It was the only significant convective event
inside the model domain after a sufficiently large number of stations had been installed until spring 2009.

At 0600 UTC 27 December 2008, Missouri was in the warm sector of an extratropical cyclone with southerly winds and dewpoints near 60F area-wide. This primed the atmosphere for explosive thunderstorms later in the day. By 1800 UTC (Figure 4), the cold front extended through the middle of the two WRF domains with ongoing precipitation along the front. The front had completely passed through the model domains by 0600 UTC 28 December 2008 with high pressure building in from the west.

4. Results

At this preliminary stage of our study, the thermal field has been the most closely examined. This choice was made due to the relatively uniformity of the temperature field (compared to precipitation) and the importance of thermal forcing in this case. The results indicate progress has been made toward a real-time data assimilation process for the needs of the QuantumWeather project. WRF-ARW output resulting from the activation of observation nudging is different from the nonFDDA output in noticeable yet subtle ways. Some examples are shown in Figures 5-10. In these figures, the thermal field is displayed at 1800 UTC 27
December 2008, 12 hours into the runs. This also coincides with the time that the cold front extended across the heart of the two domains, inducing much of the rainfall that was present.

**Figure 5:** Left: 2m temperature field at 1800UTC 27 December 2008 on domain 1 for full array assimilation; Right: Same field as left, with noFDDA output. Contours are every 2.5C.

**Figure 6:** Left: 2m temperature field at 1800UTC 27 December 2008 on domain 1 for the North Array Test; Right: Same field as left, with full mesonet FDDA output. Contours are every 2.5C.
Figure 7: Left: 2m temperature field at 1800UTC 27 December 2008 on domain 1 for the South Array Test; Right: Same field as left, with full mesonet FDDA output. Contours are every 2.5C.

Figure 8: Left: 2m temperature field at 1800UTC 27 December 2008 on domain 1 for the Central Missouri Array Test; Right: Same field as left, with full mesonet FDDA output. Contours are every 2.5C.
Figure 9: Left: 2m temperature field at 1800UTC 27 December 2008 on domain 1 for the Westplex Array Test; Right: Same field as left, with full mesonet FDDA output. Contours are every 2.5C.

Figure 10: Left: 2m temperature field at 1800UTC 27 December 2008 on domain 1 for the Metro Array Test; Right: Same field as left, with full mesonet FDDA output. Contours are every 2.5C.
The results show small differences in the temperature field in each test by 12 hours into the run. Very small if any differences appear until several hours after the start of the run. The results shown in Figure 5 depict the full impact of the 37-station mesonet on WRF-ARW output. Small deviations from the nonFDDA run are apparent throughout the domain, although the location of the front is not significantly changed. The front did not appreciably change in any of the tests run, likely due to the 3-hourly boundary forcing provided by the NAM-218 data. Extending the nudging to more than 3 hours may have a more profound impact on this feature; however, the intended real-time application of the assimilation process imposes limitations to the assimilation time. Examination of domain 2 reveals more apparent changes, although this is likely due to the effects of higher resolution. The model run was 2-way nested.

The north array showed very little impact as of t = +12hours (Figure 6). Mean flow ahead of the cold front during the first 12 hours of the period was from the southwest, indicating that northern stations would not have as much impact on the total affect of the mesonet as other stations farther south and west.

Figure 7 shows that the southern stations did not have much of an impact either, although the designated south array had the fewest stations of any subgroup. Close examination of the South Array Test reveals small changes ahead of the front, but not behind the front as of 1800 UTC.

The elimination of the central Missouri stations caused relatively significant changes in the temperature field, although the frontal location and thermal gradient were consistent with the nonFDDA run (Figure 8). This subarray constituted the southwesternmost stations in the existing mesonet.

The Westplex Array Test, involving the elimination of stations to the west of the St. Louis metropolitan area, also shows small changes which were not as apparent as of 1800 UTC (Figure 9). Larger differences were observed as the front passed through the westplex region.

Finally, the Metro Array Test shows the largest impact of all subarray tests. Clearly, the Metro Array of surface stations contributed most to the full impact of the mesonet. This result is expected because this subarray included more stations than any other subarray.

5. Future Research

Now that the observation nudging technique has been enabled in the QuantumWeather forecast process, it is important to objectively verify the results. It is quite obvious that mesonet data assimilation alters the forecast fields- what is not obvious is if these changes degrade or improve forecasts. Also, since factors such as $G_a$ and $R$ are chosen rather than theory-based, it will be beneficial to play with these numbers a bit to get the right fit for our particular application.
References

