Validation of an offshore wind atlas using the satellite data available at the coastal regions of Portugal

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Abstract –In this study a validation methodology for regional mesoscale model simulations when ingested with surface wind data inferred from satellite sources around Continental Portugal is evaluated. Observational wind data from a "quasi" offshore anemometric mast located in the Berlenga Island – near Peniche region – was used for the validation study. Satellite sources of wind data under assessment are the ones being used in the EC funded FP7 NORSEWInD project, such as the QuikSCAT and SAR. The validation study evolves 10 years of full wind data, starting in January 2000 to December 2009. The evaluation was performed in two different spatial validation approaches. Results from this study indicate that the wind satellite data has good quality to be assimilated on high resolution mesoscale model simulations particularly the ones concerned with long term behavior of the wind field near the coastal areas.

1. Introduction

Mesoscale model simulations are a very promising tool to characterize the wind flow and for the production of wind atlases for wind power studies. The output of these models consists on a group of several meteorological variables for different height levels on a grid that covers the area under investigation. Generally, the results provided by those models contain systematic errors that are not exclusively dependent on the physical parameterizations but are in fact influenced by the topography shape, the spatial resolution of the simulated grid, interpolation errors between observational and grid model points, among others. To interpret and characterize these errors a spatial statistical methodology, using the observational data as reference, was applied and evaluated.

The purpose of this work is to validate the wind field from a long term simulation provided by the WRF [1] mesoscale model, using spatial observational surface wind data from the QuikSCAT [2] satellite data for Portugal. The observational wind data from the satellite was given as input to two different spatial interpolation methodologies used for validation and evaluation of the quality of the simulated results, namely, the known Kriging interpolation method and a newer Composite interpolation method [3]. To evaluate the validation quality between each of the spatial interpolation schemes, a statistical analysis was then performed with the observational met mast tower installed at the Berlenga Island. Figure 1, depicts the area under study. The Berlenga Island is a small rocky island located about 10 miles away to the west coastal region of Peniche, in the vicinity of the Lisbon region.

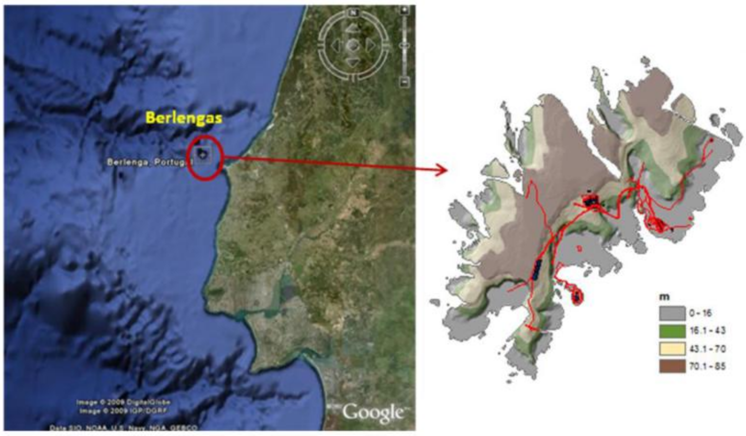


Figure 1 – Island of Berlenga under the area of investigation.

The work developed in this study is in the scope of the validation research activities of the EU FP7 NORSEWInD project [4].

2. Spatial Interpolation Methodologies

The first procedure to validate the deviations between the winds predicted (WRF results) and observed (satellite data from QuikSCAT) was to compute the mean bias at each QuikSCAT location using the nearest WRF grid point:

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

Where N is the total number of wind observations at each point along 10 years. A positive bias value indicates that the mesoscale model overestimates the wind whereas a negative bias implies an underestimation.

Next, a spatial deviation matrix was computed with the help of a spatial interpolation technique. Two different interpolation schemes were tested. Each one is described in the following sub-sections. The spatial deviation matrix should preserve the same area under investigation, the same spatial resolution and the same aspect 2D grid ratio between model grid and satellite data points.

After being built, this matrix will reflect the mean spatial deviations that represent the spatial validation or the uncertainty of the simulated wind fields. From the observational wind data placed in the study area, the quality of the interpolation method used for validation purposes will be inferred. This task will be done using the independent anemometric mast installed in Berlenga Island.

The quality of the spatial interpolation scheme can be inferred by evaluating the following statistical parameters, BIAS and MSESS (Mean square error skill score named here as SCORE) which is mathematically defined as:

$$\mathrm{MSESS} = \frac{\mathrm{MSE}_{\mathrm{WRF}} - \mathrm{MSE}_{\mathrm{WRF+Deviation}}}{\mathrm{MSE}_{\mathrm{WRF}}} \tag{2}$$

Where MSE is defined as:

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

And $\mathrm{MSE}_{\mathrm{WRF+Deviation}}$ means

$$MSE_{WRF+Deviation} = \frac{1}{N}\sum_{i=1}^{N}[Wind_{WRF}(x)+BIAS(x)]^2 \quad (4)$$

The SCORE results will be represented in percentage (%). A value near 100% means the interpolation method for spatial statistical correction is perfect while a value near 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 technique became an important spatial prediction tool in Geostatistics. It is a method that interpolates a 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 as variogram. A simple formulation of this method can be expressed by:

$$z_0^* = z^*(x_0) = \sum_{i=1}^{N}\lambda_i\, z(x_i) \quad (4)$$

z_0^*: predicted value at x0;
λi: weight at location xi;
di: distance between xi and x0;
N: Number of sample values used in prediction;

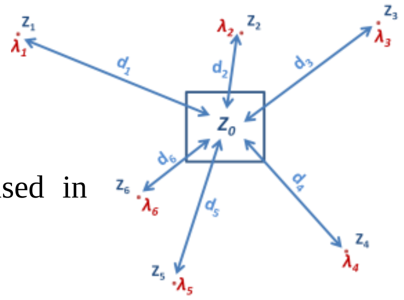


Figure 2 – Weights of Kriging interpolation estimator.

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

2.2. Composite method

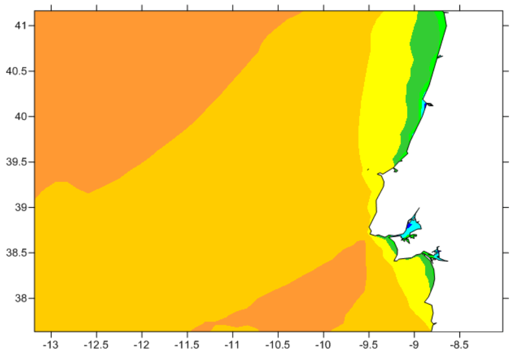
The Composite method is a spatial interpolation tool developed by LNEG [6] where the deviation matrix is computed as a weighted linear combination of several data points. The linear coefficients associated to each grid point are calculated according to the inverse distance but applied to the nearest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

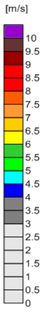
3. Case Studies

The input data for testing both spatial interpolation schemes was:

- Ten years of wind data (2000-2009) from the WRF mesoscale model, at a height of 21 m with a spatial resolution of a 10x10Km.
- The available QuikSCAT points on the same simulation area, but extrapolated to 21 m a.g.l. with the wind power law (neutral stage) provided with an alpha coefficient of 0.104 which is common for the area under study.

Figures 3 and 4 displays the simulated wind field by WRF model and the QuikSCAT wind field, respectively.





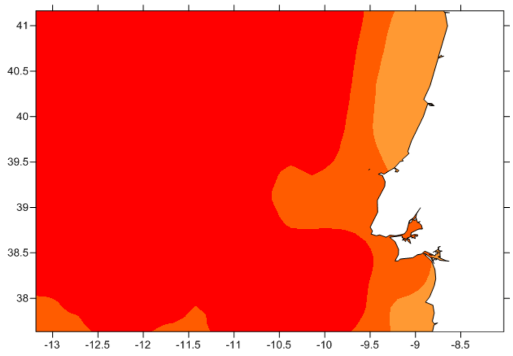


Figure 3 – WRF mean wind field for the period between January 2000 and December 2009. (h=21m)

Figure 4 – QuiKCAT mean wind field for the period between January 2000 and December 2009 (all data available for the area). (h=21m after 10m extrapolation with the wind power law)

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

3.1 Case study A

In this case, the grid presented in figure 3 with all the available QuikSCAT data points (figures 4 and 5) was used to perform the deviation matrix of the WRF field.

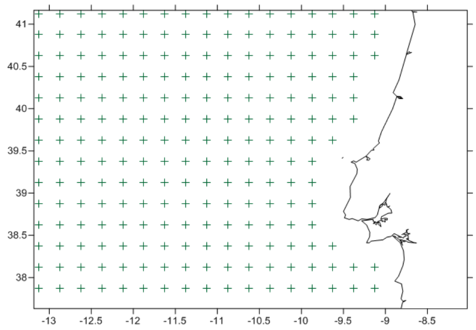


Figure 5 – QuikSCAT available points at the simulated area – GRID 1.

The figures below show the deviation matrix and the final wind field for 219 QuikSCAT data points after the application of both interpolator methods (figures 6 and 7 with Kriging interpolator and figures 8 and 9 with the Composite method).

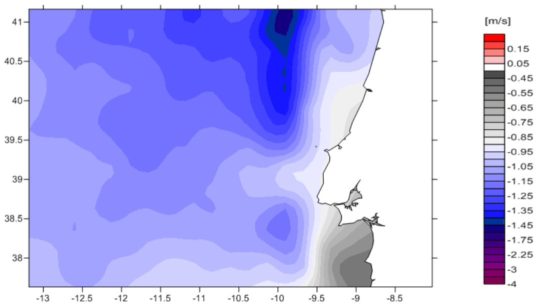


Figure 6 –Deviation matrix performed with Kriging interpolation.

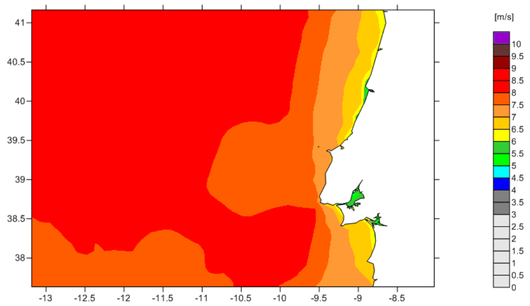


Figure 7 – WRF+Deviation matrix with Kriging interpolation.

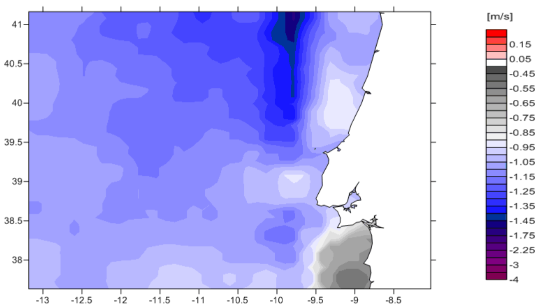


Figure 8 – Deviation matrix performed with Composite method.

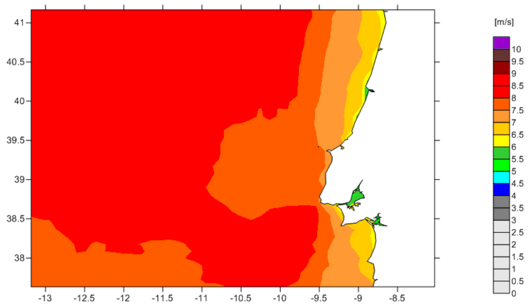


Figure 9 – WRF+Deviation matrix with Composite method.

In figure 10 a plot of the spatial differences between both deviation matrixes is presented and table 1 represents the statistics obtained for three QuikSCAT data points identified in the figure.

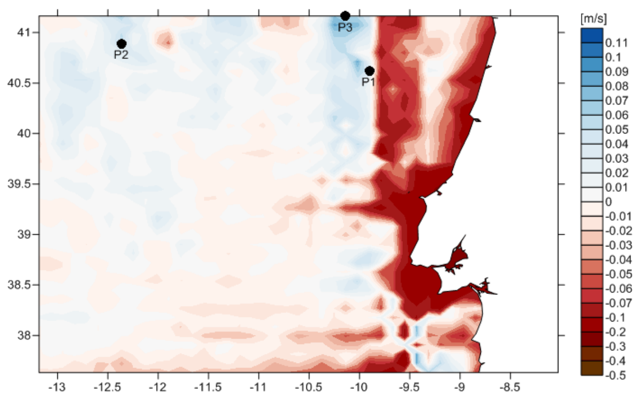


Figure 10 – Difference between the deviation matrixes generated by the Composite and Kriging interpolation methods (Composite - Kriging).

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 11 and 12). These were obtained from a selection of ten available 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 satellite data unsynchronized in time or in spatial resolution (e.g. SAR satellite data).

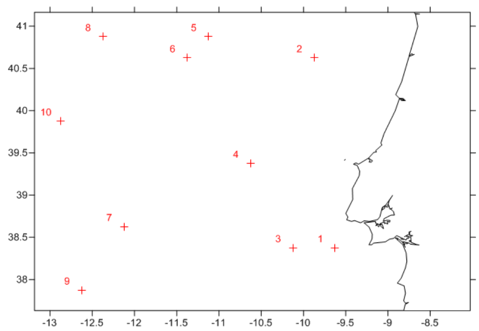


Figure11 – Ten QuikSCAT points inside the simulated area – GRID 2.

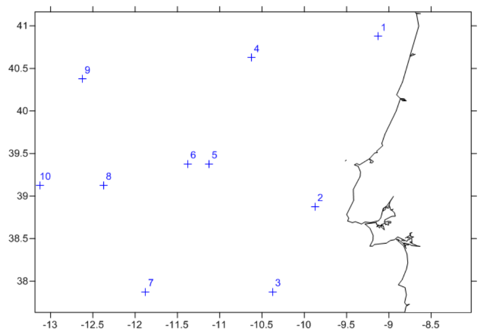


Figure 12 – Ten QuikSCAT points inside the simulated area – GRID 3.

Following this idea, the results presented in figure 13 and 14, were obtained by averaging the two deviation matrices (as having two sources of different wind satellite data) created with Kriging interpolation scheme.

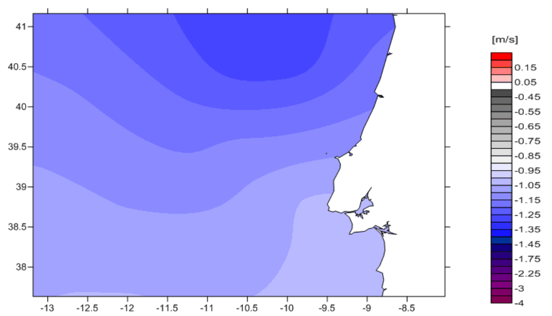


Figure 13 – Final deviation matrix performed with Kriging interpolation method (two grids as input).

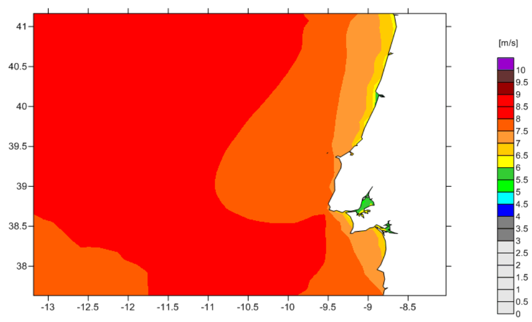


Figure 14 – WRF+Deviation matrix with Kriging interpolation method (two grids as input).

For the Composite interpolation method the results were also assessed in a similar two step approach:

- First, the deviation matrix from each case (figures 11 and 12) using the selected data points was created.
- Secondly, the Composite method ingests the two deviation matrices and generates the final deviation matrix.

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

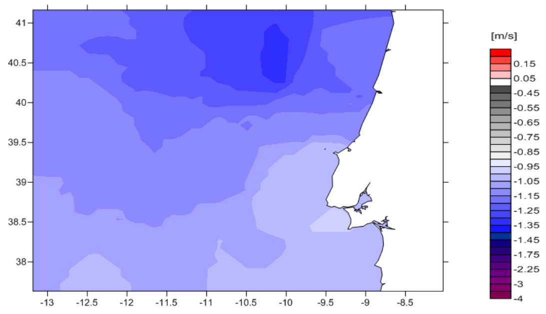


Figure 15 – Final deviation matrix performed with Composite interpolation method (two grids as input).

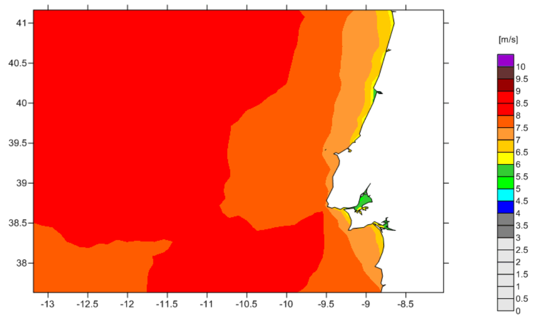


Figure 16 – WRF+Deviation matrix with Composite interpolation method (two grids as input).

Figure 17 depicts the difference between the results from both deviation matrices (figure 13 and figure 15) and table 2 illustrates the obtained statistics for three QuikSCAT points identified in the figure.

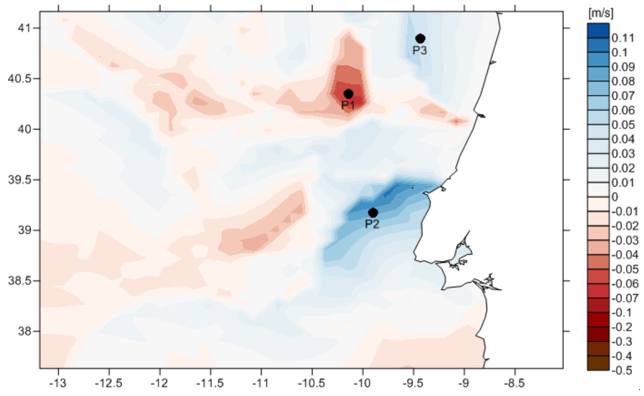


Figure 17 – Difference between the deviations matrices from the Composite and the Kriging interpolation methods (Composite minus Kriging).

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

3.2 Evaluation

An evaluation of the validation quality provided by the two different spatial interpolation schemes is here presented. The independent wind data was taken from the anemometric mast located on Berlenga Island (see figure 1) which is operating since 2006. The anemometric tower is composed by an anemometer and a wind vane both installed at 20m (a.g.l.) and a second anemometer at 10m height (a.g.l.) corresponding to the meteorological reference height.

An observational wind database from the simultaneous periods between the mast and the two model data inputs (QuikSCAT and WRF) was built in order to evaluate the spatial interpolator schemes. Table 3 shows the statistical validation results.

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 interpolation schemes were used as a spatial validation technique to infer the uncertainties in the wind flow from the WRF mesoscale model results. A comparison of the Kriging interpolation method against the Composite method using two different case studies was performed. To interpret and characterize the spatial quality of both statistical schemes, some of 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 that the Composite method has better performance on all studied cases. This hasn't been observed on case study B, where Kriging shows a better performance on the blue areas, depicted in figure 17, (which are represented by points P2 and P3 of table 2) and the Composite method shows a better performance on the red areas. Comparing all Kriging and Composite results it is noted that maximum bias values are always obtained by the Kriging interpolation method.

The performance of both statistical interpolator schemes is assessed via an independent anemometric mast for the period between 2006 and 2009. Results show a very similar behavior (scores between 99% - 100%) for 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 the 94% of the Kriging method.

The high scores obtained with both statistical interpolator schemes enhance the fact that, inferred satellite wind data for the region around the meteorological mast of Berlenga has good quality. It is appropriate for assimilation studies on regional mesoscale models like wind atlases studies, offshore wind power prediction or even for characteristics studies of the long term wind behavior for the Atlantic coast of Continental Portugal.

5. Acknowledgements

The results and the meteorological and satellite data included in this study are part of the EU FP7 NORSEWInD project from which the authors are partners. The authors would also like to acknowledge the project ROADMAP WW (PTDC/SEN-ENR/105403/2008), FCT funded (Portuguese Foundation for Science and Technology).

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