Validation of "Virtual" Wind Datasets from Mesoscale modelling

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Abstract

The application of limited area numerical weather prediction (NWP) models for wind assessment is not new to the wind industry. One of the most common applications is the so called "Virtual" wind data.

MEGAJOULE has been using mesoscale models since 2007. An initial validation effort based on the "virtual" wind data approach was already published in 2011[1]. This paper presents a second validation effort, which includes developments made in the meantime.

Validations are based on 3x3 km resolution estimates from mesoscale model WRF of 10 minute horizontal wind speed and direction time series. Input weather data used is the NCEP - FNL data set.

Simulations are compared with local measurements from 13 sites located in Portugal.

Observations are taken in typical wind assessment masts compliant with IEC and MEASNET recommendations. These observations are not used or assimilated in simulations, neither as inputs nor with MOS on any post-calibration of results.

In what concerns mean wind speed, results show a good agreement with observations. Root Mean Square error is of 0.47 m/s while BIAS is of -0.04 m/s.

Frequency distribution of absolute error shows that more than 50% of results are within +/-0.50 m/s deviation and that 80% of results show a deviation not above +/-0.56 m/s.

These results compare well with previous validations from MJ, with evidence of improvements. Still, some limitations related with the geographical spread and the number of sample should be considered.

Keywords: virtual wind data, mesoscale, WRF, NCEP -FNL, NWP

Introduction

The application of limited area numerical weather prediction (NWP) models, often called mesoscale models, in wind resource assessment is not new to the wind industry. In fact, applications like wind resource mapping, "virtual" mast data and "virtual" long term reference data are becoming more and more an everyday's tool to wind analysts.

Particularly talking about "virtual" wind data sets (by "virtual" wind data we mean simulated wind and direction data series from mesoscale models than could be used as an approximation to observed local wind data), the easiness with which one can get access to consistent looking wind data is tempting to any wind analyst which routinely deals with problems in observations like small length, low quality or gaps, low number or no observations at all.

Almost every provider of NWP data as its own validations published and reported accuracy on results is within acceptable intervals by the industry, regarding the typical applications.

Still, in our opinion the case for "virtual" wind data sets has not yet been made. Validation efforts are still short in number and difficult to compare and generalize, given the large number of alternatives possible to mesoscale modelling (different NWP models, different input weather and surface data, different configuration and parameterization, different horizontal resolution of output data, etc...).

MEGAJOULE has been using mesoscale models since 2007. An initial validation effort based on the "virtual" wind data approach was already published in 2011 [1]. This paper presents a second validation effort, which includes developments made in the meantime.

With these results, along with a contribution to the validation of the approach followed by MJ, the authors which to contribute to the growing credibility of mesoscale applications for wind energy purposes.

The authors have compiled a set of new 13 test cases. This validation effort follows previous ones from 2011 and considers some changes in the modelling procedure, which are discussed.

For each site, observations were compared with "virtual" wind date estimated from a NWP.

Al sites are located in Portugal and observations were taken in the scope of typical wind resource assessment campaigns for wind farm development.

Observations are not included, directly or indirectly, in input weather data used and are not assimilated or used to calibrate results in any kind.

NWP used is WRF. Model setup and configuration is site independent, besides the definition of domain size which depends from an initial analysis of surrounding orography.

Validations are based upon simple statistics in regards to mean wind speed. Present results are also compared with previous ones from 2011.

Previous validation efforts from MJ

During 2010 previous validation efforts were performed, similar to the ones presented in this paper [1]. The comparisons involved a larger number of sites, 34, in 3 different countries - Portugal (14 sites), Romania (14 sites) and Poland (6 sites).

The differences between the previous validation and the one discussed here are related with input weather and elevation data. In validations from 2011 the input weather data used was the NCEP/NCAR - R1 reanalysis data set and input altimetry was the USGS 30-second Global Elevation Data.

The changes from these input data were made after preliminary indications of improvement in results. All model setup and configuration and other input data were, however, kept unchanged and are well described in the following section.

Unfortunately, when compared to previous sites from 2011 validation, none of the present 13 sites mach previous ones, also from Portugal. Although some are, in fact, located in the same region, sites are often several kilometres apart. Thus, any direct comparison on changes in results must be made with care.

Results from 2011 validations are shown in this paper together with validations from 2012. To help comparisons, a smaller subset from 2011 validations, corresponding only to Portuguese sites, is also considered.

Numerical Weather Modelling

The NWP model used was the Weather Research and Forecasting (WRF) in its version 2. [2]. No microscale or any other model was used.

Input weather data considered was from NCEP FNL (Final) data. For each site, weather data concurrent with observations will be run. An initial spin-up period of 5 days (simulated time) is always rejected to allow results to stabilize.

Input elevation data was from the Shuttle Radar Topography Mission, from NASA, SRTM, digital elevation model. with a resolution of 3 arc seconds [3]

Land cover data is provided by the Global Land Cover Characteristics Data Base (USGS, National Center for Earth Resources Observation and Science – EROS, Joint Research Centre of the European Commission). It consists of a 1 km resolution global land cover characteristics dataset, [4, 5, 6].

The time resolution of the smaller domain is approximately 50 seconds.

The calculation is carried out with 42 vertical nodes within the boundary layer for the lower domain. Final vertical resolution, for heights between 40 and 100 m a.g.l. is approximately around 20 m. This will vary slightly as vertical node are defined according to air pressure levels rather than distance to ground.

Typical calculation domain for the inner nesting was around 80x80km wide. However, the actual configuration of the model's calculation domain was defined for each simulation and was extended in cases of where known important weather patterns and topographic features (like mountains, valleys or land/sea interface) were present.

The calculation domain was also adjusted when simulations presented numerical instability, to achieve required convergence.

The Microphysics scheme used is the Eta Grid-scale Cloud and Precipitation (2001) scheme, also knowned as Eta Ferrier scheme.

Solar radiation schemes used are, for long-wave, the Rapid Radiative Transfer Model (RRTM) [7], and for short-wave the Dudhia scheme [8]. The interval of application of radiation schemes is of 15 minutes.

The surface layer scheme is the the Monin-Obukhov scheme.

The Land Surface Model used is the Noah land-surface model.

Cumulus Parameterization used is the Kain-Fritsch (new Eta) scheme

High resolution Sea Surface Temperature is assimilated in simulations from the National Centers for Environment Prediction (NCEP) and National Weather Service (NWS/NOAA) database with a resolution of 0.5 degrees.

The output data considered for comparison against local observations are the wind fields for 10 minute averages (converted into average horizontal wind intensity and average direction) for the exact coordinate point and height of measurements. Output data was extracted from the three-dimensional mesoscale fields by means of tri-linear interpolation.

Final resolution for the "virtual" data is 3 km. The WRF is run with 3 nested domains of 27, 9 and 3 km, in two-way nesting mode.

Sites and Wind Measurements

A total number of 13 sites are considered for validation of NWP results. All sites are located in mainland Portugal.

Almost all sites (85%) are in complex inland locations. The remaining are in flat coastal sites.

The local measurements were taken at lattice masts used for wind assessment fully compliant with IEC/MEASNET requirements. All masts are operated by MJ and overall wind data available is considered to be of high quality.

Measurement height is 60 m above ground level for all sites but one, with 49 m.

Measurement periods used for comparisons are of one single year.

Measurement data is not in any way neither assimilated in the input global datasets nor assimilated in simulations, neither used as input in the model nor in any post-calibration of results.

Unfortunately, when compared to previous sites from 2011 validation, none of the 13 sites mach previous ones also from Portugal. Although some are, in fact, located in the same regions, sites are often several kilometres apart. Thus, any direct comparison on changes in results can only be made with care and limitations.

Results

The results presented below focus in error statistics for the datasets mean wind speeds. The results for the 13 sites (*2012*) are compared with previous ones (*2011*) and also with a subset of those which corresponds only to Portuguese sites (*2011 PT Only*).

Table 1 -   Summary validation statistics of mean wind speeds

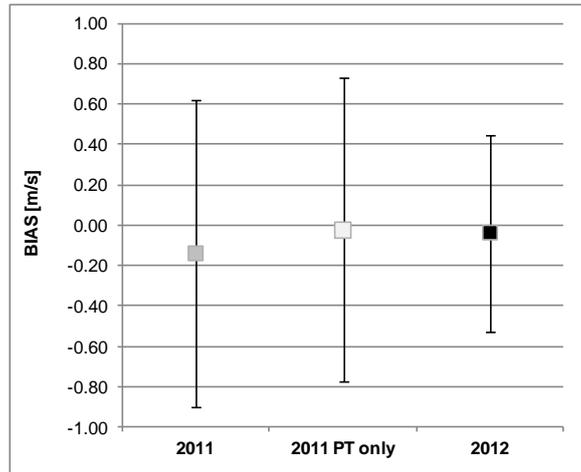| Stage	MAE (m/s)	RMSE (m/s)	BIAS (m/s)	SD (m/s)
2012	**0.43**	**0.47**	**-0.04**	**0.49**
2011 PT only	0.62	0.53	-0.02	0.75
2011	0.66	0.76	-0.14	0.76

Figure 1 -   BIAS and Standard Deviation of Mean Wind Speed estimate
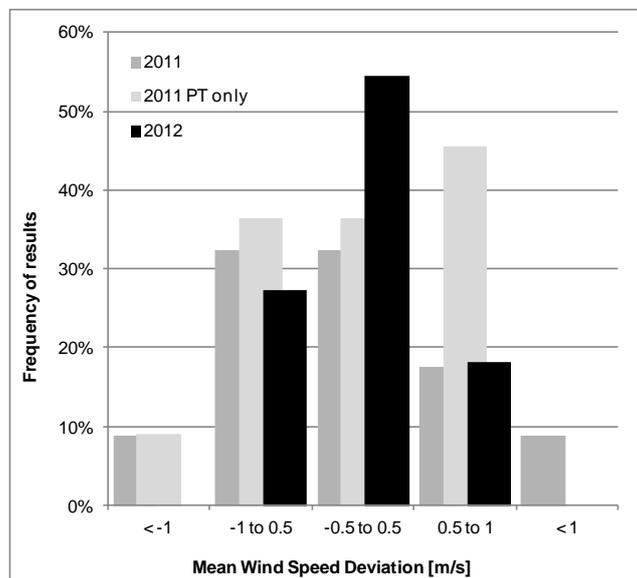

Figure 2 -   Frequency distribution of Mean Wind Speed deviations

Table 2 -   Maximum Mean Absolute Error for 3 Probability of Exceedance levels

Probability of Exceedance	Maximum MAE (m/s) 2012	Maximum MAE (m/s) 2011 PT Only	Maximum MAE (m/s) 2011
50%	**0.45**	0.56	0.71
80%	**0.56**	0.71	0.93
90%	**0.73**	0.75	1.16

Results for 2011 show an almost unbiased estimate of mean wind speed and Mean Absolute Error below 0.5 m/s. Still the Standard Deviation around the Bias is high, showing a high dispersion of results.

Present results show evidence of improvement from 2011 validation, namely by the reduction of the dispersion around the Bias. Change in Bias seems to be small.

Still, the subset of results from 2011 (*2011 PT Only*) also indicates that the accuracy for Portugal was already higher than the rest of the sample thus, any generalization should be made with care.

The frequency distribution of errors in figure 2 shows a better behaved distribution of results around the central value (more Gaussian like) and a significant increase in frequency of results with less than +/-0.5 m/s of absolute error, when compared with previous results. The improvement in the shape of the frequency distribution when compared with the Portuguese subset from 2011 is very noticeable.

Finally, in table 2, showing the Mean Absolute Error for 3 different exceedance probabilities levels, results also show the concentration of errors around smaller values – 80% of results are below a Mean Absolute Error of 0.56 m/s. Above 90% exceedance level improvement in results is not clear.

Conclusions

In general, and in respect to mean wind speed, simulated "virtual" wind data as shown an interesting agreement with observations, aligned with previous validations.

Changes in input data indicate an improvement in accuracy when compared with previous results. This improvement is clearer in the reduction of the Standard Deviation around the Bias. The Bias on estimates seems to be little affected by improvements.

The risk in estimates seems to be diminished, as a consequence of the tighter and better behaved frequency distribution. The maximum Mean Absolute Error with a probability of 80% of being exceeded is 0.56 m/s.

Main limitations to these results and conclusions are the small number of samples and small geographical spread. Only 13 sites were analysed and all of them are located in Portuguese complex terrain sites. As shown by the subset of previous results from Portugal results can be considered slightly optimistic when used as reference for other geographies.

Further work should consider the enlargement of the validation sample from the 13 sites, both in number and geographical spread. Ideally, the initial 34 sites from the previous validation should be considered.

The authors hope that these results can help the community to build up knowledge and trust around the use of mesoscale models for this wind energy of applications.

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