A Comparative Study of virtual and operational met mast data

Dr. Ö. Emre Orhan
Wind Engineering Manager, Borusan EnBW Energy
Nurol Plaza No:255 Kat:4 34398 Maslak-Şişli İstanbul

Gökhan Ahmet
Researcher-PhD candidate, METU Center for Wind Energy

Abstract. Performance of wind assessment studies depend on the adequacy and duration of the wind data. For a reasonable wind assessment, at least one full year wind data is needed so that, all the variations throughout the year are represented. On the other hand, it is always a question of time and cost how to get the wind data. On-site measurements are the most common way of obtaining wind data but it is the most expensive and time consuming as well. Apart from on-site data, there are also reanalysis long term data sources like MERRA, NCAR, etc. Time and spatial resolution of these long term data are lower compared to on-site measurements but in cases where on-site measurements are not available, they are also utilized. On top of on-site and reanalysis wind data, weather forecasting models like WRF, MM5 are available. Although, these models mainly are used for forecasting services, flexibility of the models makes them suitable for preliminary resource assessment purposes. In this study, comparisons of annual energy production estimations are computed using virtual and on-site met mast data separately for a specific time range. The widely used weather research and forecasting model (WRF) is used to provide virtual met mast data. Once WRF simulations are completed, interpolation routines are employed in order to extract data for a specific location. The on-site met mast is located inside a wind farm project area which is under development. Project site is located in the south of Turkey. There are four different met masts, three of them recording wind data presently. On-site measurements together with WRF results are used to obtain energy yields for the project area. The performance of both methodologies is compared. It has been observed that WRF can as well serve as a preliminary model in cases where no other data source is available but the model has to be implemented with great care depending on the project site conditions.

1 Corresponding author
1. Introduction

Accurate predictions of unsteady atmospheric flow fields have a wide range of usage such as micro-site selection for wind farms and pollution tracking, each of which are of current research topics with several examples in literature [1,2]. As wind farms consisting of a large number of wind turbines have a high initial investment cost, wind farm siting must be given a significant importance [3,4]. Low resolution wind energy potential atlases have the necessary statistical information for macro-siting of wind farms but lack the precision for the micro-siting. Therefore; high resolution, more accurate wind field information may be needed for micro-siting in order to improve the power output of a wind-farm.

In the literature, there are studies comparing different methodologies of calculating flow fields. F.J.Zajackowski et.al.[5] compares Numerical Weather Prediction Models (NWP) and Computational Fluid Dynamics (CFD) simulations. They conclude that NWP can take radiation, moist convection physics, land surface parameterization, atmospheric boundary layer physics closures, and other physics into account, but wind flow features finer than 1 km are not captured by the turbulence physics of such models. CFD simulations, however, have proved to be useful at capturing the details of smaller scales due to a finer scale topography, and details around urban features such as tall buildings. Ahmet et.al.[6] couples Weather Research and Forecasting (WRF) solution with two different CFD codes. The aim is to obtain a reasonable solution using in-house CFD software instead of commercial ones.

Different from what is discussed above; in this study; results of on-site measurements are compared with WRF simulations. On-site measurements are available for a wind farm project of 50 MW that is under development. WRF results are obtained using two different interpolation schemes, trilinear and logarithmic. Then WRF results are compared with on-site measured 10 minute averaged wind speeds and directions. After the comparison of the wind speed and direction, annual energy yields are computed using Wind Atlas Analysis and Application Program (WASP).

2. Details about the wind farm

The project of interest is situated south of Turkey. The site is classified as highly complex located at a high elevation plateau, elevations ranging from 1600 m to 1700 m. Currently there are 3 lattice measurement (met) masts (86m, 86m and 60m) at the site recoding data since August 2012. And there was another tubular met mast of 71.4 m which collapsed at the end of 2010. The basis of comparison is wind data obtained within 2010 from the tubular met mast only. In Figure 1, project location together with the project borders is given.
The met mast is 71.4 m and has 5 cup anemometers (@71.4 m, 69.5 m, 50.0 m, 30.1 m and 19.5 m) and 3 wind vanes (@67.0 m, 48.0 m and 28.0 m).

3. Methodology
WRF is a fully compressible, Eulerian, $\eta$-coordinate based, nest-able, non-hydrostatic, NWP model with a large suite of options for numerical schemes and parameterization of physical processes [7, 8]. WRF uses an $\eta$ based coordinate system instead of an orthogonal Cartesian coordinate system. The vertical coordinate, $\eta$, is defined as:

$$\eta = \frac{p - p_{ht}}{p^*}$$  \hspace{1cm} (1)

and pressure perturbation $p^*$ is simply
\[ p^* = p_{hs} - p_{ht} \]  

where \( p \) is pressure, \( p_{hs} \) is surface pressure, and \( p_{ht} \) is the pressure at the top of the model. As seen in Figure 3, the \( \eta \) coordinate system causes a poor representation of the surface topography.

![Figure 3. Representation of \( \eta \) coordinate system](image)

WRF model outputs are first obtained over the geographical domain of interest. The local terrain data is downloaded automatically from UCAR (University Corporation of Atmospheric Research) server via WRF. The time dependent initial and boundary conditions for the WRF simulations are obtained from NCEP (National Centers for Environmental Prediction) Final Analysis (FNLS from GFS) (ds083.2 dataset). It should be noted that this dataset has globally 1 degree resolution data for every 6 hours. Nested WRF solutions are first run for a 1 year period, within a parent domain of 3 km horizontal resolution and a nest of 1 km resolution around the wind farm area. The computations are performed from 01.01.2010 to 28.12.2010. The parent and the nested solution domains are 100x79 (horizontal) x 50 (vertical) size, and 88x67 (horizontal) x 50 (vertical) respectively. Model outputs for the nested domain are saved in 5 minute time intervals. Table 1 shows the physics and dynamics options that are used in the WRF simulations. Parent and nested domains used for the WRF simulations are shown in Figure 4.

**Table 1. WRF Physics and dynamics options**

| Selected Options                        |
|-----------------------------------------|
| Microphysics                           | WRF Single-Moment 6-class scheme |
| Longwave Radiation                     | RRTM scheme                     |
| Shortwave Radiation                    | Dudhia scheme                   |
| Surface Layer                           | MM5 similarity                  |
| Land Surface                            | Noah Land Surface Model         |
| Planetary Boundary layer               | Yonsei University scheme        |
| Cumulus Parameterization               | Kain-Fritsch scheme             |
In order to obtain the wind statistics for the met mast location, two different interpolation schemes are utilized: trilinear and logarithmic. Trilinear interpolation is an approximation where the value required for the point of interest is obtained using the data on the lattice points. On the other hand, with logarithmic interpolation values are calculated for two different heights (different from the point of interest). Later, these two points are fitted using a logarithmic law and the value for the required height is computed. Results of both methods are compared with on-site values in the following section.

4. Results and Discussions

Results discussed within this section are obtained using two different calculation methodologies and then compared to on-site measurements. WRF calculations are based on trilinear and logarithmic interpolations. Non-dimensional mean wind speeds and normalized Root Mean Square Error (NRMSE) values that are calculated as a result of both methods are given in Table 2. RMSE values are calculated with the following formula and normalization is performed using the mean wind speeds.

$$NRMSE = \sqrt{\frac{n}{\sum_{i=1}^{n}(V_{meas} - V_{calc})^2}}$$  \hspace{1cm} (3)

where $V_{meas}$ and $V_{calc}$ are the 10 minute measured and calculated wind speeds. $V_{calc, ave}$ is the average wind speed of the WRF simulations and $n$ is the number of 10 minute wind speed occasions.

| Table 2. Normalized mean wind speeds and NRMSE |
|-----------------------------------------------|
| Measurement | WRF-log | WRF-tri |
|-------------|---------|---------|
| 1.00        | 0.97    | 0.95    |
| NRMSE WRF-log | 0.48    | NRMSE WRF-tri | 0.49    |
Annual mean wind speeds are normalized using the maximum value of all the results being the measured wind speeds. Comparisons of WRF results with the measurements reveal that mean results are quite close to each other, logarithmic being slightly better than trilinear. Although the mean wind speed prediction is well performed using both methods, NRMSE values are relatively high. This result confirms the main difficulty in short term forecasting. This fact can also be verified using the time series for wind speed and direction as shown in the figure below. In Figure 5, time series for normalized wind speed and wind direction are plotted for the logarithmic interpolation scheme. It is clear from the figure that the overall trend fits very well. However, there are time shifts and time periods where the fit is not very good. It is believed that this is the main reason for a considerably high NRMSE value. On top of that, one has to remember that the boundary conditions used for WRF simulations are for 6 hour time intervals which is also causing a shift in the comparison of the time series.

![Figure 5. Normalized wind speed and wind direction for 2010.](image)

Another performance check can be done using Weibull distribution and wind rose patterns. Normalized Weibull parameters are given in Table 3 below for all the options considered in this study. Normalization is performed using the Weibull parameters for the measurement.

| Table 3. Normalized Weibull parameters |
|----------------------------------------|
| Scale parameter- A (m/s) | Measurement | WRF-log | WRF-tri |
|----------------------------|-------------|---------|---------|
| 1.00                      | 0.98        | 0.96    |
| Shape parameter - k       | 1.00        | 0.87    | 0.87    |

In Figures 6 and 7, Weibull distributions and wind roses are plotted for the measurement and WRF logarithmic options respectively. Together with Table 3, Figure 6 also shows that there is a considerably good agreement for the scale parameter, A; while calculations for the shape parameters is worse. Comparison of the wind rose patterns given in Figure 7 shows that it is possible to capture the prevailing wind direction in a more reasonable manner than the wind speeds. There is a few percentage differences in the north-south directions and the biggest difference is the overestimation around north-northeast. This can be considered as a promising result that could be improved with better WRF simulations in the future.
In order to assess the reliability of the results obtained, a final check is performed calculating the Annual Energy Production (AEP) for the wind farm composed of 16 wind turbines. Wind turbines are of 3.3 MW commercial ones and the comparison is given in Table 4. For the comparison, result obtained using on-site measurements is assumed to be 100 % and the others are calculated based on that assumption. Calculations are performed using WASP model version 10.2 and the given values are all gross without any loss and uncertainty involved. For WASP modelling, default parameters are used within WindPro.

Results in Table 4, show that WRF results are very close to the on-site measurement based calculations. In contrast to monthly mean wind speeds, this time, trilinear interpolation scheme performed better compared to logarithmic interpolation. Very surprisingly, energy yield obtained using trilinear interpolation is almost identical, almost only 100 kWh apart.

### Table 4. Normalized Annual Energy Production (AEP) values

|          | AEP-Measurement | AEP-WRF-logarithmic | AEP-WRF-trilinear |
|----------|-----------------|---------------------|-------------------|
|          | 1.00            | 1.02                | 1.00              |
The outcome of all the discussions above is the possibility of utilizing WRF to overcome the difficulty of missing wind data. It is clear that, WRF will not replace any other simulation method or on-site measurements but can be used as a supplement.

5. Conclusion and Future Work
The purpose of this study is to check the performance of WRF calculations and compare the simulation results with on-site measurements. Simulations are important in the sense that, it is not always possible to work with on-site measurements due to some limitations. Then the developer has the possibilities of obtaining the wind data using simulations like CFD and WRF.

Comparison results show that, WRF can be a promising approach when on-site measurements do not cover a full year. Normally, WRF simulations are used for forecasting purposes or obtaining long term data. However, it is shown in this study that WRF can also be considered as a viable candidate for short time purposes. But this does not mean that it is satisfactory enough for the investment decision phase. Rather it can be used as a preliminary tool in order to have a more through view.

To conclude, the following list of comments is relevant for this study:

- This study only includes the comparison of WRF with on-site measurements and WASP. However, there are simulation techniques like CFD, etc. This has to be expanded including such techniques.
- Simulations are based on only 1 year wind data. Wind energy is well known for its yearly interchangeability. Therefore, long term analysis shall be included to check the performance of WRF especially in long term aspect.
- The wind farm considered here is relatively flat compared to complex topographies encountered in Turkey. Results shall also be checked for sites having simple to very complex topography in order to have a general overview of short term performance of WRF.
- WRF shall be improved where poor performance is observed. Although the general trend is very promising, there are some time intervals intra-monthly or intra-annual that the performance improvement is required.
6. References

[1] Cochran, B.C., Damiani, R.R., 2008, “Harvesting Wind Power from Tall Buildings”, Wind Power 2008, (Houston, Texas).
[2] Politis, E.S., Chaviaropoulos, P.K., 2008, “Micrositing and classification of wind turbines in complex terrain”, European Wind Energy Conference and Exhibition Brussels, (Belgium).
[3] Damiani, R., Cochran, B., Orwig, K., Peterka, J., 2008, “Complex Terrain: A Valid Wind Option?”, American Wind Energy Association.
[4] Derickson R.G., Peterka J.A., 2004, “Development of a Powerful Hybrid Tool for Evaluating Wind Power in Complex Terrain: Atmospheric Numerical Models and Wind Tunnels,” American Institute of Aeronautics and Astronautics
[5] Zajaczkowski F. J., Haupt S.E., Schmehl K.J., 2011, “A preliminary study of assimilating numerical weather prediction data into computational fluid dynamics models for wind prediction”, Journal of Wind Engineering and Industrial Aerodynamics 99, pp 320-329.
[6] Ahmet G., Leblebici E., Tuncer I.H., 2013, “Terrain fitted turbulent flow solutions coupled with a mesoscale weather prediction model”, EAWE PhD Seminars, Gotland, Sweden.
[7] Skamarock W. C., Klemp J. B., Dudhia J., Gill D. O., Barker D. M., Duda M. G., Huang X.-Y., Wang W., Powers J. G., 2008, “A Description of the Advanced Research WRF Version 3”, National Center for Atmospheric Research, (Boulder, Colorado, USA)
[8] Leblebici E., Ahmet G., Tuncer I.H., 2012, “Atmospheric turbulent flow solutions coupled with a mesoscale weather prediction model”, Torque Conference, Oldenburg, Germany.

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