# Assimilation Of Wind Profiler Data Into Mesoscale Simulations: Impact And Evaluation

**Wayne M. Angevine[1], Mark Žagar[2], Robert M. Banta[3], Christoph J. Senff[1], Raul J. Alvarez[3], R. Michael Hardesty[3]**
*[1]Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, and NOAA Earth System Research Laboratory, 325 Broadway, Boulder, Colorado 80305 USA*
*email:Wayne.M.Angevine@noaa.gov*
*[2]Wind & Site Competence Centre, Vestas Technology R&D, Vestas Wind Systems A/S*
*[3]NOAA Earth System Research Laboratory, 325 Broadway, Boulder, Colorado 80305 USA*

## 1. INTRODUCTION

Simulations of lower atmospheric flow patterns on time scales of order 1 day with resolution of a few kilometers are commonly used for interpretation of field measurements, and prediction of air quality, wind energy availability, or electricity demand. Measured wind profiles can be assimilated into retrospective simulations to improve their fidelity to reality, or to provide better initial conditions for predictions. It is vital to evaluate the impact of assimilation, which may not always be helpful. We present results from WRF simulations of Houston and southeast Texas for 10 weeks of 2006. Data from three boundary layer wind profilers was assimilated by four-dimensional data assimilation (FDDA or nudging). Traditional statistics do not crisply display differences between runs. A new metric of sea breeze correspondence shows improved model performance at seven surface sites with FDDA. The average wind over the middle of the day is a very good predictor of maximum ozone, and runs with FDDA are clearly better than without by this metric.

Many groups have run models over the Houston area and reported results [1-5]. Our goal here is *not* to claim that the results we present are superior. In fact, our goal is to demonstrate the difficulty of supporting such a claim, and contribute to the discussion about how such claims can be evaluated.

The second Texas Air Quality Study (TexAQS II) was held in 2006. Many groups contributed resources, including several aircraft, ground chemistry sites, and a heavily-instrumented ship. These resources augmented the operational chemistry and meteorology monitoring network operated by state and local authorities.

We present results from runs of the Advanced Research core of the Weather Research and Forecasting model (WRF-ARW) model system for 75 days at 5 km grid spacing. Results from shorter runs with a finer grid have been shown by Angevine et al. (2008). That presentation included comparisons with mixing heights measured by Doppler lidar, and with surface fluxes, over the waters of the Bay and Gulf. Three WRF configurations are presented here: With four-dimensional data assimilation (FDDA) of three wind profilers; FDDA plus 1-hour water surface temperatures; and no FDDA. All three use soil moisture values reduced over land to produce approximately correct near-surface temperatures, since the default soil moisture tables produced temperatures that were substantially too cool. All runs were initialized at 0000 UTC every day from the European Center (ECMWF) analyses, and used analysis nudging to the 6-hourly ECMWF analyses on the outer (15-km spacing) grid. All the WRF configurations used the MYJ PBL scheme, 5-layer thermal diffusion ("slab") land surface, RRTM longwave and Dudhia shortwave radiation.

For comparison, we primarily use surface meteorology measurements from the operational air-quality monitoring network in the Houston area. These measurements have the advantage of continuous availability, and are representative of the types of measurements available in many locations when no major field campaign is in progress. We also use wind measurements from the radar wind profiler at the nearby city of LaPorte.

## 2. TRADITIONAL STATISTICS

The basic figures of merit for model – measurement comparisons are systematic and random error, also known as accuracy and precision, bias and scatter, and many other terms. Of the many possible statistics that could be shown, we present a small selection. Figure 1 shows the mean difference (bias) and standard deviation of the difference (random error) of the wind speed and direction every 3 hours at 7 sites over the entire 75-day run. One challenge is immediately apparent: The ECMWF analysis used to initialize the WRF model performs better than any of the WRF configurations for some sites and measures. However, there is a general tendency for FDDA to improve the random error of wind direction.

Figure 2 shows the random error of wind speed and direction by time of day for a single site, C45. This is the closest site to the Bay and Gulf, so it would be expected to have the most sea breeze influence. Only data for the 17 days with ozone levels of regulatory concern are included. Here, FDDA improves random error in both speed and direction. The use of 1-h SST (rather than default daily values from ECMWF) improves random error in the afternoon, but makes it worse at night. ECMWF has different but comparable errors, but WRF with FDDA is better at hours 18 and 21in the critical afternoon period.

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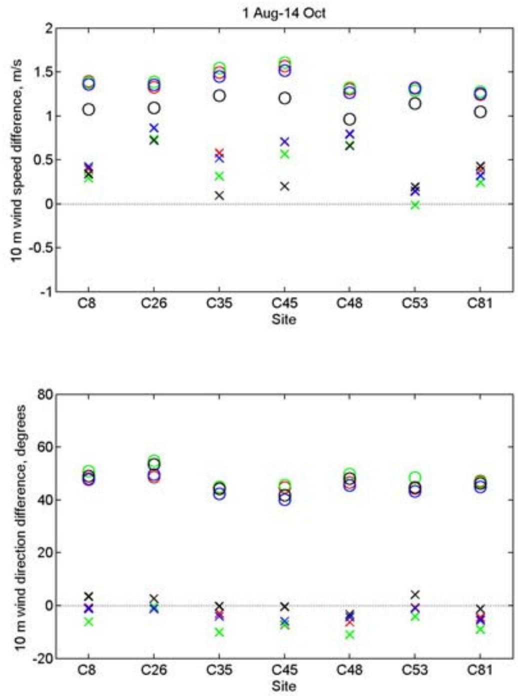


Figure 1: *Mean (X) and standard deviation (O) of wind speed and direction difference between model and observation at 7 surface sites every 3 hours for the entire 75-day run. The runs are color coded: Black = ECMWF analysis, green = WRF without FDDA, red = WRF with FDDA, blue = WRF with FDDA and 1-h SST.*

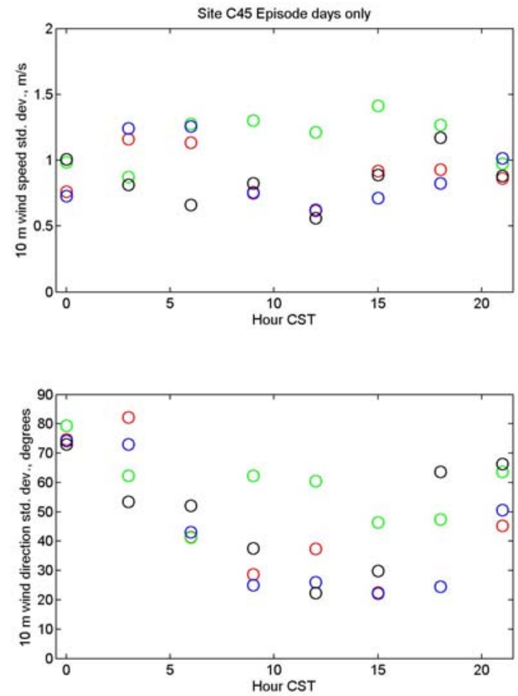


Figure 2: *Standard deviation of wind speed and direction difference between model and observation at site C45 by hour of day (every 3 hours) for the 17 ozone episode days. The runs are color coded: Black = ECMWF analysis, green = WRF without FDDA, red = WRF with FDDA, blue = WRF with FDDA and 1-h SST.*

## 3. DISTRIBUTION OF ERRORS

Means and standard deviations can mask important information that can be revealed by looking at the actual distribution. If we compare the 2-m temperature between the model run with FDDA and the measurements, we find that 10 days have at least one hour with temperature difference > 5K at site C35 (28 hours total). All differences > 5K have model > measurement (model too warm). All 10 days have convection or a cold front in reality. The model also has clouds and fronts but different amount, timing, or location.

## 4. NEW METRICS

Having found that traditional statistics do not clearly demonstrate the improvements we expected to find by running a better modeling system, we devised other metrics. Analysis of air quality in Houston has shown that the sea breeze is implicated in the most severe episodes.

The correspondence between sea breeze occurrence in each model run and in the surface observations is shown in figure 3. This is a measure of how often a sea breeze occurs simultaneously in the simulation and the measurement. The figure shows results when a sea breeze is defined as a northerly component >1 m/s between 0600 and 1200 UTC and a southerly component >1 m/s after 1200 UTC. Many other definitions are possible, but the results are not particularly sensitive to the threshold speed. The runs with FDDA alone or with FDDA and 1-h SST are better (closer to the measurement, that is, to 1) at all 7 sites, although at two sites the improvement is marginal.

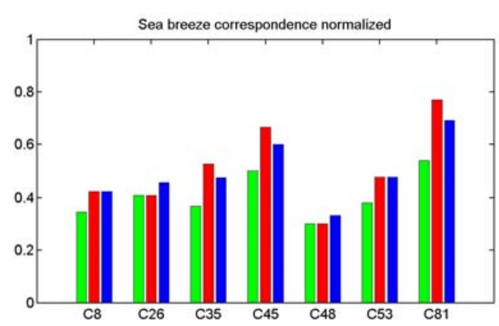


Figure 3: *Correspondence between sea breeze in each of the model runs and the measurements at 7 surface sites. Perfect agreement would be indicated by a value of 1. See text for definitions. The runs are color coded: Green = WRF without FDDA, red = WRF with FDDA, blue = WRF with FDDA and 1-h SST.*

## 5. AVERAGE WIND

The vector average wind is found by averaging the u and v components over 10 hours and computing the speed from those. It thus accounts for recirculation. In an extreme example, if the wind blows from the south at 6 m/s for 5 hours and then switches to the north at the same speed for 5 hours, the average speed is 6 m/s but the vector average wind is zero. There is a tight relationship (r = 0.91, not shown) between (either) average wind in the column above LaPorte from the model runs with FDDA and the wind profiler measurement. This is not too surprising since the profiler data was assimilated, so the comparison is not independent.

Figure 4 shows the relationship between the vector average wind and the maximum ozone measured by the NOAA airborne lidar [6]. This is a fully independent comparison. The correlation coefficient is r = -0.85 or $r^2 = 0.73$. The results shown in the upper panel of figure 3 are from the WRF run with FDDA and 1-h SST. In this case, the run without 1-h SST performs about the same. The run without FDDA (lower panel) is clearly worse, with r = -0.58, $r^2 = 0.34$.

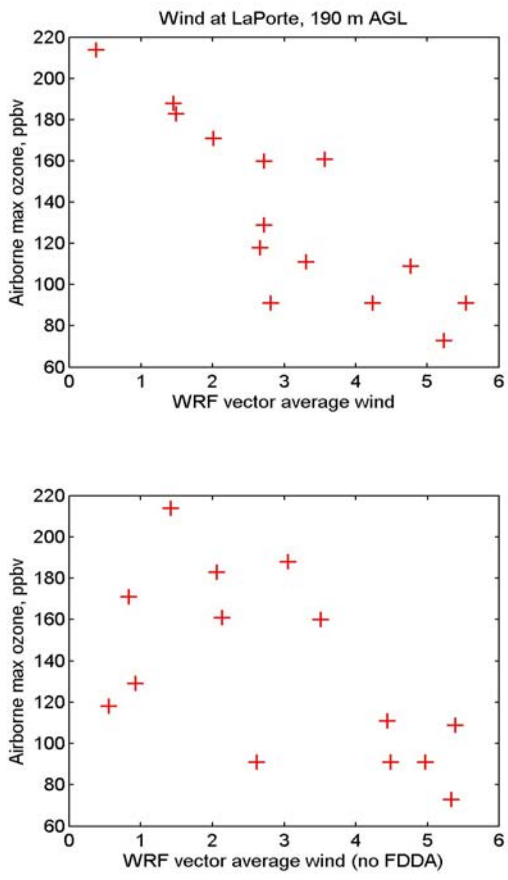


Figure 4*: Vector average wind versus average wind speed at LaPorte (top). Averages are over 10 hours, 1400-2400 UTC. Maximum ozone observed by airborne platforms on 14 days vs. vector average wind from WRF (bottom).*

## 6. SUMMARY

The search for metrics that clearly indicate whether the addition of complexity to the model system in the form of data assimilation or improved water surface temperatures is at best partially successful. We begin with the handicap that the ECMWF analysis used for initialization is already quite good, as good as any results in the literature. However, we expect that simulations with finer resolution, such as those shown here, should resolve fine-scale features driven by the complex coastline effects better. Even this is difficult to conclusively demonstrate. Part of the explanation for that difficulty may be related to the unique nature of the sea breeze at 30 degrees latitude (see sidebar in [7]). The large scale of the coastal oscillation near that critical latitude may make finer resolution less useful than at other locations. Another factor may be the lack of terrain and the relatively small contrasts in temperature between land and water in the Houston/Galveston area. Finer resolution is likely to be more important in areas with coastal mountains and/or cold water.

Traditional statistics (bias and standard deviation), whether computed over the full period of time or only on episode days, by individual sites or time of day, do not crisply display differences between runs. They do, however, generally indicate improvement with FDDA of wind profiler data.

Looking at the distribution of errors is clearly useful in diagnosing when and why major problems occur. In these simulations, large errors in temperature (>5K) occurred when moist convection was present in reality.

The new metric of sea breeze correspondence shows improved model performance at all 7 surface sites with FDDA.

The average wind over the middle of the day is a very good predictor of maximum ozone. The vector average is slightly better than the scalar average, but the difference may not be significant. Runs with FDDA are clearly better than without by this metric.

Uncertainty analysis is needed to establish the significance of both traditional and new metrics.

In conclusion, we find that assimilation of wind profiler data improves the model results overall, primarily by reducing the random error in wind direction. The improvement is most easily seen in the wind profile away from the surface, and confirmed by a tight correlation with measured ozone.

Some philosophical issues must be considered. How good is good enough? What if we know we have improved the model, but can't show that we have improved the results? Are there fundamental or practical limits to predictability of the phenomena most relevant to air quality, such as stagnation?

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