OFFSHORE WIND FIELD: Application of Statistical Models as a Spatial Validation Technique

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Abstract

Generally, atmospheric mesoscale models are used as tools to perform wind atlases. In recent decades, significant efforts have been applied to the development and improvement of this kind of models to reduce their systematic errors. These ones are assessed when model results are compared with observations. In practice, such errors could be statistically corrected if observational data was available for the same area.

A deviation matrix of the wind field between WRF (*Weather Research and Forecasting*) *mesoscale model and wind data retrieved from the QuiKSCAT satellite was obtained by the application of two statistical techniques – kriging interpolation and composite method. The spatial validation performance was evaluated with observational wind data from an anemometric mast installed on Berlengas islet since November 2006 to the present.*

The following are a preliminary assessment of the statistical methods as spatial validation techniques. These are a part of the spatial validation methodology to be used within the EU FP7 NORSEWInD project.

1. Introduction

For the installation of energy systems is necessary to have a detailed study about the physical quantities that define them. In the case of wind energy, the study focuses on the wind flow characteristics.

A preliminary wind study can be performed with the wind atlas – defined as a wind resource map where it is possible to identify the areas of higher potential. These maps are based on atmospheric mesoscale models results.

Output mesoscale models are meteorological variables fields on different levels for a specific grid. These results have systematic errors that not only depend on physical parameterization but also on the local topography, spatial resolution, interpolation errors between observational and grid model points among others. To interpret and characterize these errors a statistical methodology, using the observational data as reference, needs to be applied.

A comparison of two methodologies for obtaining wind deviation fields was performed. Using as input the WRF mesoscale model [1] results and the QuikSCAT satellite [2] data as observational reference a Kriging interpolation and a Composite method were applied. This work is a preliminary study in the scope of EU FP7 NORSEWInD project [3].

2. Methodology

The first procedure was to calculate the mean bias at each QuikSCAT location using the nearest averaged WRF grid point:

$$BIAS(x) = \frac{1}{N}\sum_{i=1}^{N} Wind_{WRF}(x) - Wind_{QuiKSCAT}(x) \tag{1}$$

Where N is the total number of wind observations at each point. A positive bias value indicates that the mesoscale model overestimates the wind whereas a negative bias implies an underestimation.

After applying the interpolation methodologies a deviation matrix for each of the case studies was created. The final procedure was to apply the deviation matrix to the WRF modeled wind field which was then validated with the anemometric mast installed on the simulated area (Berlengas Island).

The quality of the methodology was evaluated with BIAS and MSESS (Mean square error skill score named here as SCORE) determined by:

$$MSESS = \frac{MSE_{WRF} - MSE_{WRF+Deviation}}{MSE_{WRF}} \tag{2}$$

Where MSE is defined as:

$$MSE(x) = \frac{1}{N}\sum_{i=1}^{N}\left[\left(Wind_{WRF}(x) - Wind_{QuiKSCAT}(x)\right)\right]^2 \tag{3}$$

The SCORE results are presented in percentage (%). Obtaining a value of 100% means the statistical model correction applied is perfect while a value of 0% means the mesoscale model and the statistical model are equivalent. A negative value indicates that the application of the correction will worsen the initial results.

2.1 Kriging Interpolation Method

Over the years, Kriging Interpolation became an important spatial prediction tool in Geostatistics. It is a method that interpolates the value of a random field at an unobserved location based on the available surrounding measurements. The Kriging interpolation scheme is a best linear unbiased estimator (BLUE) that minimizes the spatial variance with a stochastic spatial function known by variogram. A simple formulation of this method can be expressed by:

$$z_0^* = z^*(\mathrm{x}_0) = \sum_{\mathrm{i}=1}^{\mathrm{N}} \lambda_\mathrm{i}\, \mathrm{z}(\mathrm{x}_\mathrm{i}) \tag{4}$$

z_0^*: predicted value at $x_{0;}$

λ_i: weight at location $x_{i;}$

d_i: distance between x_i and $x_{0;}$

N: Number of sample values used in prediction;

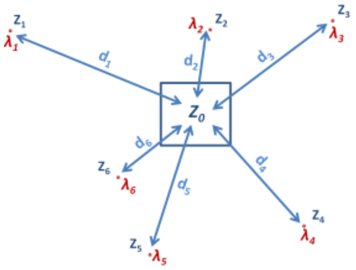


Figure 1 – Weights of Kriging estimator.

More details about this spatial interpolator method can be found in [4,5].

2.2 Composite Method

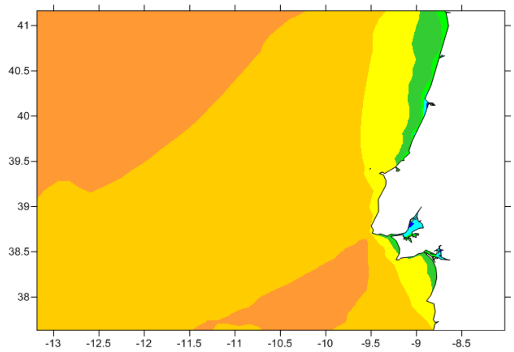
Composite method is a spatial tool developed by LNEG in [6] where the deviation matrix is computed as a weighted linear combination of several data points and the linear coefficients associated to each grid point are calculated in accordance to the inverse distance but applied on nearest points. In this case, the distance is automatically computed via a radius of influence which depends on the spatial variance of the data.

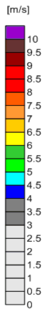
3. Case Study

As input for both methodologies was used:

- Ten years of wind data (2000-2009) from WRF mesoscale model, at a height of 21 m.
- The available QuiKSCAT points on the simulated area, extrapolated to 21 m a.g.l. with an alpha coefficient of 0.104.

Figures 2 and 3 display the wind field of WRF and QuiKSCAT, respectively.





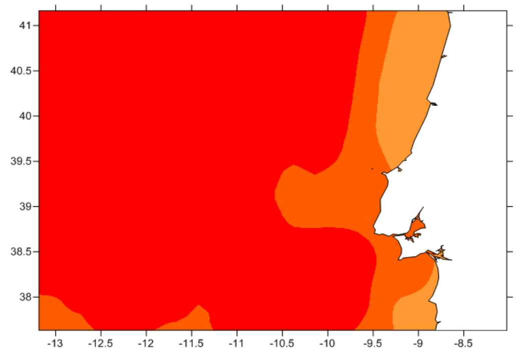


Figure 2 – WRF wind field for the period between January 2000 and December 2009.

Figure 3 – QuiKCAT wind field for the period between January 2000 and December 2009 (all data available for the area).

To demonstrate the usefulness of each method, two different case studies were performed.

3.1 Case Study A

In this case, a grid with all the available QuikSCAT data (figures 3 and 4) as observational reference was used to perform the deviation matrix of the WRF field presented in figure 2.

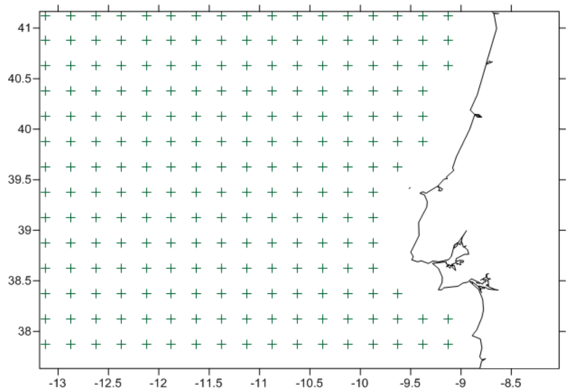


Figure 4 – QuiKSCAT available points at the simulated area – GRID 1.

The following figures present the deviation matrix and the final wind field for 219 QuiKSCAT data points with the application of both methods (figures 5 and 6 with kriging interpolation, figures 7 and 8 with the composite method).

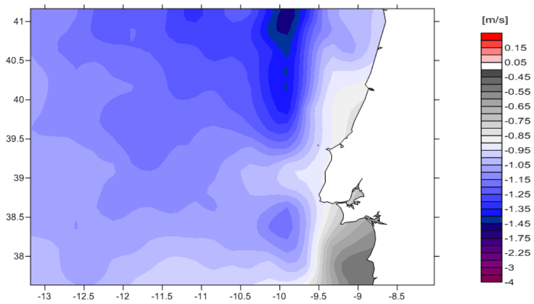


Figure 5 –Deviation matrix performed with kriging interpolation (one grid as input).

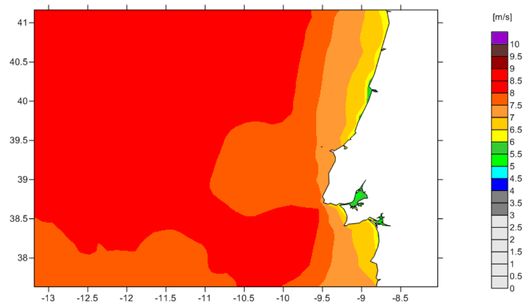


Figure 6 – WRF+Deviation matrix with kriging interpolation (one grid as input).

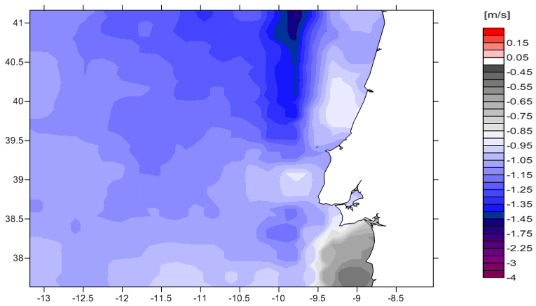


Figure 7 – Deviation matrix performed with composite method (one grid as input).

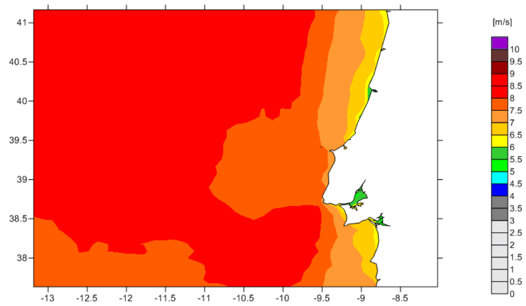


Figure 8 – WRF+Deviation matrix with composite method (one grid as input).

The figure 9 presents the difference between both deviation matrixes and table 1 the statistics for three points of QuiKSCAT data, also identified in the figure.

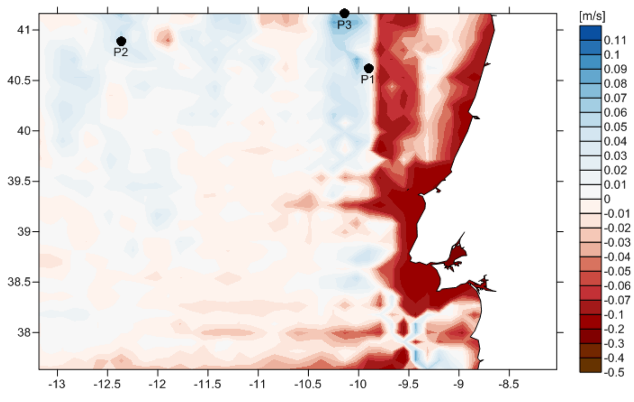


Figure 9 – Difference between the deviation matrixes of composite method and kriging interpolation (Composite - Kriging).

Table1 - Bias between QuiKSCAT points and model results (considering model results minus QuiKSCAT).

		QuiKSCAT	***WRF***	***Kriging***	***Composite***
P1	***Wind speed (m/s)***	8.04	6.75	8.15	8.11
	Bias (m/s)	-	-1.29	0.11	**0.07**
P2	***Wind speed (m/s)***	8.12	7.19	8.44	8.38
	Bias (m/s)	-	-0.94	0.32	**0.26**
P3	***Wind speed (m/s)***	8.01	6.79	8.32	8.27
	Bias (m/s)	-	-1.22	0.31	**0.26**

3.2 Case Study B

Case study B is based on the application of two different grids (figures 10 and 11).These were obtained from a selection of ten distinct wind data points from QuiKSCAT in order to compose a final deviation matrix. This approach can be useful when there is more than one source of data/or unsynchronized time steps.

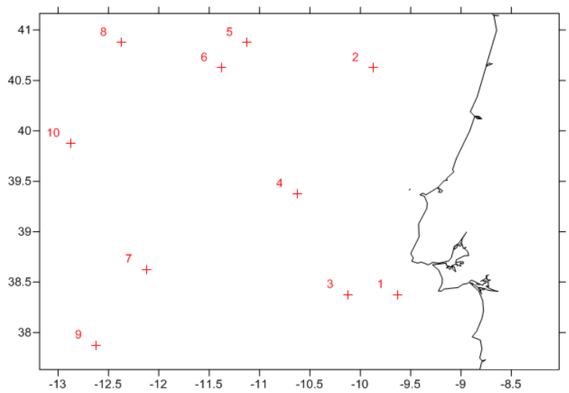


Figure10 – Ten QuiKSCAT points at the simulated area – GRID 2.

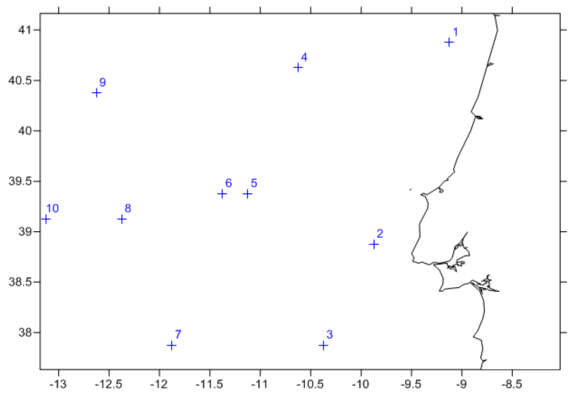


Figure 11 – Ten QuiKSCAT points at the simulated area – GRID 3.

The results presented in figure 12 and 13, were obtained by averaging the two deviation matrixes created with kriging interpolation.

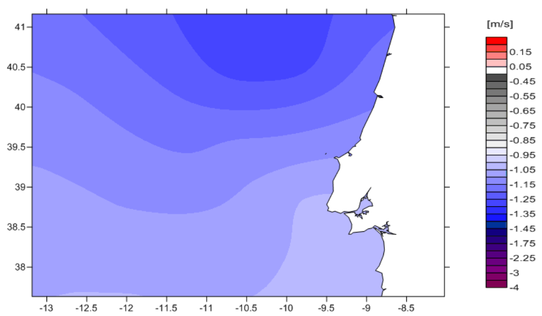


Figure 12 – Final deviation matrix performed with kriging interpolation (two grids as input).

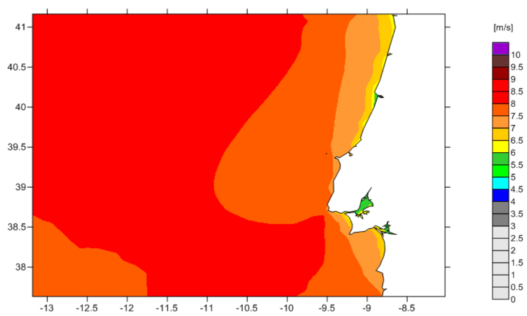


Figure 13 – WRF+Deviation matrix with kriging interpolation (two grids as input).

In the composite method the results were also assessed by a two-step approach:

- The first step was the creation of a deviation matrix from the selected data points.
- On the second step, the composite method ingests the above created to generate the final deviation field.

The following figures show the final deviation matrix on the left and the corrected wind field on the right.

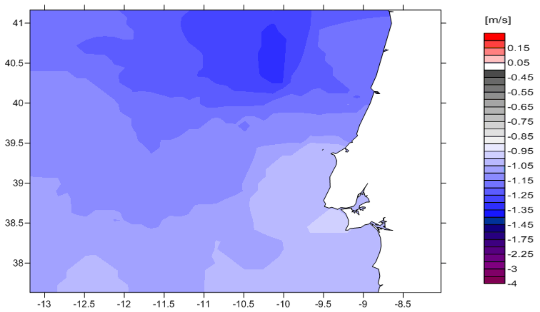


Figure 14 – Final deviation matrix performed with composite method (two grids as input).

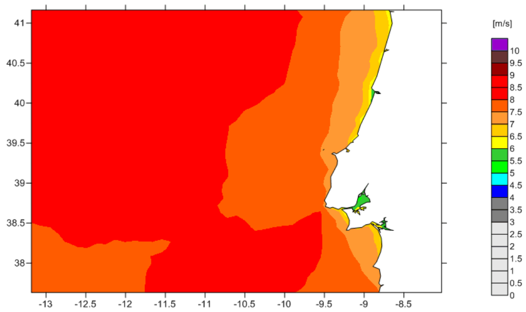


Figure 15 – WRF+Deviation matrix with composite method (two grids as input).

The figure 16 presents the difference between both deviation matrixes and table 2 the statistics for three points of QuiKSCAT data, also identified in the figure.

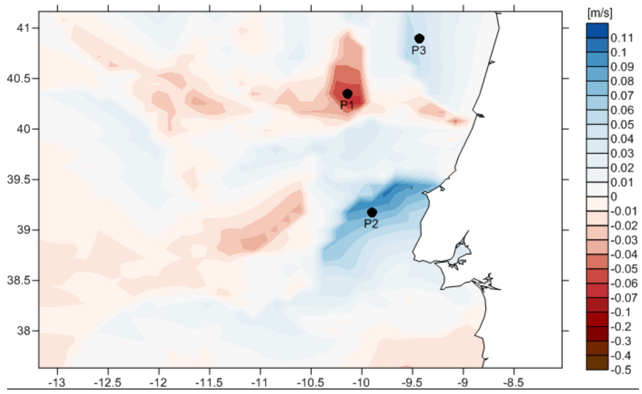


Figure 16 – Difference between the deviations matrix of composite method and kriging interpolation (Composite minus Kriging).

Table 2 - Bias between QuiKSCAT points and model results (considering model results minus QuiKSCAT).

		QuiKSCAT	*WRF*	*Kriging*	*Composite*
P1	***Wind speed (m/s)***	8.27	6.90	8.03	8.09
	Bias (m/s)	-	-1.37	-0.24	**-0.18**
P2	***Wind speed (m/s)***	7.77	6.83	7.78	7.70
	Bias (m/s)	-	-0.94	**0.01**	-0.07
P3	***Wind speed (m/s)***	7.58	6.46	7.69	7.64
	Bias (m/s)	-	-1.12	0.11	**0.06**

3.3 Validation

The validation was performed with independent data from an anemometric mast located on Berlenga Island (figure 17) which is operating since 2006.

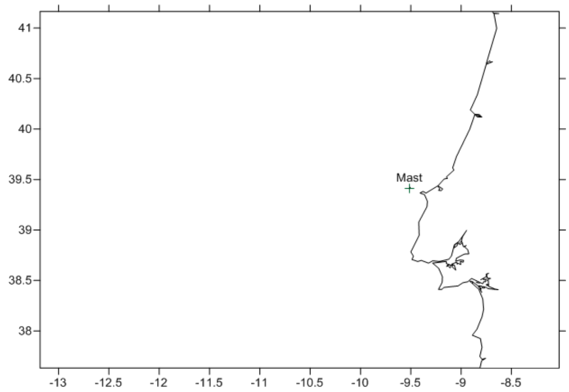


Figure 17 – Location of the anemometric mast on the simulated area.

The anemometric mast is composed of an anemometer and a wind vane installed at 20m a.g.l and a second anemometer at the meteorological reference high (10m a.g.l.).

A wind data base from the simultaneous period between the mast and the two model inputs (QuiKSCAT and WRF) was used to perform the wind validation. Table 3 shows the results of the quality evaluation of each case study for both statistical methods.

Table 3 – Statistical validation results at anemometric mast point.

				Case A		***Case B***	
	WRF	***QuiKSCAT***	***Mast***	***Kriging***	***Composite***	***Kriging***	***Composite***
Mean (m/s)	6.58	7.56	7.27	7.33	7.28	7.44	7.31
Bias (m/s)	-0.69	0.29	-	0.66	**0.01**	0.17	**0.04**
SCORE (%)	-	-	-	99.24	**99.97**	93.93	**99.66**

4. Conclusions

Two statistical models used as a spatial validation technique to evaluate the performance and to correct the systematic errors of the WRF mesoscale model are presented in this work. A comparison of the kriging interpolation method against the composite method using two different case studies was made. To interpret and characterize the statistical methods the QuikSCAT satellite data was used as observational reference.

For case study A, the bias of the two methodologies at the selected points (table 1) shows a better performance from the composite method on all cases. This hasn't been observed on case study B where kriging method shows a better performance on the blue areas, depicted in figure 16, which are represented by point P2 and P3 of table 2 and the composite method shows a better performance on the red areas. From both statistical analyses can be noticed that the maximum bias values have been obtained by the kriging interpolation method.

The validation at the independent anemometric mast for the period between 2006 and 2009, shows similar results (scores between 99% - 100%) on both spatial methods when all the available reference data was used (case study A). On case study B, the composite method has achieved a performance near 100% against 94% of the kriging method.

For the cases where only few observational data is available (case study B) the kriging method has demonstrated a smoothing of the deviation matrix (figure 12) while the composite method enhances the spatial deviation variability (figure 13). This motivates the operational use and development of the composite method as a spatial validation technique.

5. References

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