Assimilation of Surface Meteorological Observations in COAMPS® NAVDAS

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NAVDAS for COAMPS®

Introduction

Mesoscale surface observations are vital sources of data in meteorological applications such as nowcasting, short-term weather forecasting, wind power management, transportation safety, wildfire management, dispersion modeling, and defense applications (Dabberdt et al. 2005; Horel and Colman 2005). Often, these observations are utilized in the creation of diagnostic surface analyses, which are typically used as end products to help diagnose current conditions or verify previous forecasts (Tyndall and Horel 2013). However, some numerical weather prediction models are assimilating these observations to improve their initial conditions and forecasts (Benjamin et al. 2010).

The NRL Atmospheric Variational Data Assimilation System (NAVDAS) for the Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS®) assimilates very little surface data as part of its operational cycle—only wind measurements from coastal, ship, and buoy observations are assimilated (temperature and humidity observations from these stations are automatically rejected). The research presented here tests the assimilation of mesoscale surface observations across the CONUS domain and their impact on COAMPS forecasts.

Mesonet Assimilation and Experiment Methodology

Surface observations are generally more difficult to assimilate than radiosonde or aircraft observations due to representativeness issues between the model terrain elevation and the real terrain elevation. Figure 1 shows the elevation difference between the reported mesonet station elevations and the 15-km model terrain used in this experiment. While large elevation differences are not surprising in the mountainous terrain of the western United States, there are still some large terrain differences in the Midwest (± 50 m). To account for the terrain representativeness error, the base observation error (set individually for each network type) for each mesonet observation is multiplied by the error multiplier depicted in Figure 2.

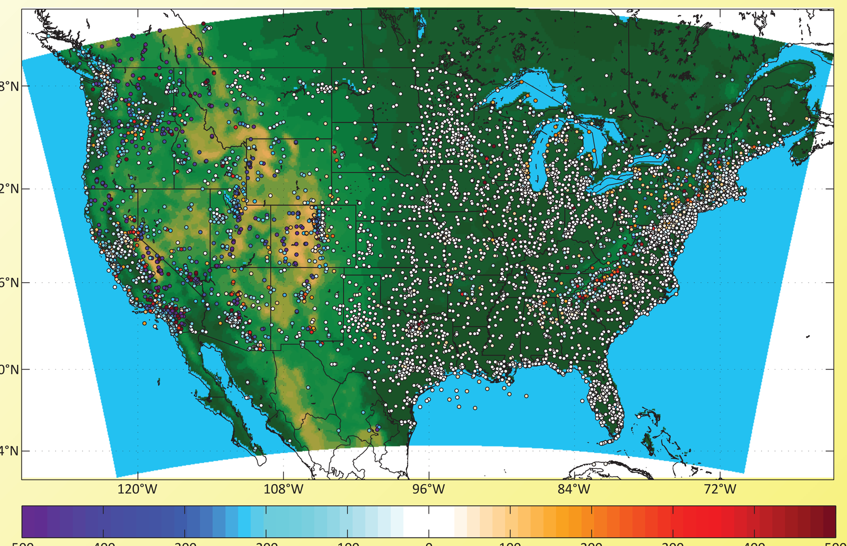

Figure 1. Elevation difference (m) between reported mesonet station elevation and 15-km resolution model terrain used in this research.

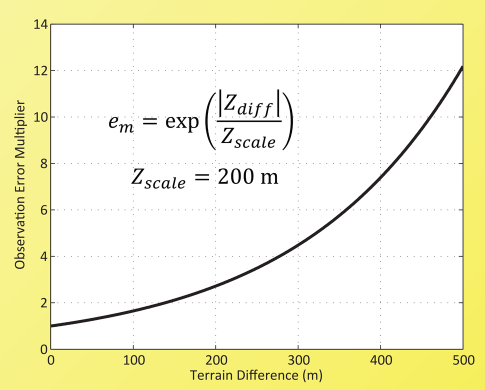

Figure 2. Observation error multiplier function for terrain difference.

In addition to terrain representativeness, differences between mesonet networks can also lead to more difficulty in assimilating these surface observations compared to radiosonde assimilation. Network operators must balance sensor cost against the number of stations they must deploy. Higher grade sensors generally are more accurate; however, the operator may not be able to deploy as many stations due to the increased cost. Additionally, some operators design networks that try to measure local area atmospheric extremes instead of the local area averages that would be forecasted by a numerical prediction model. For example, stations within the Remote Automated Weather Station (RAWS) network are often located on southern facing exposures for wildfire condition monitoring. Additionally, many networks that support agricultural operations utilize 3-m towers for wind observations, which can lead to low-biased wind observations when compared to a 10-m wind field from a numerical model (Tyndall and Horel 2013). Following Tyndall and Horel, mesonets were grouped into network categories based on their observational purpose. Networks with potential biased observations from siting or other reasons were set with higher observation errors (see Table 1). These observation errors were multiplied by the terrain difference multiplier (Figure 2) to compute the station's observation error. The most trusted networks had their observation errors set to the radiosonde observation errors (at the lowest level near the surface). Because NAVDAS computes analyses on pressure surfaces, only observations that also reported station pressure were assimilated. Mesonet observations within a ±30 minute time wind about the analysis time were used.

Network Abbreviation	Purpose/Type	σ_{o_T}	$\sigma_{o_{prh}}$	$\sigma_{o_{u/v}}$
AG	Agricultural networks	3	20	3
AQ	Air quality monitoring	3	20	3
EXT	Offshore, Canadian, and Mexican networks	3	20	3
FED+	Federal networks, W. Texas mesonet	2	10	2
HYDRO	Hydrological networks	4	25	4
LOCAL	Commercial, state, and local mesonets	3	20	3
NWS	NWS/FAA/synoptic stations	2	10	2
PUBLIC	Primarily citizen weather observing program (CWOP)	3	20	4
RAWS	Fire weather/remote area monitoring	4	25	4
TRANS	Road and rail weather monitoring	3	20	3

Table 1. Observation errors as a function of parameter and network category.

Impacts from mesonet observation assimilation were assessed using a data withholding methodology on forecasts between 0000 UTC 01 Dec 2010 and 1800 UTC 15 Dec 2010. The control and experimental forecasts (which assimilated the mesonet data) were both initialized by COAMPS forecasts made between 27-30 Nov 2010 (this warm up period did not use any mesonet observation data).

Case Study: 0000 UTC 01 Dec 2010

The forecasts from 0000 UTC 01 Dec 2010 offer an excellent depiction of the impacts from the assimilation of mesonet surface observations. The weather during this time was characterized by a ridge over the western United States and a strong low pressure system just north of Lake Superior. The low pressure system produced strong winds recorded at many surface stations in Minnesota and the eastern Dakotas (see the markers, which represent observation wind speeds, depicted in the upper left and middle panel of Figure 3). While the lowest level radiosonde observations do capture the high winds in the region, the relatively few radiosondes are unable to significantly adjust the 10-m wind analysis (Figure 3, upper left panel). Assimilation of the mesonet surface winds causes the analysis wind speeds in the region to more closely match observations. The difference between the experimental and control 10-m wind analyses is depicted in the upper right panel of Figure 3; the mesonet observations increase analysis winds by 8 m/s in some areas.

Mesonet observations also produced significant differences in the 2-m temperature analysis when compared to the control analysis (Figure 3, lower panels). Temperature observations reduced temperatures in the experimental analysis by 2-3 K over northern Texas, and almost 1 K over much of the Midwest. The surface observations produced additional differences in the relative humidity analyses of ±25% over much of the CONUS domain (not shown).

Unfortunately, increased wind speeds in the experimental wind analysis are not maintained by the forecast model (see Figure 4). Within the first hour of the forecast, COAMPS reduces wind speeds in the region by more than half of the observed values. Forecasted wind speeds in the region continue to slow through the next 5 hours of the forecast (but at a much slower rate). This erroneous behavior was not seen in the temperature or relative humidity forecasts for this time period (not shown).

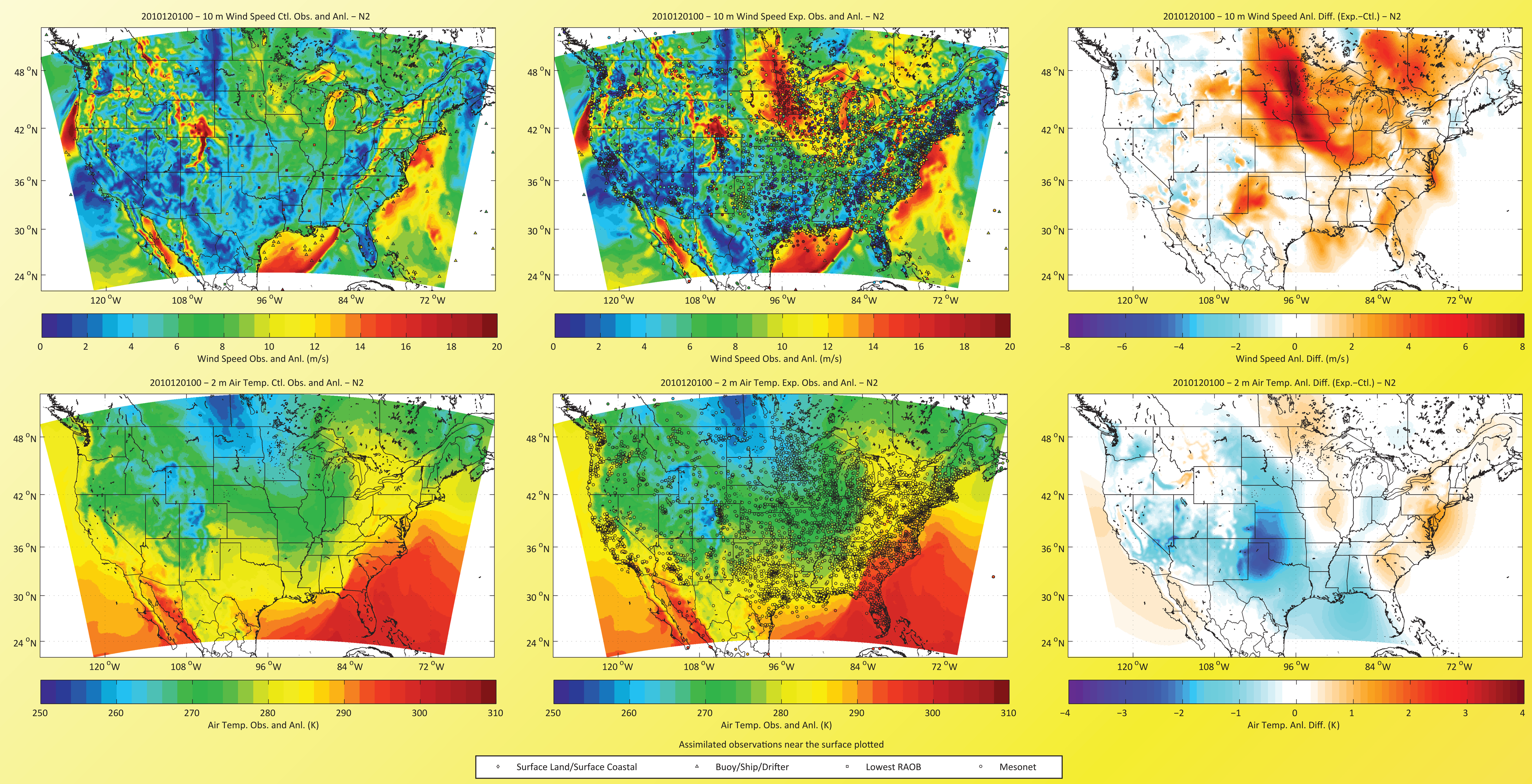

Figure 3. Control, experimental, and control-experimental analysis differences of 10-m wind speed (top panels) and 2-m air temperature (bottom panels) analyses from 0000 UTC 01 Dec 2010. Markers in the analysis panels denote near surface observations assimilated by each forecast.

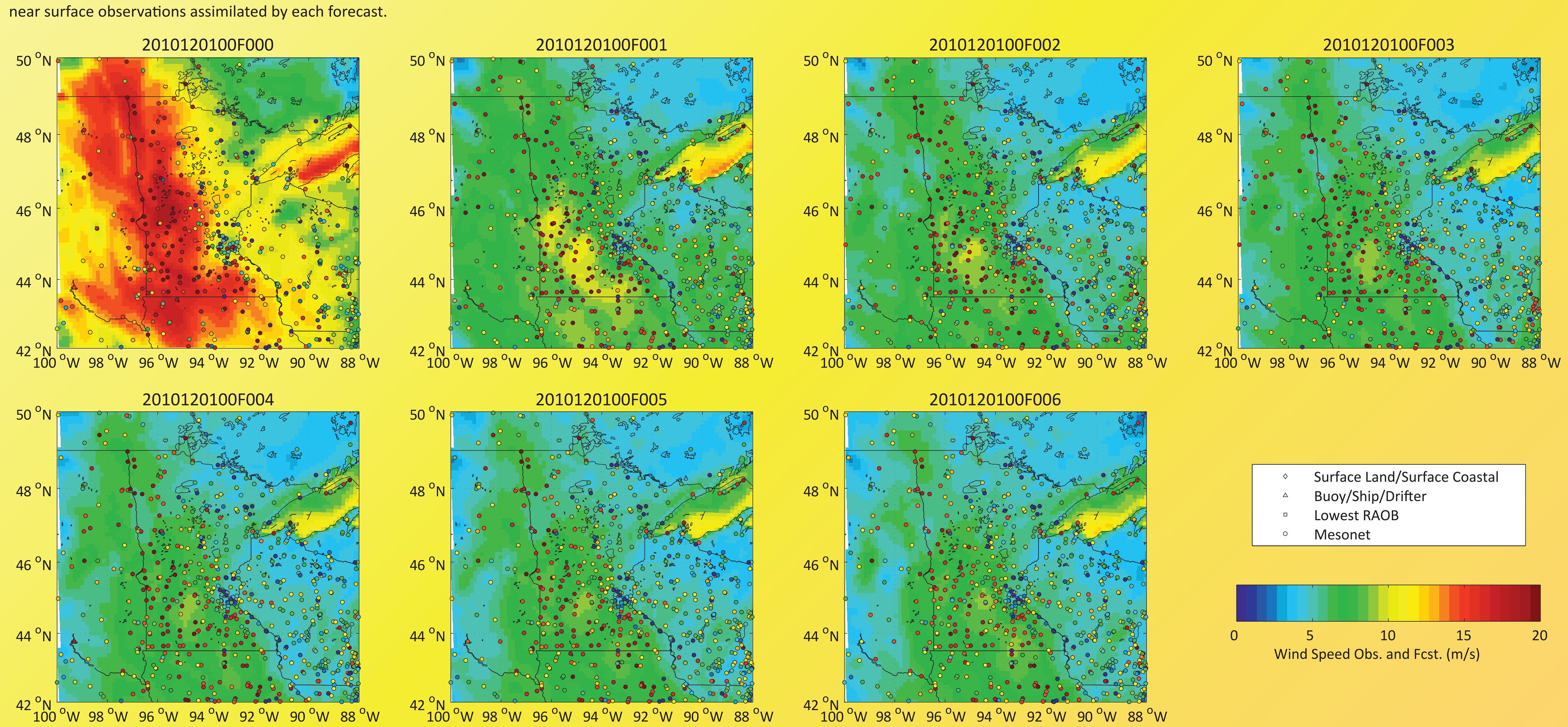

Figure 4. First 6 hours of 10-m wind speed forecasts and the analysis from 0000 UTC 01 Dec 2010 over Minnesota. Markers in the analysis panel denote near surface assimilated wind speed observations, while markers in the forecast panels show all mesonet wind speed observations recorded within ±30 minutes of the verification time (some of these observations in the forecast panels may not pass quality control procedures, as they were not assimilated; they are shown for reference).

Results: 15 Day Study Period

Figure 5 shows root-mean-square (RMS) error and bias of 2-m air temperature, 2-m dewpoint temperature, 10-m wind direction and speed over the 15 day study period, verified against METAR observations (observations mostly from the NWS network category). As seen in Figure 5, the reduction in RMS error during the first 12 hours of the forecast caused by the mesonet observation assimilation is statistically significant at the 99% confidence level. The lack of forecast improvement after 12 hours is likely due to the increasing dominance of large scale weather patterns on the small scale information captured by surface observations with time.

The reduction in wind direction RMS error at forecast hours beyond the analysis time is most likely the result of COAMPS failing to maintain the strong winds in the analysis throughout the model integration. The lack of improvement in wind speed RMS error with mesonet assimilation is mostly likely the result of high biased wind speed observations passing the quality control—a situation which was not expected (generally, mesonet wind observations are low biased because many observations are measured at heights lower than 10-m).

Figure 6 shows innovation statistics from mesonet observations. Generally, mesonet observations were relatively unbiased, except for pseudo-relative humidity (which showed a slight negative bias), and wind speeds (not shown), which may explain the lack of improvement in wind speed RMS error as noted above.

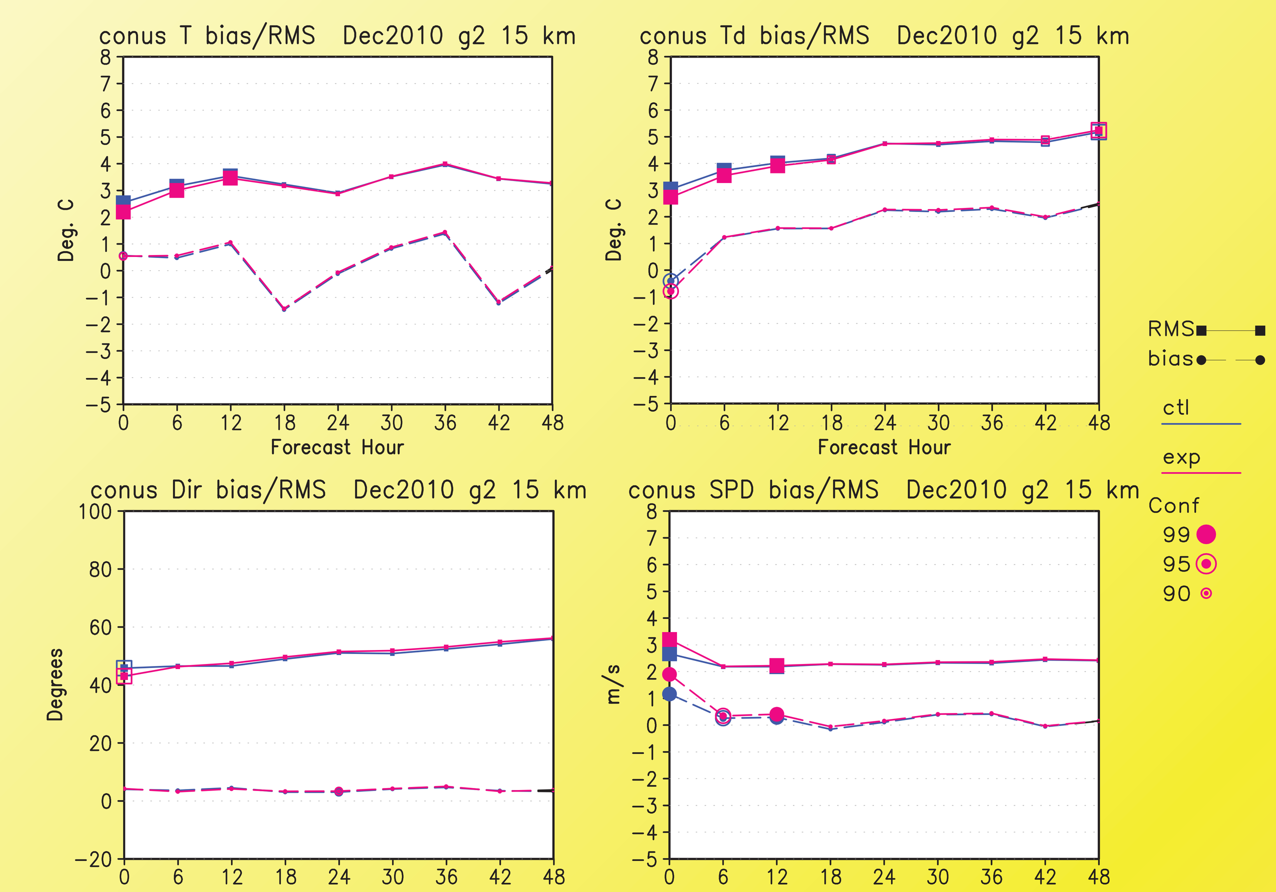

Figure 5. Forecast RMS error and bias for 2-m temperature, 2-m dewpoint, and 10-m wind speed and direction over the 15 day study period. Statistically significant differences are denoted by the larger markers/markers with outlines.

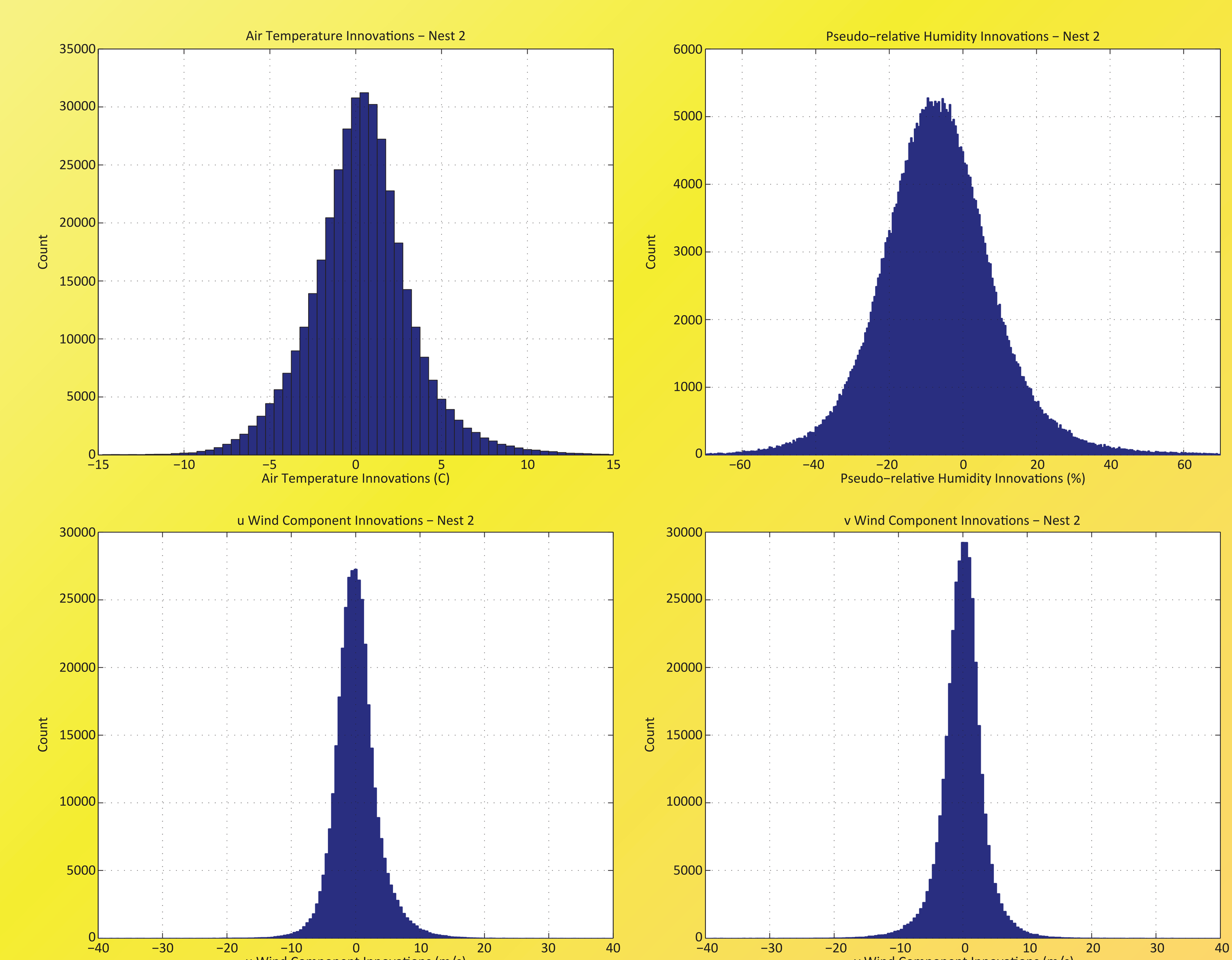

Figure 6. Mesonet observation innovations over 15 day study period for air temperature, pseudo-relative humidity, and u and v wind components.

Future Work and Acknowledgements

Future work for this research will include studying the impacts of expanding the assimilation time window for mesonet observations, attempting to remove biases from mesonet observations, as well as evaluating the benefits of mesonet assimilation on COAMPS forecasts by utilizing the COAMPS adjoint to determine observation impacts by mesonet observation and mesonet network.

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