Data-Denial Experiments for the Improvement of Wind Energy Forecasts with the NCEP North American Mesoscale Modeling and Assimilation System: The WFIP and POWER Projects

Jacob R. Carley[a], Geoff DiMego[b], James Wilczak[c], Eric Rogers[b], Steve Levine[d], Jeff Whiting[a], Yanqiu Zhu[a], Laura Bianco[c e], Irina Djalalova[c e], and Yelena Pichugina[c e]

[a]IMSG NCEP/EMC, USA, jacob.carley@noaa.gov, [b] NOAA/NWS/NCEP/EMC, [c]NOAA/ESRL/PSD,[d]SRG Inc., [e]CIRES

G-P05

Abstract

In a partnership with the Department of Energy (DOE) and the Earth Systems Research Lab's Global Systems and Physical Sciences Divisions (ESRL/GSD and ESRL/PSD), the National Centers for Environmental Prediction/Environmental Modeling Center (NCEP/EMC) has participated in two separate projects which focused on improving short-term wind forecasts, O(6 hrs), for the wind energy community. The first, the Wind Forecast Improvement Project (WFIP), involved a year-long field experiment which covered two separate study regions over the Northern and Southern Great Plains of the United States. In both regions special wind profiler, SODAR, and RASS observations were taken throughout the duration of the project. Using these special observations, along with industry-provided tall tower and nacelle wind speed observations, data-denial experiments were conducted with the North American Mesoscale model forecast system (NAM) to assess the impact of these special observations on the wind energy forecast over two, week-long periods. In addition to performing analysis/forecast cycles with the standard 12 km NAM domain the system was also extended to include an analysis/forecast cycle for its 4 km CONUS-nest.

The second project, POWER (Position of Offshore Wind Energy Resources), is a collaborative effort with DOE, ESRL/GSD, and ESRL/PSD to provide information about observation networks needed to support offshore wind energy development. Currently, maximizing the potential of offshore wind energy resources is made difficult by our inability to measure the shallow layer above the sea-surface, where offshore wind turbine rotors reside. During the summer 2004 New England Air Quality Study ~13 coastal wind profilers and one shipborne Doppler lidar were deployed in the New England area. The POWER project takes advantage of these pre-existing data and uses them in a set of data-denial experiments with an hourly-updated version of the NAM system. These data-denial experiments evaluate the potential benefits of assimilating coastal profiler observations upon short-term, offshore wind energy forecasts.

Preliminary results from both WFIP and POWER projects are shown here. For more on the hourly-updated NAM forecast system please see **B-P03**.

NAM-NMMB Configuration

12 km NAM Parent Description	Configuration
Model	Non-hydrostatic Multiscale Model on the B-grid (Janjic and Gall, 2012)
Points in x, y, z directions	954, 835, 60
Microphysics parameterization	Ferrier et al. (2002, 2011)
Boundary layer parameterization	Janjic (2001)
Convective parameterization	Janjic (1994)
Long/short wave radiation parameterization	Iacono et al. (2008), Mlawer et al. (1997)
Land surface model	Ek et al. (2003)
Gravity wave drag parameterization	Alpert (2004)

Table 1. 12 km NAM domain configuration.

4 km CONUSNEST Description	Configuration
Points in x, y, z directions	1371, 1100, 60
Convective parameterization	Janjic (1994): Modified to be less active for higher resolution
Gravity wave drag parameterization	None

Table 2. The NAM 4 km CONUSNEST configuration. Same as the NAM 12 km parent domain configuration (Table 1) except with the differences noted here.

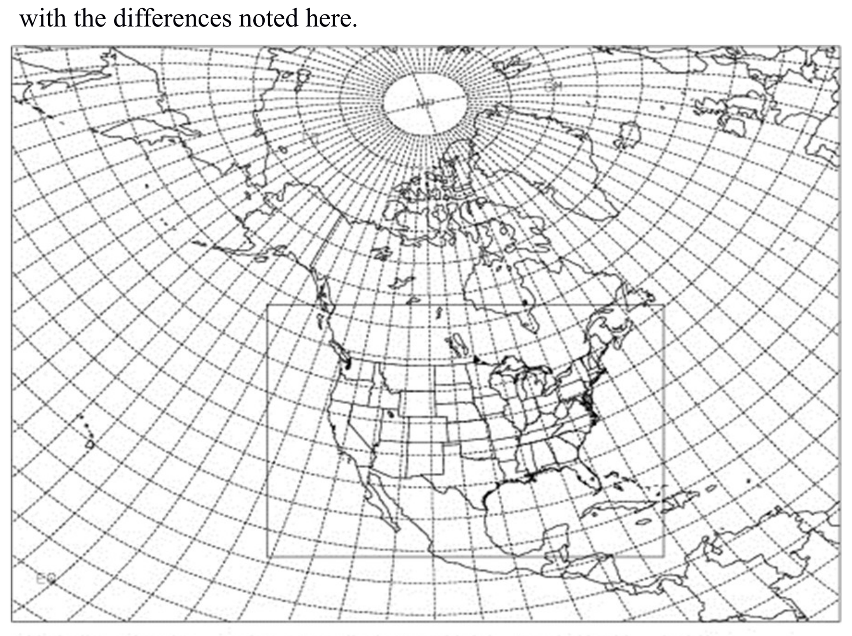

FIG 1. NAM Parent 12 km and 4 km CONUSNEST computational domains used during WFIP and POWER. The parent 12 km domain covers all areas depicted in the figure. The 4 km CONUSNEST domain covers only the area shown by the inner-rectangle.

Both WFIP and POWER experiments used the NCEP Gridpoint Statistical Interpolation data assimilation package operating in 3DVar mode (Wu et al., 2002). To control effects of initial imbalances in the forecast model, the NMMB was run with a diabatic digital filter with a window length of 40 minutes with both 12 km and 4 km domains.

Select References

Alpert, J., 2004: Sub-grid scale mountain blocking at NCEP. Proc. 20[Th] Conference on Weather on Analysis and Forecasting/17th Conference on Numerical Weather Prediction, American Meteorological Society. Seattle, WA. P2.4.

Ek, M. B., K. E. Mitchell, Y. Lin, E. Rogers, P. Grunmann, V. Koren, G. Gayno, and J. D. Tarpley, 2003: Implementation of Noah land surface model advances in the National Centers for Environmental Prediction operational mesoscale Eta model. *J. Geophys. Res.*, **108** (D22) .

Ferrier, B. S., Y. Jin, Y. Lin, T. Black, E. Rogers, and G. DiMego, 2002: Implementation of a new grid-scale cloud and precipitation scheme in the NCEP Eta model. Preprints, *15th Conf. on Numerical Weather Prediction*, San Antonio, TX, Amer. Meteor. Soc., 280–283.

Ferrier, B. S., W. Wang, and E. Colon, 2011: Evaluating cloud microphysics schemes in nested NMMB forecasts. *24th Conf. on Weather Analysis and Forecasting/20th Conf. on Numerical Weather Prediction*, Seattle, WA, Amer. Meteor. Soc.

Hamill, T. M., 1999: Hypothesis tests for evaluating numerical precipitation forecasts. Wea. Forecasting, 14, 155–167.

Iacono, M. J., J. S. Delamere, E. J. Mlawer, M. W. Shephard, S. A. Clough, and W. D. Collins, 2008: Radiative forcing by long-lived greenhouse gases: Calculations with the AER radiative transfer models. *J. Geophys. Res.*, **113**, D13103.

Janjic, Z. I., 1994: The step-mountain Eta coordinate model: Further developments of the convection, viscous sublayer, and turbulence closure schemes. *Mon. Wea. Rev.*, **122**, 927–945.

Janjic, Z. I., 2001: Nonsingular implementation of the Mellor-Yamada level 2.5 scheme in the NCEP meso model. NCEP Office Note, 91 pp. [437].

Janjic, Z. I. and R. Gall, 2012: Scientific documentation of the NCEP nonhydrostatic multiscale model on the B grid (NMMB). Part I Dynamics. NCAR Tech. Note NCAR/TN- 489 +STR. 74 pp.

Mlawer, E. J., S. J. Taubman, P. D. Brown, M. J. Iacono, and S. A. Clough, 1997: Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave. *J. Geophys. Res.*, **102**, 16 663–16 682.

Wu, W.-S., R. J. Purser, and D. F. Parrish, 2002: Three-dimensional variationalanalysis with spatially inhomogeneous covariances. *Mon. Wea. Rev.*, **130**, 2905–2916.

Wind Forecast Improvement Project (WFIP)

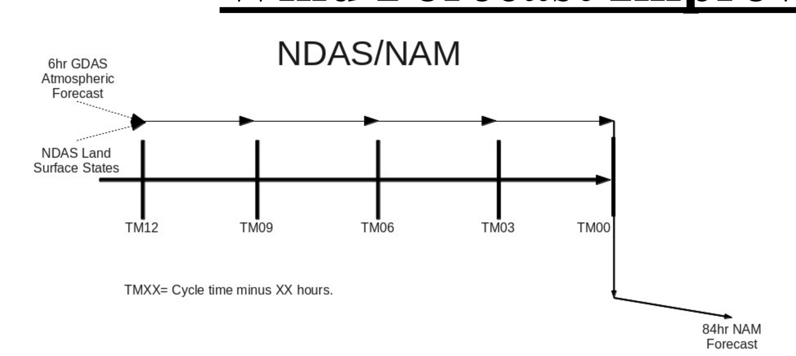

FIG 2. NAM/NDAS data assimilation cycling diagram. Each forecast cycle begins with a 12 hour analysis-forecast window during which analyses are conducted at three hour intervals (TM12, TM09, etc.). TM00 refers to the forecast initialization time (e.g. 00, 06, 12, or 18 UTC). At TM12 the first guess for the atmosphere is a 6 hour forecast from the GDAS. The land states are cycled from the previous NAM/NDAS cycle.

Five new observing platforms were tested as a part of data denial experiments during WFIP. Two of these platforms, wind turbine nacelle and tall tower, were new observation types that had never been used in the NAM Data Assimilation System (NDAS; Fig. 2). The other three platforms featured in the data denial experiments were wind profilers, SODARs, and RASSs.

Forecast performance was evaluated by comparing forecasts against WFIP profiler observations in both the northern and southern study domains during the combined winter quarter data denial experiment periods. The first period covered Nov. 30[th] - Dec. 6[th], 2011 while the second covered Jan. 7[th] - the 15[th], 2012.

Northern Study Domain

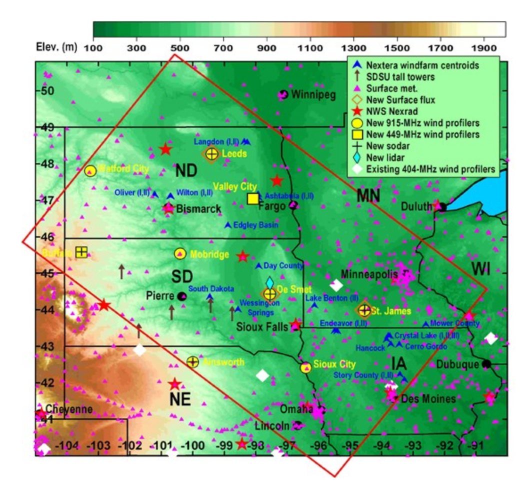

FIG 3. WFIP northern domain.

Lines falling outside the rectangles are significant at the p=0.05 level (Hamill, 1999)

RED Traces = Control Simulation

Blue Traces = Exp. Simulation with supplemental WFIP observations assimilated

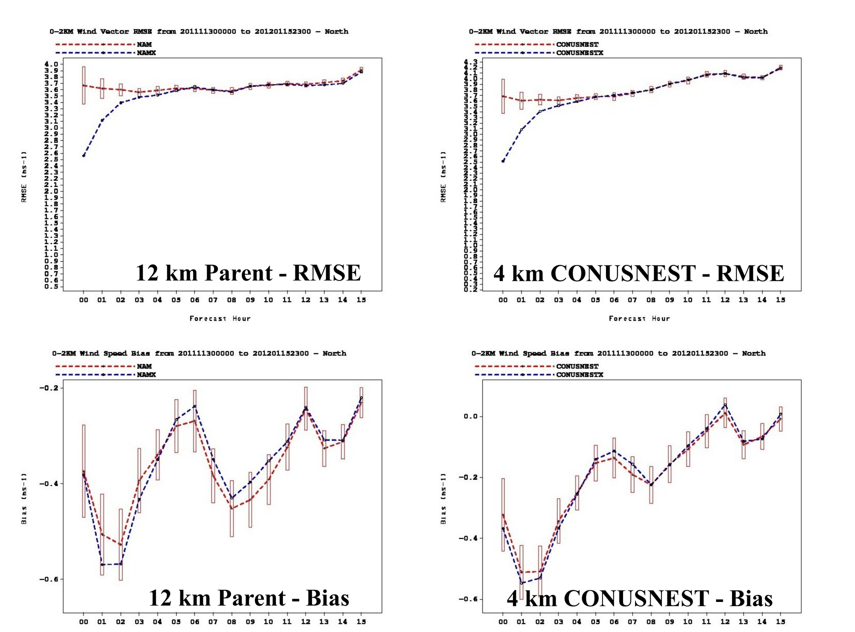

FIG 4. Vector wind RMSE (top) and wind speed bias (bottom) against WFIP wind profiler observations within the 0-2km AGL layer in the northern study region (Fig. 3). Statistics from the 12 km parent domain occupy the left panels and statistics from the 4 km nest domain occupy the right panels. Red traces are the control simulation and blue traces are the experimental simulation. Verification covers the entire winter quarter data denial period.

Southern Study Domain

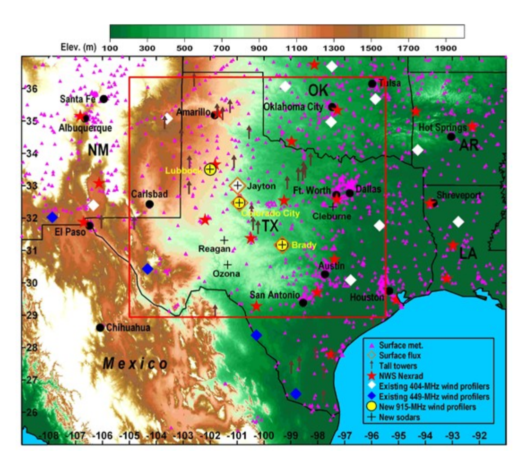

FIG 5. WFIP southern domain.

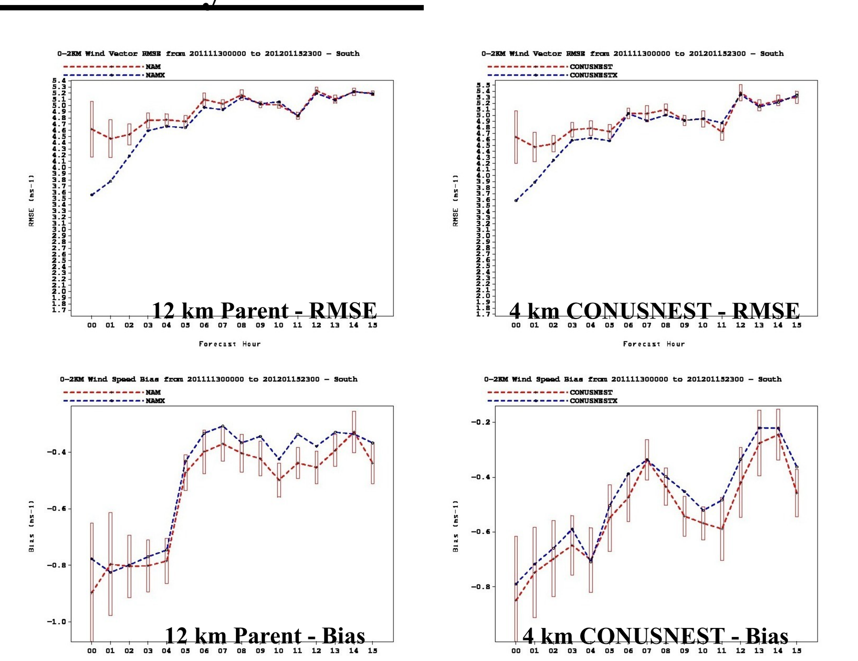

FIG 5. As in Fig. 4 except over the WFIP southern study region (Fig. 5).

Assimilation of Wind Turbine Nacelle Wind Speeds

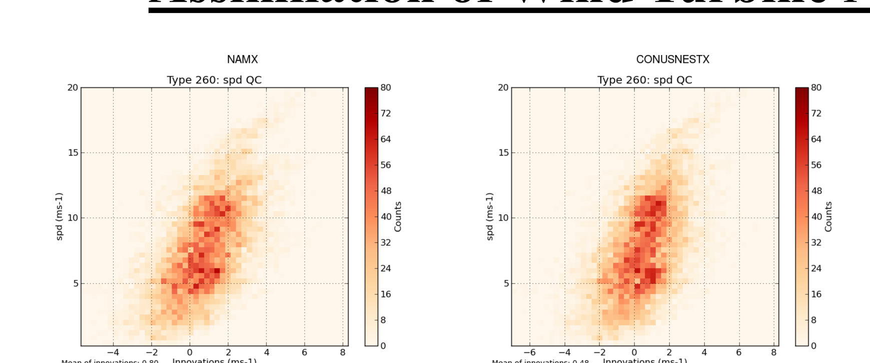

FIG 6. Nacelle wind speed observations and innovations (O-F) depicted as two-dimensional histograms. Plotted data are from all analysis steps during the WFIP winter quarter data denial period from the NAMX (left) and CONUSNESTX (right).

Fig. 6 suggests that the current forecast system has a *slow* speed bias as wind speeds increase beyond 5 – 8 m/s compared to the nacelle winds at the turbine level, perhaps indicating an issue of representativeness with the forecast model. Note that the 4 km CONUSNESTX shows a slightly lower overall bias compared to the 12 km NAMX.

Position of Offshore Wind Energy Resources (POWER)

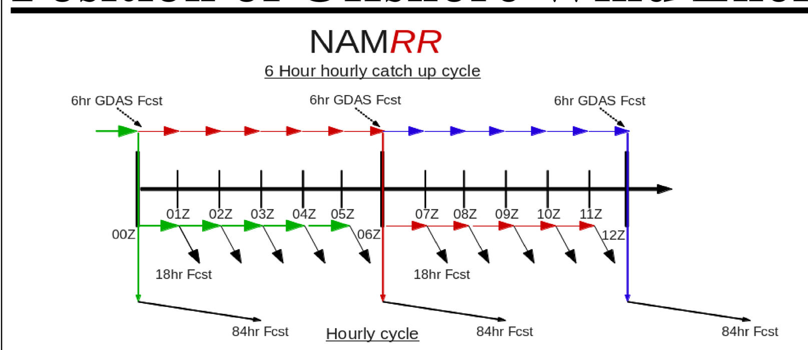

FIG 7. NAMRR data assimilation cycling diagram. The NAMRR's configuration is broken up into two run-types, 'catchup' and 'hourly'. Catchup types occur at 00Z, 06Z, 12Z, and 18Z and are similar to the current NDAS configuration (Fig. 2). The 'catchup' step starts using a 6 hour forecast from the Global Data Assimilation System (GDAS) for the first guess atmospheric state for the analysis while still cycling the model land states from the previous 1 hr NAMRR forecast. However, unlike the NDAS system the NAMRR only goes back 6 hours, instead of 12, but does perform an analysis every hour (instead of every 3). Once the catchup's analysis/forecast cycling is finished (e.g. at 06Z) a 60 hour forecast with the 4 km nest and an 84 hour forecast with the 12 km parent domain is conducted. It should be noted that *both* the parent and the nest are cycled in this system.

For the 'hourly' runtype (occurring at all other hours, e.g. 13Z, 14Z, etc.) an analysis is performed based upon a 1 hour forecast from the previous cycle. Following the analysis an 18 hour forecast is conducted with both the nest and the parent domain.

POWER aims to provide information about observation networks needed to support offshore wind energy development. This ongoing project involves two sets of data denial experiments using data from the summer 2004 New England Air Quality Study (NEAQS) which deployed ~13 coastal wind profilers, several RASS platforms, and one shipborne Doppler lidar for independent verification in the New England area (Fig. 8).

Each data denial period is about a week in length and tests the assimilation of the extra wind profiler and RASS observations associated with NEAQS study. For POWER the newly developed NAM-Rapid Refresh (Fig. 7; NAMRR) system was adopted. The NAMRR is an hourly updated forecast-analysis system which cycles *both* 12 km and 4 km nest domains (Fig. 1). The POWER project is currently ongoing, however results from the Aug. 6[th] - 13[th], 2004 study period are presented here (Figs 9 and 10).

Future work involves a joint assessment of both the NAMRR and RAP/HRRRR forecasts off the New England coast using shipborne Doppler lidar and profiler observations from the NOAA *Ron Brown* for verification.

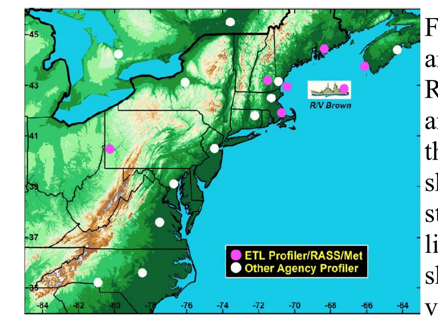

FIG. 8. The POWER study area with wind profiler and RASS observation locations annotated via circles. Note the location of the *Ron Brown* ship, which was *not* stationary during the project. lidar observations from this ship will be used for verification in future work.

Lines falling outside the rectangles are significant at the p=0.05 level (Hamill, 1999)

RED Traces = Control Simulation

Blue Traces = Exp. Simulation with supplemental POWER profiler and RASS observations assimilated

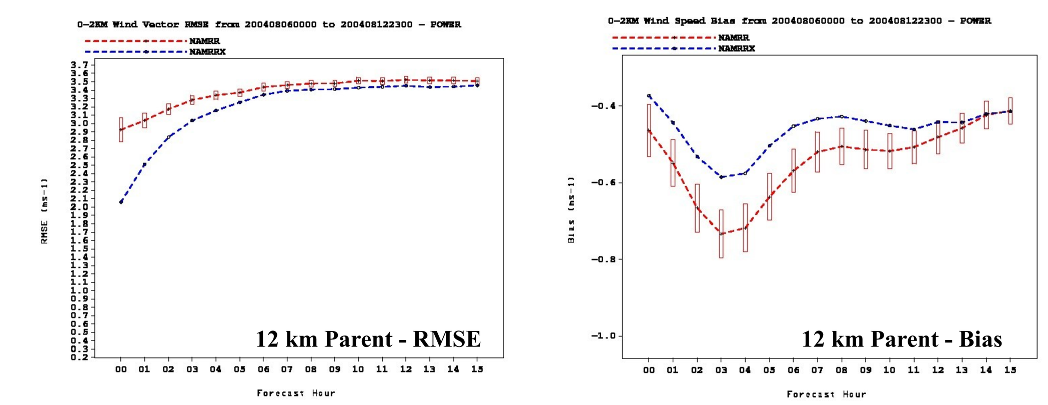

FIG 9. 12 km parent domain vector wind RMSE (left) and wind speed bias (right) against POWER wind profiler observations (Fig. 8) within the 0-2km AGL layer.. Red traces are the control simulation and blue traces are the experimental simulation. Verification covers only the August study period.

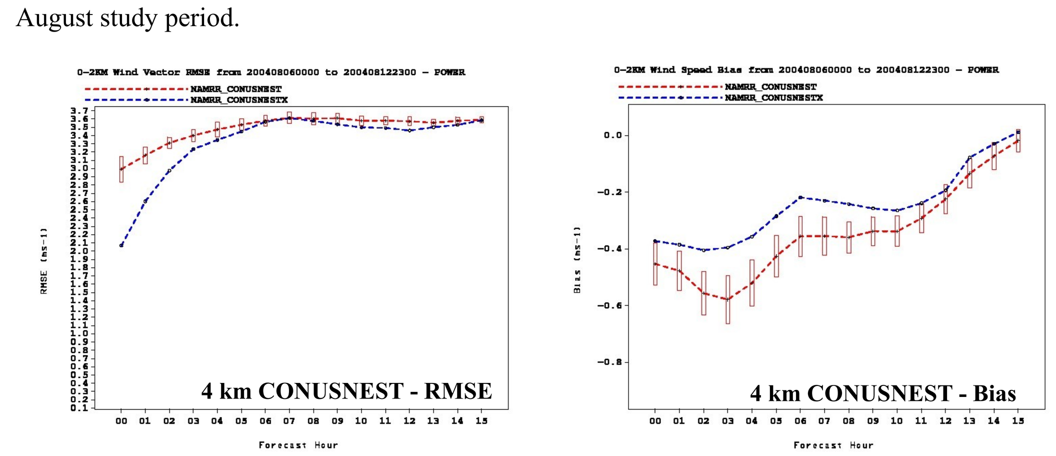

FIG 10. As in Fig. 9 except for the 4 km CONUS nest domain.

Synopsis

WFIP: Additional field experiment observations generally yielded statistically significant wind forecast improvements within the 0-2 km AGL layer at profiler locations during first several hours of the forecast period.

POWER: *Preliminary* results suggest that assimilation of a handful of coastal profilers and RASS observations can produce statistically significant wind forecast improvements up to several hours, and small improvements out to ~14 hours within the 0-2 km AGL layer.

Acknowledgements

During a substantial portion of this work, J. R. Carley was affiliated with the UCAR Visiting Scientist Program. The DOE is acknowledged for providing funding for both WFIP and POWER projects. Perry Shafran is thanked for his help with the grid2obs verification system.