Wind resources map of Spain at mesoscale. Methodology and validation

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Abstract

A wind resource map of Spain has been built using the mesoscale model Skiron. It covers all the Iberian geography. To measure the accuracy level of this map, a protocol of validation has been developed. It provides global information as well as reports about different regions, levels of wind speed, direction sector etc. A validation of the map using 50 meteorological stations is presented.

1 Introduction

The recent increase of wind energy projects in countries without wind measurements remarks the need of wind resources maps to be calculated without measurements, to help in the wind resource evaluation process.

This paper presents a methodology to make wind resource maps based on a mesoscale model (Skiron), joint to a validation study which attempts to show the accuracy of this type of mesoscale simulations.

2 Wind resources map methodology

The regional weather forecasting system Skiron was developed for operational use at the Helenic National Meteorological Service [1], [2]. The entire system is fully parallelized and requires Unix computational environment. Its central component is the Eta limited area weather forecasting model [3]. It uses a specific "step mountain" vertical coordinate. Partial differential equations are represented by finite-difference schHellenic the model. In the horizontal the model is defined over the semi-staggered E grid.

Skiron runs operationally at CENER from October 2005 [4], [5], [6]; getting the initial and boundary conditions from the Global Forecast System (GFS). The GFS initial conditions at 12 hours UTC cycle (1^o x 1^o horizontal resolution) are downloaded each day and stored.

Figure 1 shows the model domain used for this study. It covers the west Mediterranean sea, southeast Europe, Northeast Africa and East Atlantic Ocean. No nesting techniques are used here, just one main domain covering the area of interest is created with an horizontal resolution of $0.1^o \times 0.1^o$ on latitude and longitude.

To make the wind resource map of the Iberian Spanish Penninsula, Skiron operational runs covering year 2006 were used. A total of 365 runs have been used to obtain mean hourly of wind speed and direction at each point of the grid. In this work we have processed and analysed wind speed at a height of ten meters above ground level. Each Skiron run produces +72 hours ahead predictins (hourly values). To make the present wind map, we have considered the horizons between 13 to 36. The first 12 horizons have been discarded due to the spin-up of the model.

Finally, annual mean wind speed was calculated at each point of the grid using the 8760 hourly values of wind speed obtained with Skiron, which allowed us to build the wind resource map. See figure 2

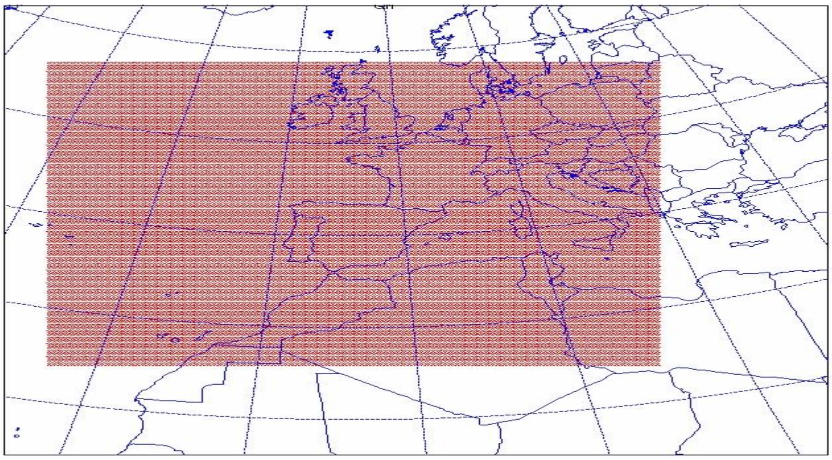

Figure 1: Skiron domain.

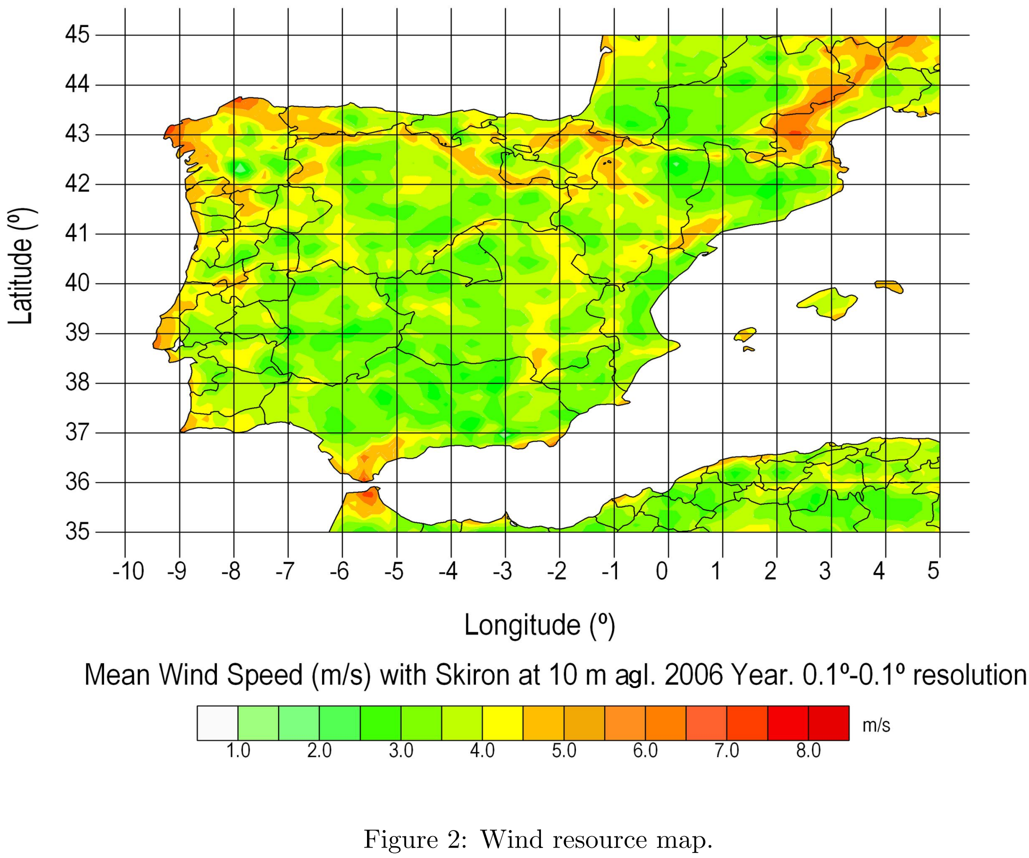

Figure 2: Wind resource map.

3 Validation methodology

A validation procedure and respective results for 50 meteorological stations are presented together with the wind resource map. The objective of this study is to show the accuracy of Skiron model with medium spatial resolution to buil wind resources maps. Two levels of validation have been done. The first validation corresponds to the annual mean wind speeds obtained with Skiron, BIAS values were calculated for each validation station and BIAS deviation value was calculated using all the avaliable BIAS values for the different validation stations. The second validation corresponds to the hourly time series generated by Skiron. MAE values were calculated again for each validation station and MAE deviation was calculated using MAE values obtained for all the validation stations.

The validation stations were grouped according to the characteristics of the surrounding terrain:

- Simple terrain.
- Simple coastal terrain.
- Complex terrain.
- Complex coastal terrain.

3.1 Description of the validation data set

To make the validation, a data set from 50 meteorological stations placed all over Spanish geography have been used, covering different types of terrain taking into account, complexity, geographical areas etc. The database consists of hourly wind speed and direction measured at a height of 10 meters above ground level. This database covers year 2006. Figure 3 shows the location of the 50 validation stations.

Figure 3: Location of the 50 validation stations.

3.2 Description of the validation methodology

To make the wind resource map validation, as first step, we have associated and synchronised each real data series with the corresponding one generated by Skiron at the nearest point of the grid.

A comparative study with descriptive statistics, histograms, qq-plots and wind roses for each pair of series was made (figures 5 to 10). This information characterises both simulated and measured values for each validation station.

Complexity of terrain, wind direction sector and level of wind speed have been used as discriminatory criteria.

BIAS deviation gives an estimation of the uncertainty of the wind map, while BIAS values show if the values of the wind map are centered compared to real measurements. MAE values represent the errors when using the hourly wind speeds simulated with Skiron instead of the measured hourly values. MAE deviation represents the dispersion of errors for the different validation stations. Each validation station has a BIAS and MAE value calculated following equations 1 and 2. For each case (global, type of terrain etc.) mean value and deviation of BIAS and MAE have been calculated.

$$BIAS_i = \sum_{h=1}^{H} \frac{VS_h - VM_h}{H} \tag{1}$$

$$MAE_i = \sum_{h=1}^{H} \frac{|VS_h - VM_h|}{H} \tag{2}$$

Where VS is the simulated wind speed, VM is the measured wind speed, i indicates the validation site, h the hourly data and H the number of hourly data.

Figure 4 shows a summary of the validation methodology used in this work.

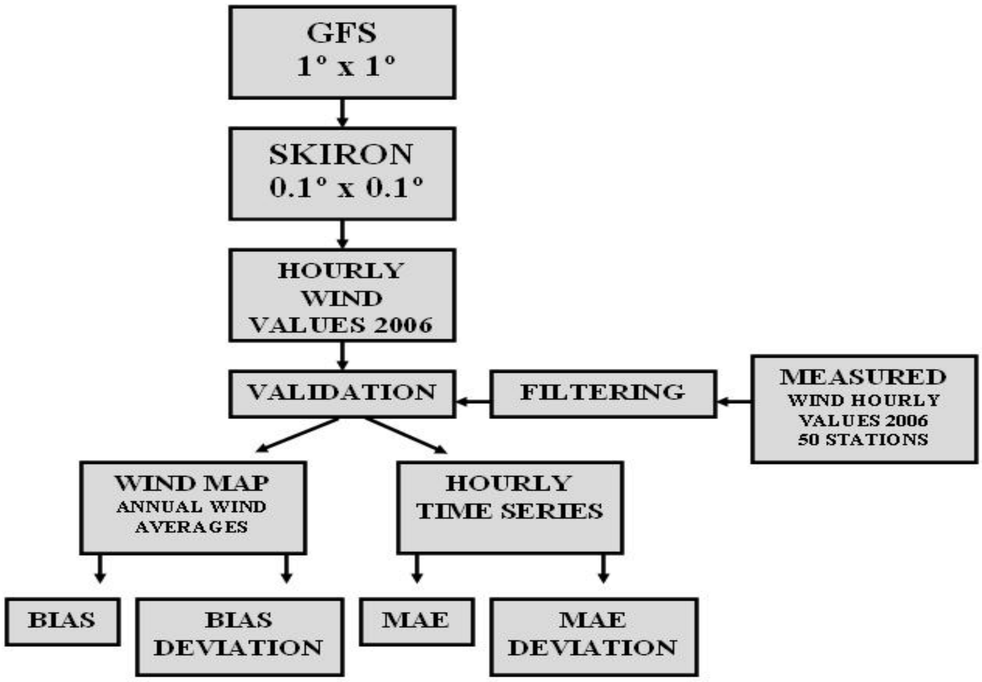

Figure 4: Scheme of the validation methodology.

3.3 Error characteristics for two representative stations

In this section two examples with the complete error statistical analysis are presented, one for flat terrain and the other one for complex terrain. Table 1 and figures 5, 6 and 7 collect the descriptive statistics and studies for a validation tower in a simple terrain place. On the other hand, table 2 and figures 8, 9 and 10 present an example of complex terrain validation. These studies include a set of descriptive statistics as mean, quartiles, Kurtosis and Skewness coefficients etc.

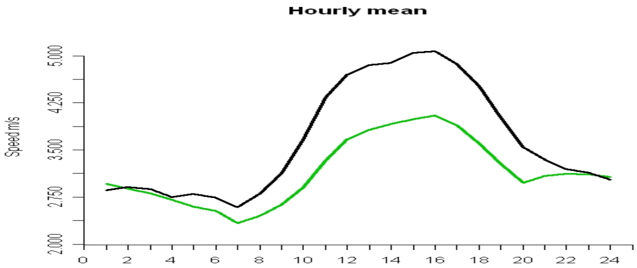

Figure 5: Hourly averages. Simple terrain case. Skiron simulations in green, measurements in black.

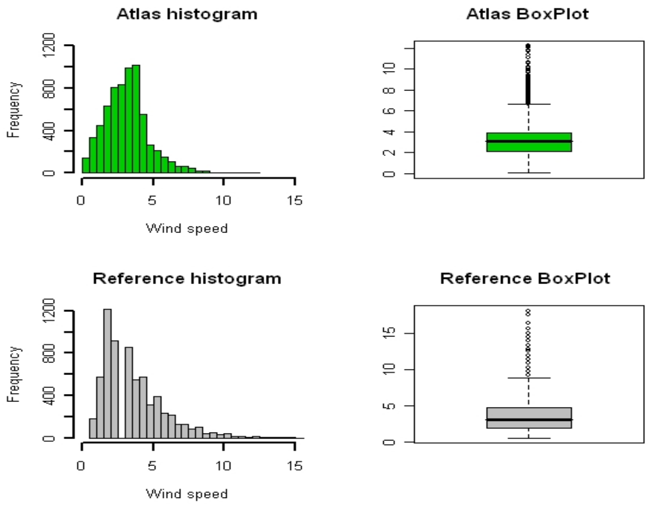

Figure 6: Histograms and qq-plots. Simple terrain case. The two plots on the left correspond to the simulated value. The two plots on the right correspond to the measured data.

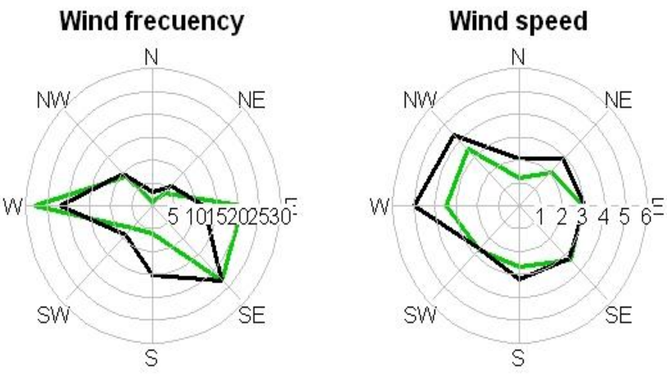

Figure 7: Wind roses plots. Simple terrain case. Skiron values in green, measurements in black.

	Valid data	Average speed	Quartile 25%	Quartile 50%	Quartile 75%	Min speed	Max speed	Standard deviation	Skew	Kurt
Skiron simulations	6741	3.2	2.1	3.1	3.9	0	12.2	1.6	0.9	2
Measured data	6741	3.6	1.9	3.1	4.7	0.6	18.1	2.3	1.5	3.1
Comparison		-0.5	-	-	-	-0.5	-5.8	-0.7		

Table 1: Descriptive statistics of a simple terrain case.

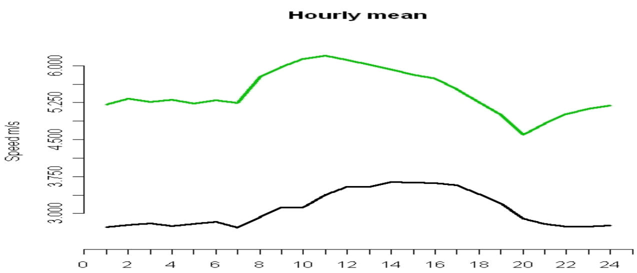

Figure 8: Hourly averages. Complex terrain case. Skiron simulations in green, measurements in black.

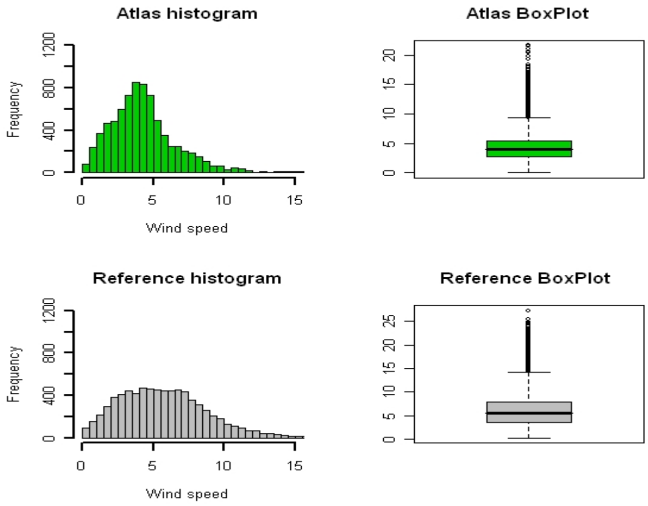

Figure 9: Histograms and qq-plots. Complex terrain case. The two plots on the left correspond to the simulated value. The two plots on the right correspond to the measured data.

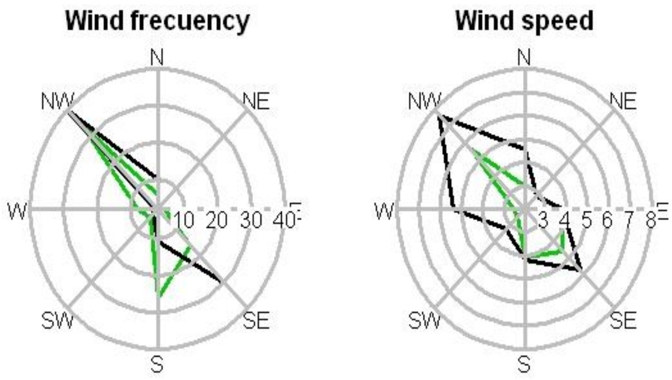

Figure 10: Wind roses plots. Complex terrain case. Skiron simulations in green, measurements in black.

	Valid data	Average speed	Quartile 25%	Quartile 50%	Quartile 75%	Min speed	Max speed	Standard deviation	Skew	Kurt
Skiron simulations	7824	4.4	2.8	4	5.4	0	21.6	2.5	1.6	5.1
Measured data	7824	6	3.5	5.6	7.8	0.2	27.3	3.5	1.3	3
Comparison		-1.6	-	-	-	0.2	-5.7	-1		

Table 2: Descriptive statistics of a complex terrain case.

These two examples of validation stations show the differences that can be expected when comparing the results of the wind map in flat and complex terrain. In the simple terrain case it can be seen (figure 5) that the diurnal variation of the wind speed can be followed by Skiron, being the BIAS -0.5 m/s. Prevailing directions (figure 7) are well captured by Skiron.

Other characteristics of the wind speed distribution are also comparable (table 1), like the quartile analysis and the standard deviation of the wind speeds. The difference of simulated and measured standard deviations of the hourly wind speeds was, in this case, only 0.7 m/s.

In the complex terrain case, it can be seen (figure 8) that the diurnal variation is also captured but with higher BIAS level -1.6 m/s. Prevailing directions are also captured (figure 10) but with some more discrepancies than for the simple terrain case. The comparison of the statistical distributions shows a reasonable agreement between measured and simulated hourly wind speeds (table 2).

Summarising, Skiron model is able to reproduce average wind speed, prevailing directions and hourly wind speed distribution for this two examples. The errors are higher for the complex terrain case, as it could be expected due to the limitations of the model (at 0.1º x 0.1º resolution) to simulate local scale phenomena.

3.4 Validation results for the complete data set

In this section, validation results of the wind resource map from a global point of view and taking into account the terrain characteristics are presented. Validation stations have been divided into four categories acording to the characteristics of the surrounding terrain:

- Simple terrain, include all stations located in flat and inner places.
- Simple coastal terrain, include stations placed in the coast but with simple orography.
- Complex terrain, include all stations located in inner places joint to complex orography.
- Complex coastal terrain, include stations placed in the mountainous coast.

Figure 11 shows the average BIAS level obtained, jointly to the corresponding uncertainty for the 50 stations. We can see relatively low BIAS values, lower than $0.7m/s$, even in complex terrain cases. The uncertainty of the wind map increases in complex terrain zones. BIAS deviation is lower than $1m/s$ in simple terrain cases increasing for the complex ones to be higher than $2m/s$.

Tables 3, 4, 5, 6 and 7 present obtained results taking into account the type of terrain and the wind speed level generated by the model. It can be seen that the uncertainty of the map is $1.44m/s$ as average for all validation stations.

	Global	Low speed	Mean speed	High speed
BIAS	0.1	-0.73	0.08	0.95
BIAS deviation	1.44	1.02	1.39	2.04
MAE	1.97	1.45	1.81	2.65
MAE deviation	0.70	0.74	0.76	0.91

Table 3: Results using all validation stations.

	Global	Low speed	Mean speed	High speed
BIAS	-0.08	-0.65	0.03	0.39
BIAS deviation	0.75	0.56	0.82	0.96
MAE	1.47	1.19	1.43	1.79
MAE deviation	0.34	0.38	0.37	0.39

Table 4: Results using simple terrain stations.

	Global	Low speed	Mean speed	High speed
BIAS	0.67	-0.44	0.59	1.87
BIAS deviation	0.88	0.62	0.79	1.38
MAE	1.83	1.23	1.58	2.66
MAE deviation	0.33	0.27	0.27	0.79

Table 5: Results using simple coastal stations.

	Global	Low speed	Mean speed	High speed
BIAS	-0.21	-1.03	-0.42	0.81
BIAS deviation	2.4	1.83	2.42	3.14
MAE	2.5	1.84	2.33	3.32
MAE deviation	1.08	1.36	1.32	1.07

Table 6: Results using complex terrain stations.

	Global	Low speed	Mean speed	High speed
BIAS	-0.57	-1.15	-0.46	-0.09
BIAS deviation	1.64	1.03	1.46	2.45
MAE	2.44	1.88	2.32	3.12
MAE deviation	0.57	0.64	0.64	0.55

Table 7: Results using complex coastal stations.

In flat terrain the uncertainty is very low $0.75 m/s$, increasing to $0.88 m/s$ when the terrain is flat and close to the coast. This increase is related to the limitations of the mesoscale model to capture (at the selected resolution) the thermal effects that appear in coastal areas.

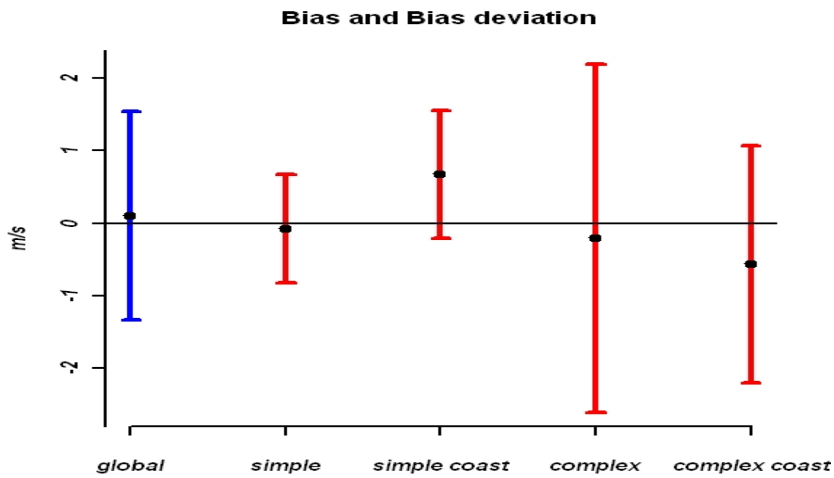

Figure 11: BIAS and BIAS deviation.

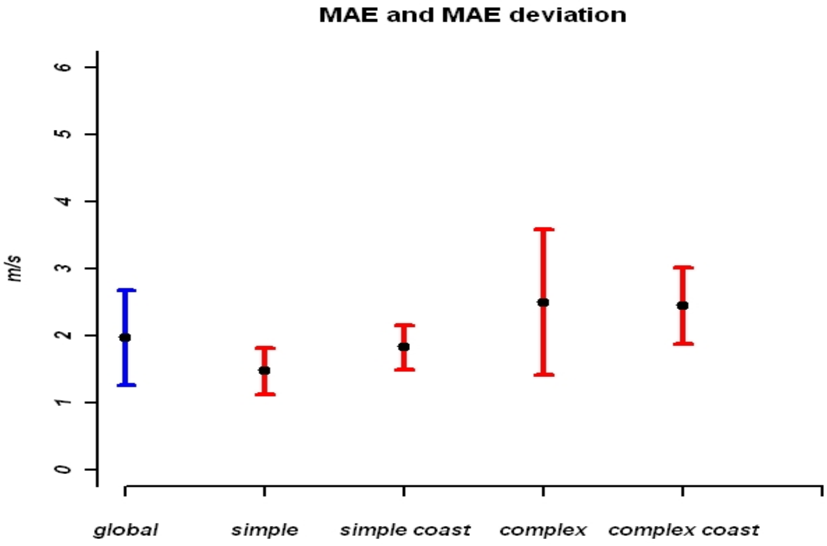

Figure 12: MAE and MAE deviation.

Although in complex terrain the BIAS is relatively low, the deviation of the BIAS is significantly higher than in flat terrain. For complext terrain stations the effect of the coast is not evident, complex coastal stations showed a lower uncertainty than the complex ones. This fact can be related to the specific set of complex coastal stations selected or to the different level of complexity of the two sets of stations.

MAE values are also related to the complexity of the terrain. For flat terrain average MAE is $1.47m/s$ increasing to $1.87m/s$ in simple coastal sites, showing again that local coastal effects are not perfectly captured by the model. In complex sites MAE reaches $2.5m/s$ without a clear effect of the coast.

4 Conclusions

A simulation of one year of hourly wind values has been carried out with Skiron mesoscale model for the Iberian Penninsula (Spain). A good performance to estimate the mean wind speed over the complex and heterogeneous terrain of Spain has been shown by Skiron model with medium resolution (10 Km x 10 Km spatial grid).

The BIAS and MAE deviation increase with the complexity of the terrain and the wind speed, but they present acceptable levels.

The wind map obtained with Skiron is not significantly biased, independently of of the type of terrain. The uncertainty levels have been calculated for 4 different types of terrain. Hourly time series can be used as representative of the area of interest, specially in flat terrain.

5 Future work

The next step will be to calculate a wind resource map of Spain increasing Skiron resolution to 1 Km x 1 Km and evaluate the improvements obtained when comparing with the actual medium resolution map. On the other hand a 20 years reanalysis with Skiron for all Europe is under calculation.

Further error analysis based on the terrain characteristics will be done.

References

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