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EOLMAP: A web tool to assess the wind resource over Spain

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Abstract. A wind data base and a web tool have been developed to estimate the wind power over the Iberian Peninsula (IP). This tool also allows estimating the most appropriate Small Wind Turbine (SWT) for a given location. The wind database includes observational and simulated wind data. The simulated data consists on a 10 km hindcast, covering the period 1960-2007, generated with a Regional Climate Model (RCM) driven by ERA40. The observational data base has been built from hourly records encompassing the period 1999-2007 and includes more than 450 stations evenly distributed over Spain. A quality control has been applied to the data in order to assess the reliability of the observational data set. Although the web tool provides information which allows the users to estimate the reliability of the modelled data in the location of the interest, a previous general validation of the simulation has been performed. This previous validation indicates that most of the disagreements between simulation and observations are attributable to the too coarse spatial resolution of the regional model.

Key words

Regional Climate Model, simulations skill, wind resource assessment, sitting

1. Introduction

The development of the renewable energy allows reduce the CO_2 emitted to the atmosphere and consequently mitigate the Climate Change. Additionally, this kind of energy reduces the dependence on foreign energy and avoids macroeconomic imbalances and inflationary risks due to rising oil prices. In the framework of renewable energy, wind energy is presented as one of the most suitable alternatives.

Nevertheless, one of the drawbacks of wind power is the wind variability, so the dependence of the energy production from weather conditions presents a very important problem. The study of geographical distribution of wind speeds, characteristic parameters of the wind, topography, local wind flow and measurement of the wind speed are essential in wind resource assessment for a successful application of wind turbines. The best method to determine the wind energy potential at some location is to measure the wind on site during several years. On the other hand, most of the wind power studies are focused on evaluating the wind resource in order to look for the most suitable place to install large turbine wind farms. Usually, performing these kind of studies are expensive and in the case of the SWT as being non-profitable. Despite the necessity of having wind data bases of a high quality, they are scarce nowadays, and there are yet many barriers to overcome.

In this respect, the use of regional climate models (RCM) for renewable energy assessment studies is an interesting issue that can provide pseudo-real data base to estimate the wind resource at specific locations, where there is scarcity of observations. However, these techniques have a number of limitations related to the physics parameterizations employed, the spatial resolution, the representation of the soil, etc. On the other hand, we need an observational wind data base to evaluate the skill of a model in reproducing the wind behavior. This observational data has to undergo a quality control as well as having high spatial resolution and a long enough temporal period.

In this work, an RCM has been used to generate a suitable wind data base, i. e., large temporal series with high resolution and homogeneous spatial distribution. With this simulation, a web tool is developed for giving an estimation of the wind power in a certain place (usually predetermined) as well as which of the available SWTs would be more appropriate. Before wind resource assessment is carried out, the skill of this simulation in reproducing the surface wind behaviour has to be evaluated. For this task, an observational wind data base has been built. Records from more than 700 stations have undergone a quality control.

The web tool presented here is part of MINIEOLICA project carried out by Spanish government. This initiative encourages the implementation of SWT and supports the promotion of this kind of facilities. In this framework the goal of the web tool is to facilitate the estimation of wind power production for SWT.

2. Wind Data Base

A. Modelled Wind Data Base

A modified version of the Fifth-Generation Pennsylvania State University - National Center for Atmospheric Research Mesoscale Model (MM5) [1] is used to perform a regional climate simulation encompassing the IP. The simulation has been driven by ERA40 reanalysis [2] and analysis of the ECMWF. The simulation spans the intervals 1960-2007.

The spatial set up consists of two two-way nested domains. The outer and inner domains are centered in the IP, with spatial resolutions of 30 and 10 km, respectively (Figure 1). In this study we use 28 vertical sigma levels with the top at 100 mb.

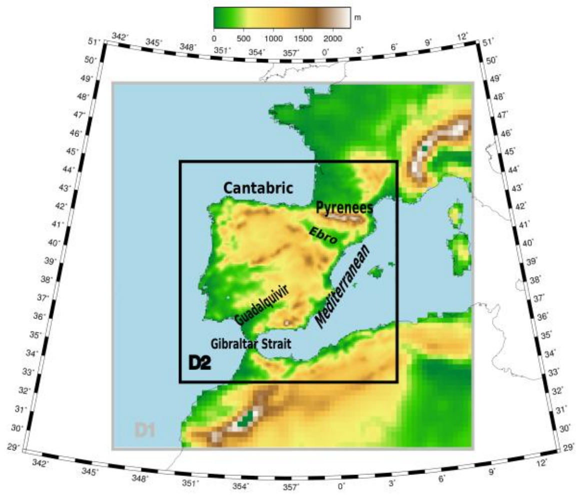

Fig. 1.: Spatial configuration of the two two-way domains used for the numerical simulation. The orography seen by the model of each domain is shown with colours.

A priori, there is not a most suitable physical configuration for every season and region in the case of the IP so several works [3] are taken into account in this election. The physical parameterizations used are: *Grell cumulus* parameterization [4], *Simple Ice* for microphysics [5], *MRF* for the planetary boundary [6] and the *RRTM* radiation scheme [7]. NOAH land surface model is used since it improves the representation on the climatology in the IP [8]. Model outputs for the inner domain are recorded every hour.

B. Observational Wind Data Base

Wind speed and direction measurements were collected from 1999 to 2007 at 769 automatic weather stations distributed over Spain (see Figure 2). The stations were managed by 9 different institutions with different ways of storing the records. The first step was the unification of the data formats and units. In some cases, the *metadata* of the weather stations is quite limited and some features of the wind sensors were not provided. This hampers the suitable election of the allowed range of values of wind speed as well as the threshold value for calms.

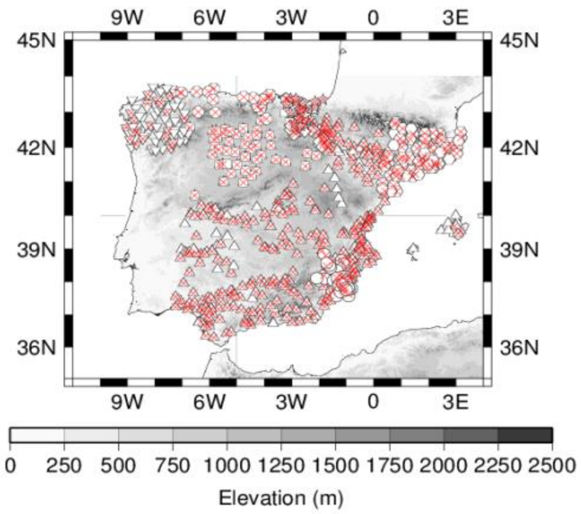

Fig. 2 Spatial distribution of the stations provided by different Spanish institutions in symbols and the stations chosen for the study in red cross. DGDR (triangle), Consejería de Medio Ambiente y Desarrollo Sostenible de Galicia, GA, (inverted triangle), Instituto Tecnológico Agrario de Castilla y León, CL (square), Servicio Meteorológico de Cataluña, CT (hexagon), Centro de Investigación del Medio Ambiente de Cantabria, CA, (pentagon), el Servicio de Información de la Rioja RI (diamond), el IMIDA de Murcia (circle), AEMET (octagon) and EUSKALMET (star).

The temporal resolution of the records varied from 10 minutes to daily. For this study the hourly resolution has been chosen. Therefore the stations with daily records were removed from the data base and the hourly records were calculated as the mean value of less temporal resolution data. Consequently, for the period available, the time series of each station has 78888 time steps for the wind speed and direction. Another source of discrepancy between the various datasets is the sensor height above ground level. The wind speed measurement obtained with sensors at different height above the ground was extrapolated to 10 m by using the power law with an exponent of 0.35. In Table I the information for each group of stations is summarized.

Table I. Number and main characteristics of the meteorological stations provided by different institutions.

Acronyms	Height (m)	#Stations	Resolution
CA	2	6	15 min.
CL	2	52	30 min.
CT	10	85	30 min./1h
DGDR	2	457	30 min.
GA	10	67	10 min.
RI	2	16	30 min./1h
AE	10	14	10 min.
EU	-	23	10 min.

In order to improve the quality of the original records, they have undergone a quality control (QC) as described in [9] which identifies the errors associated with sensor missfunction or mistakes introduced during the data processing, transmission, reception or storage. The QC applied herein consists of a sequential application of several checks attempting to identify questionable data in both wind speed and wind direction time series. The test are subdivided into three main groups: checks for the detection of manipulation errors associated with the storage and maintenance of dataset; limits consistency checks to remove records outside of the allowable range of variation; and checks to ensure the temporal consistency of individual time series by assessing records with abnormally low/high variations. The main focus of the QC is the outlier detection and it allows suppress the rough errors.

After the screening performed with the QC, the outliers undoubtedly erroneous are considered as missing data. The percentage of stations which had a large number of gaps in the times series are calculated. Then the stations which have more than 70% of missing data are removed and the stations with more than 50% are inspected manually.

Finally, 450 stations are selected, evenly distributed over Spain, whose location is shown in Figure 2 with hourly temporal resolution and extrapolated at 10 m above the ground.

3. Web tool

Using the wind data base from the RCM simulation and the observations a web tool has been developed (http://meteo.inf.um.es/eolo/map.phtml) with the aim of estimating the wind power in a given place as well as which of the available SWT would be more appropriate in terms of energy production and cost.

It is necessary to demonstrate the confidence that this tool can provide. For this task we firstly perform an evaluation of the model behavior in general terms. In any case, the web tool gives information about the behaviour of the model near the selected place comparing model results with those of the closets and reliable observational meteorological stations.

A. General validation

The evaluation of the skill of the simulations is performed with two aims. By one hand, we can expect that if a dynamic model is able to reproduce reasonably the data available in one place, then the results obtained from other places, where records are not available, should be equally representative of circulation and climate of the area. On the other hand, if the data generated by a model are consistent with a period in which data are available, it can be presumed that the temporary extension of such records from the model will be equally representative.

The assessment of modeled data is made through a comparison of the observed data base developed. Model data are interpolated (distance weighted method) to the observational point. Also the missing values of the observational time series are discarded in the simulated data.

In the model validation, firstly, the spatial patterns of the wind mean speed are analyzed for each season. Simulations and observations show that the sites with the strongest winds are the Gibraltar Strait, North-West and North-East coast and the North Ebro valley. The less windy season is summer whereas the windiest is winter or spring, depending on the location. Nevertheless, the model tends to overestimate wind speed mainly in the Mediterranean basin. The assessment of the mean wind direction shows that the model is able to reproduce the main regional features over IP. These regional winds are related with the orography, governing channeling processes in the Ebro and Guadalquivir Valleys and thermal processes as breezes land-sea in winter and sea-land in summer which are more noticeable in the Mediterranean basin (not show).

In the characterization of the wind behavior, knowing the probability density function of wind speed is important in numerous wind energy applications. The most widely used and accepted statistical distribution for describing hourly measured of the wind speed is the Weibull distribution which is defined with two parameters: scale (m/s) and form. An estimation of the wind potential over Spain is evaluated computing the wind energy density by means of the parameters. The spatial distribution of the wind energy identifies the Ebro Valley, the coast of Galicia and the Strait of Gibraltar as the areas with greater wind potential.

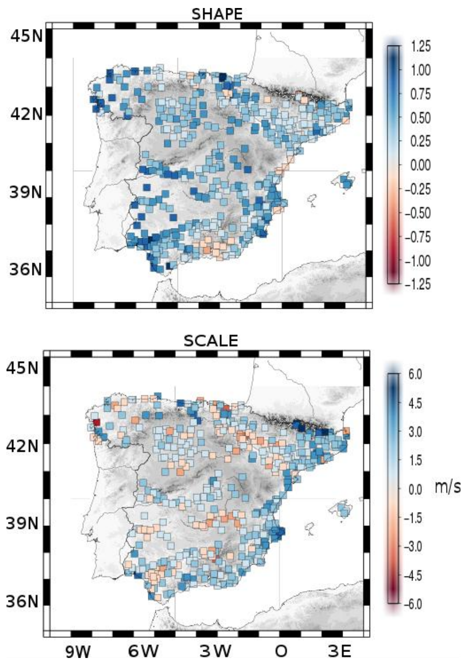

Fig. 3: Spatial patterns of the Weibull parameters, shape (top) and scale (botton) parameter in winter.

The comparison with observations shows that for the shape parameter there is an overestimation of the simulations respect the observations over all IP. Similar spatial patterns as the wind speed differences are obtained for the scale parameter. Regarding the wind energy density the greatest differences are in the Pyrenees and the Ebro Valley. Figure 3 depicts the spatial patterns of the Weibull parameters for winter, similar spatial distributions are obtained for the other seasons (not shown).

A Principal Component Analysis (PCA) is performed in order to investigate the ability of the model simulation in reproducing the main modes of wind variability. After using the scree plot technique the first five modes are retained. The accumulate variance of these modes is larger for the simulation than for the observations in every season. This behavior is associated to the local variability not reproduced by the model as well as to not detected errors in observations.

The results indicate that the model is able to reproduce quite satisfactorily the main spatial modes of variation as well as the temporal evolution (see Table II). The modes are almost identical in observations and the simulation. An example of this results is given in Figure 4, where it is represented the first two EOFs and PCs for winter.

Table II. Spatial correlations for the EOFs and temporal correlations for the PCs between the simulation and observations. The correlations are evaluated for the wind speed and wind components for each season.

Mag.	Seas.		1	2	3	4	5
MV	DJF	PC	0.94	0.85	0.46	-0.43	0.59
		EOF	0.51	0.79	0.70	-0.51	-0.11
	JJA	PC	0.77	-0.64	-0.73	0.76	-0.60
		EOF	0.92	0.64	0.90	0.20	-0.08
	MAM	PC	0.90	0.72	-0.72	-0.71	0.62
		EOF	0.64	0.88	-0.93	-0.72	0.29
	SON	PC	0.90	0.72	-0.09	0.12	-0.61
		EOF	0.90	0.62	-0.70	0.12	-0.53
UV	DJF	PC	0.94	0.93	0.49	-0.65	0.56
		EOF	0.40	0.81	0.42	-0.42	0.61
	JJA	PC	0.91	0.92	0.82	-0.19	-0.12
		EOF	0.54	-0.71	-0.56	0.79	-0.53
	MAM	PC	0.92	0.95	-0.78	-0.82	0.44
		EOF	0.31	0.77	-0.74	-0.79	0.60
	SON	PC	0.91	0.92	-0.39	0.56	-0.59
		EOF	0.33	0.79	-0.10	0.15	-0.59

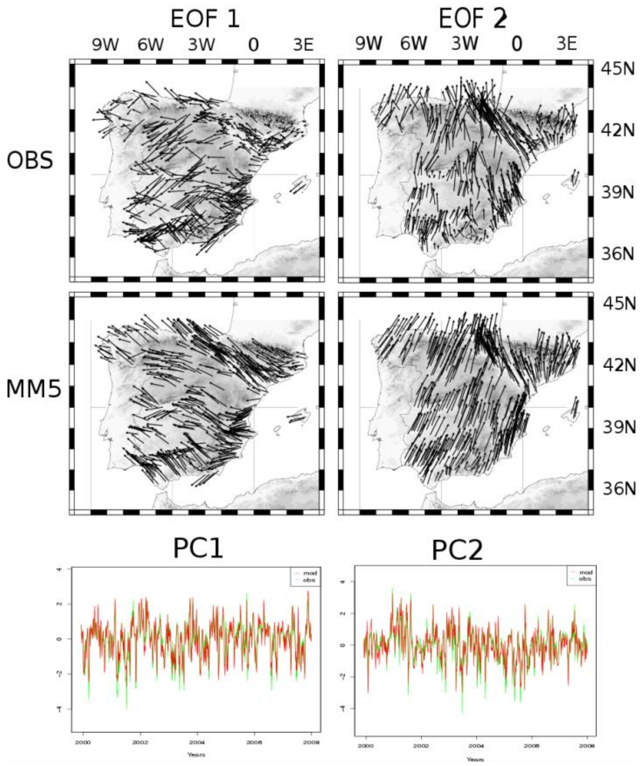

Fig. 4: Spatial patterns of wind components EOF (first and second row) and PCs series (third row) in winter. The first row represents the observational EOFs and the second the simulated ones. Only the two first EOF y PCs are showed in different columns.

Finally an assessment of the errors at local scale has been carried out. Wind measurements are strongly influenced by site characteristics, roughness and topographic effects that the model is unable to capture. A preliminary analysis of the causes of error is performed for each of the 450 stations comparing the histograms of wind speed adjusted to a Weibull distribution, the monthly series, the wind roses and annual and daily cycles. The results indicate that most of the RCM errors are related to the subgrid orography, i.e. small hills or valleys that the 10km resolution does not capture accurately as well as errors given by local channeling or shielding effects.

B. Software application

The developed web tool EOLMAP is based on a Geographical Information System. It allows the visualization and evaluation of wind resource. As part of the visualization, this tool provides a map of the IP which can overlap layers with different information, such as administrative, orographic and wind speed data. On the other hand, this tool allows the selection of a given place and the hub height. Once the system has this information, a report in pdf format is generated containing all the information concerning the wind resources, evaluation and wind power production for several WST in the selected location.

For this task, firstly the information of the simulated wind data base is stored in a PostgreSQL data base. This data base contains a 2-dimentional discrete distribution function that accounts for the wind speed and direction, f(v,θ), for each grid cell of the model at several vertical levels. Wind direction has been split into 16 sectors, and the wind speed in 27 groups (from 0 to 26 m/s, 1 m/s bin, and a grouped with wind speed equal or greater than 26m/s). Only the eight first sigma levels of the model are considered, those whose average height above the terrain is 17.9, 53.8, 89.776, 125.92, 180.39, 253.49, 401.36 and 665.68 m, respectively. On the other hand, the temporal evolution of the monthly mean wind speed for each point is also stored in our data base, which permits us to have an estimation of the inter-annual variability and the annual cycle of the wind.

The bidimensional distribution function of wind speed for the specific point where the wind resource is evaluated is obtained by interpolating the distribution functions of the eight nearest points. These eight points belong to the vertices of the cube containing the point of interest. The interpolation is weighted by the distance and is performed firstly in the horizontal direction and later in the vertical direction.

An example of some of the main products reported is shown in Figure 5. Firstly, a map of the main characteristics of the environmental conditions and the location of the selected and the nearest observational points is displayed (Figure 5a). Secondly, the histogram of the wind speed fitted to a Weibull distribution and the wind rose are evaluated in the location of interest. Also the 12 months running of the mean temporal series for the last 50 years is depicted (Figure 5b). Thirdly, the confidence level of the simulated wind is assessed using the three nearest points of the interested area with observational data (see Figure 5c). This evaluation consists on the comparison of the simulated and observed annual and daily cycle, wind speed histograms, wind speed series for the available period and wind rose. Finally, some statistics of the potential energy production using several SWTs are reported. The web tool calculates this data from the power curve supplied by the manufacturer, as well as other members of the MINIEOLICA project.

5. Conclusion and Future Works

In this project, a web tool has been developed with the aim of stimulating the SWT implementation in Spain. This tool is based on the results of a high resolution RCM simulation driven by ERA40 and Analysis products from the ECMWF. In order to evaluate the reliability of the skill of the MM5 in reproducing the observed superficial wind field, the simulation is evaluated by comparing with an observational wind data base quality-tested by us.

The model reproduces the main regional circulation features over the IP, such as sea-land breezes and channeling circulations. It is also able to reproduce the main spatial and temporal modes of wind variation. Nevertheless, the RCM tends to overestimate the wind module, mainly over the Mediterranean basin. Most of the errors are related to the orography features that the model resolution is unable to capture accurately with the 10 km resolution implemented.

Improving the use of the RCM in the wind resource assessment is the goal of our future works. Due to the role of the orography in the model simulations, the first step is developing a method for correcting directional modeled series using terrain and land uses data base up to 25 meters resolution.

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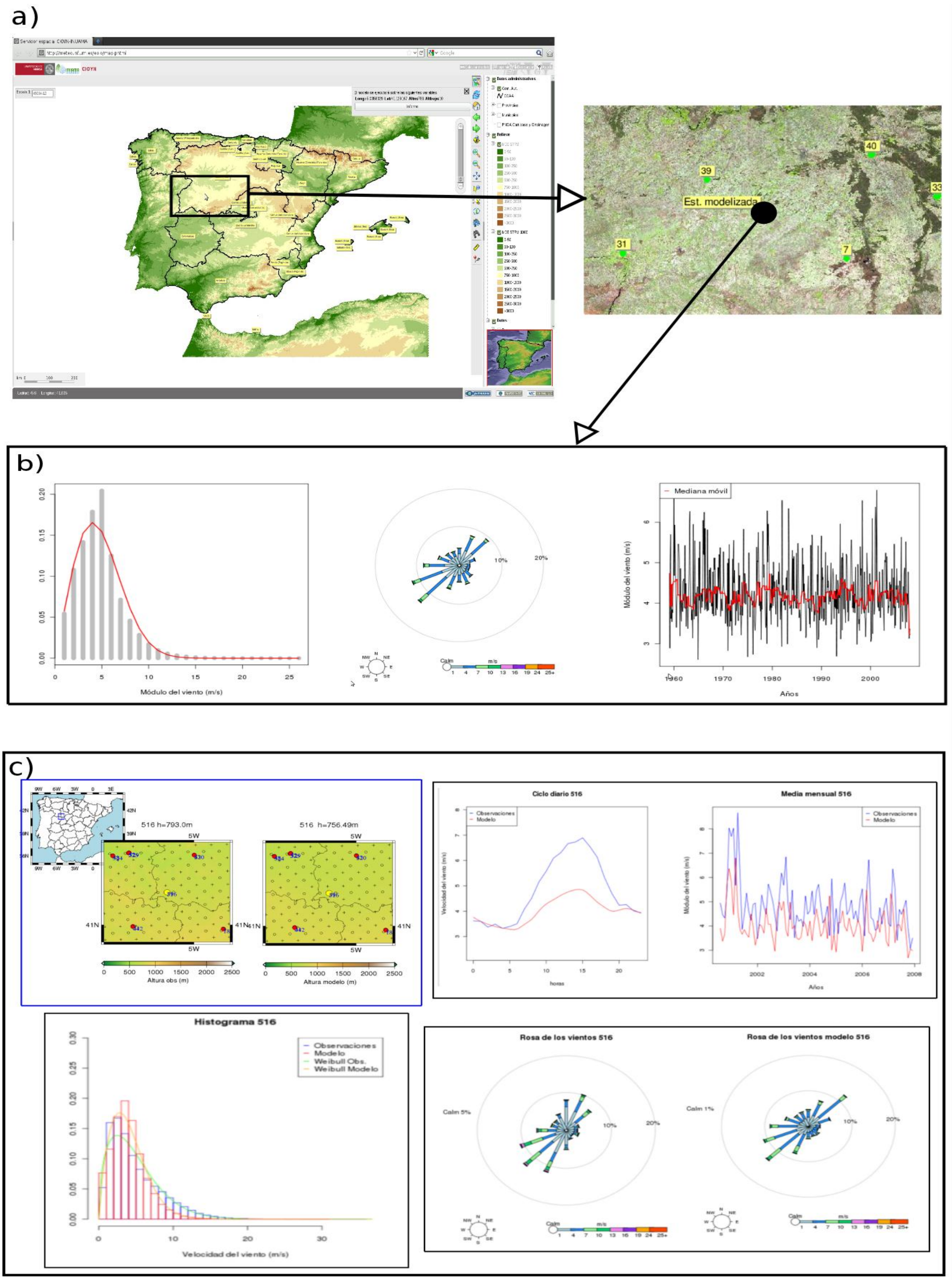

Fig. 5: Summary of some of the main products reported by the web tool. A map of the main characteristics of the environmental conditions and the location of the selected and the nearest observational points (a). The histogram of the wind speed fitted to Weibull distribution, the wind rose and 12 months run mean temporal series for the last 50 years location of interest (b). Comparison of the simulated and observed annual and daily cycle, wind speed histograms, wind speed series for the available period and wind rose (c).