Building a Wind Atlas for Mainland Portugal Using a Weather Type Classification

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Abstract:

A weather type classification scheme was implemented for the construction of a wind atlas to mainland Portugal. This methodology produced 26 different weather types computed by geostrophic vorticity at mean sea level pressure. Applying a simple calculus scheme it is possible to find the most likely representative day for each weather type if a meteorological database with wind data is available. Each selected day can be simulated by a mesoscale model (e.g. MM5) being possible to construct the final wind atlas through the sum of the simulated days, weighted by the respective frequency factor. In this paper it is shown that the results obtained by the application of this classification scheme for mean wind and energy density fields are very similar to long term simulations.

Keywords: Weather types, mesoscale models, wind resource.

1 Introduction

Recent investigation in atmospheric sciences enhances the reappearance of certain weather patterns in time. These patterns can be easily identified if Principal Component Analysis methods or even “cluster” techniques are used once one defines an area of interest. Although these methods can be easily computed for a specific region they do not always reproduce fields with good physical meaning. In this work a much simpler weather type classification technique was computed by geostrophic motion at mean sea level to produce a wind atlas for mainland Portugal. This method can identify 26 different weather type circulations, each one with a different frequency of occurrence.

To identify the 26 weather types a classification scheme was applied for the period: 1951 to 2002 (52 years) as well as 7 years (1992, 1994, 1998 to 2002) taking account the use of the meteorological reanalysis data from NCEP/NCAR [1]. Comparing the frequency of occurrence for each 26 weather types in those different periods it was concluded that they are very similar. Using the MM5 [2] atmospheric mesoscale model, a representative day of each weather type is simulated, being the wind atlas produced by an average of the simulated fields, weighted by its frequency of occurrence.

A one *long term* simulation with MM5 model forced by reanalysis data is presented. The whole 1999 year is simulated for the purposes of this work, correcting the final simulated wind velocity and energy density fields with the inter annual variability factor obtained from four long term anemometric reference stations monitored by INETI for *12* years. Comparing simulated results from this “one year” simulation with weather type results it is found that they are very similar, both in mean wind and energy density. Therefore, using a weather type classification for building a wind atlas with high resolution can drastically reduce computing time effort, and still lead to the production of wind maps representative of the climatology for continental Portugal.

2 Type of weather circulations in mainland Portugal

The synoptic atmospheric circulation in mainland Portugal can be in great part explained by the influence of the Azores high pressure circulation near the European continent during almost all the year. However, one can identify a set of additional weather types representative of the atmospheric flow combined to circulation indexes with physical meaning. Therefore, each day can be classified by a certain circulation weather type. If one possesses a long term database with atmospheric data then it is easy to identify the weight of frequency of occurrence of each weather type in that period. Through an appropriate selection criterion, it is possible to determine the closest day to the average of a certain weather type. If this process is repeated for the remaining weather type classes, then the set of days obtained can be representative of the real climatology.

2.1 Classification Method

In order to implement the wind potential atlas for mainland Portugal by using the weather type classification, a set of six daily indexes was used. Among these indexes, two are associated with wind flow direction (such as the horizontal components of wind), other two are related with the type of circulation – high and low circulation – and the remaining two are related to the magnitude and the vorticity of the atmospheric flow. [3]. Table 1 presents the circulation indexes [3].

Circulation Index	Flow type
SF	North – South
WF	west – east
FT	Magnitude
ZS	Low circulation
ZW	High circulation
ZT	Vorticity

Table 1: Circulation Indexes

The circulation indexes were calculated with the atmospheric sea level pressure at 16 observed pressure points, assuming that the wind circulation is almost-geostrophic (figure 1).

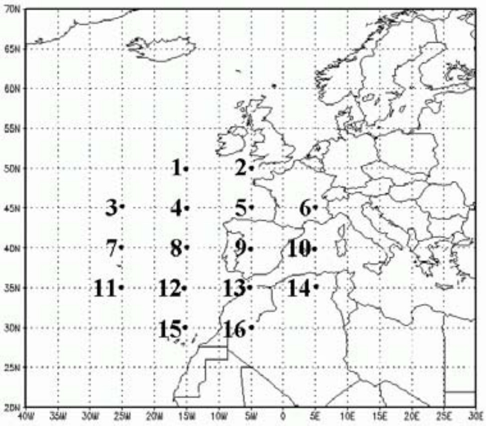


Figure 1: Grid points used to compute geostrophic vorticity for mainland Portugal

The expressions bellow, present the form of calculus for each index [6]:

$$SF = 1.305 \times \left[0.25 \times (p_5 + 2 \times p_9 + p_{13}) - 0.25 \times (p_4 + 2 \times p_8 + p_{12})\right] \tag{1}$$

$$WF = \left[0.5 \times (p_{12} + p_{13}) - 0.5 \times (p_4 + p_5)\right] \tag{2}$$

$$FT = \sqrt{SF^2 + WF^2} \tag{3}$$

$$\begin{aligned} ZS &= 0.85 \times \left[\alpha - \beta - \gamma + \eta\right] \\ &\text{where} \\ \alpha &= 0.25 \times (p_6 + 2 \times p_{10} + p_{14}) \\ \beta &= 0.25 \times (p_5 + 2 \times p_9 + p_{13}) \\ \gamma &= 0.25 \times (p_4 + 2 \times p_8 + p_{12}) \\ \eta &= 0.25 \times (p_3 + 2 \times p_7 + p_{11}) \end{aligned} \tag{4}$$

$$\begin{aligned} ZW = 1.12 \times &\left[0.5 \times (p_{15} + p_{16}) - 0.5 \times (p_8 + p_9)\right] \\ &- 0.91 \times \left[0.5 \times (p_8 + p_9) - 0.5 \times (p_1 + p_2)\right] \end{aligned} \tag{5}$$

$$ZT = ZS + ZW \tag{6}$$

The daily classification was performed by considering the following hypothesis:

a) The flow direction is given by $\tan^{-1}(WF/SF)$, adding 180º if WF is positive.

b) If |ZT|<FT, the magnitude dominates the vorticity, being the flow classified by 8 direction types in analogy with the wind rose (N,NE,E,SE,S,SW,W and NW), with 45º per sector.

c) If |ZT|>2FT, the vorticity dominates the magnitude. In this case, if ZT>0, the weather type is Low (L), or High (H) se ZT<0.

d) If FT<|ZT|<2FT, the circulation is designated as hybrid, being equally dominated by magnitude and vorticity. In this case, 8×2 weather types are considered.

In total, this method supplies a set of 26 weather types presented on table 2.

Directional	Hybrid highs	Hybrid lows
N – north	HN	LN
NE – northeast	HNE	LNE
E – east	HE	LE
SE – southeast	HSE	LSE
S – south	HS	LS
SW – southwest	HSW	LSW
W – west	HW	LW
NW – northwest	HNW	LNW
	H	L

Table 2: 26 weather patterns generated by the classification scheme presented in this work

2.2 Data used for classification

The meteorological data used in the weather type classification are from the data base (Reanalysis) of NCAR - "National Center for Atmospheric Research"

[1] in order to obtain the daily sea level pressure field in three different time periods. In the first period, the classification was performed by considering a 52 year period of data from January 1951 to December 2002.

In the second period, only seven years of meteorological data were classified: 1992, 1994, 1998-2002. The selection of these years was based on the fact that INETI as operated in these periods several anemometric stations in the course of R, D&D projects (in which the data is not classified) and concluded that the geostrophic wind climatology for this period is very similar to the 52 years of Reanalysis data. Figure 2, presents frequencies of occurrence for each of the 26 weather types in the three periods described above.

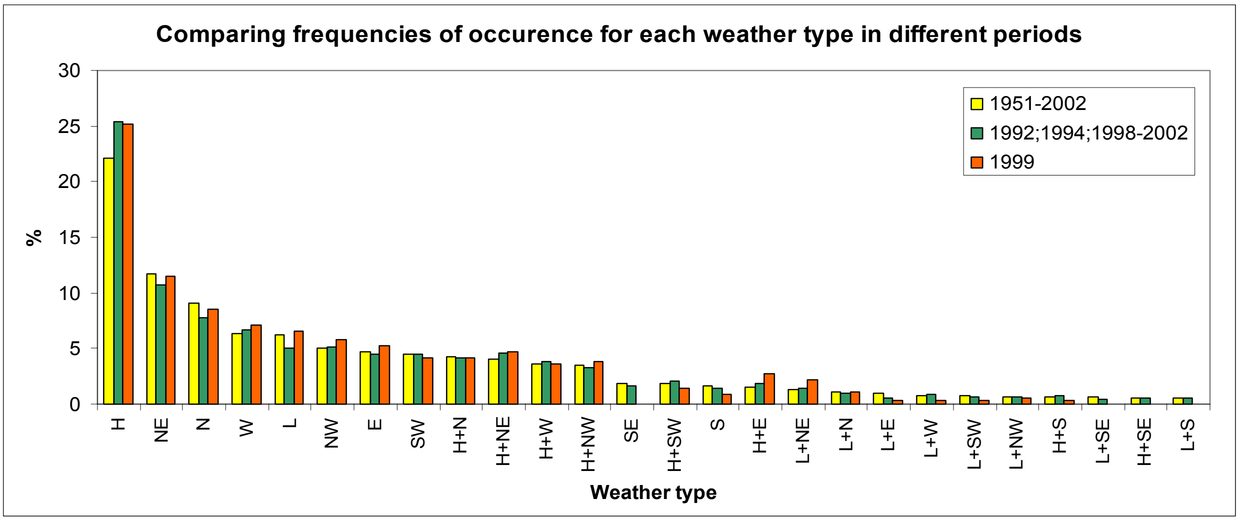


Figure 2: frequency of occurrence in different time periods Comparing three different time periods.

Figure 2 enhances the frequency of occurrence of each weather type in mainland Portugal. High pressure circulation is the most frequent circulation followed by northeast and north circulations, associated to sea-breeze circulations presented in almost time of the year.

2.3 Select representative days for each weather type in period with 7 years

In order to perform this task, the date and mean sea level pressure fields for each of the 16 point grids were used (see fig. 1). Considering the day d for a certain weather type and the respective grid points $p_{d,j}$, where j=1,...,16. For the day d the following expression was calculated

$$\delta_d = \sqrt{\sum_{j=1}^{16} \gamma_{d,j}} \qquad (7)$$

where

$$\gamma_{d,j} = \left(\frac{p_{d,j} - \overline{p}_j}{\sigma_{p_j}} \right)^2 \qquad (8)$$

Being $\overline{p}_j$ the mean pressure value in point j of every day, and σ_{p_j} the standard deviation of the sample. Repeating this calculus procedure for every day of the weather type, the one with lower δ_d values was selected, being that day the closest to the climatology of this weather type. All this procedure can be repeated for the other weather types. Table 3 presents the representative days obtained for each weather type for period with seven years of data.

H	31 October 1998	L	01 May 1999
N	27 July 1998	NE	29 July 2001
E	04 October 2002	SE	06 November 1998
S	30 November 1994	SW	22 October 2001
W	24 April 2001	NW	31 August 1992
HN	07 July 2001	HNE	30 June 2001
HE	24 November 2001	HSE	29 April 1994
HS	19 February 1998	HSW	23 November 1992
HW	22 April 1999	HNW	27 June 1999
LN	09 May 2000	LNE	24 August 2002
LE	20 March 2000	LSE	17 June 2000
LS	20 September 2002	LSW	15 May 1994
LW	25 September 1998	LNW	31 May 1992

Table 3: More likely representative day for each of the 26 weather types. Classification results after 7 years of data.

2.4 Some spatial results

In figure 3 the mean sea level pressure field obtained for some of weather types classified with 7 years of data is presented. Figure 4 shows the mean sea level field for the more likely "representative" day of each weather type illustrated in table 3. Comparing each field between the two figures one may conclude that each selected day shows good similarity with mean field obtained with 7 years of data.

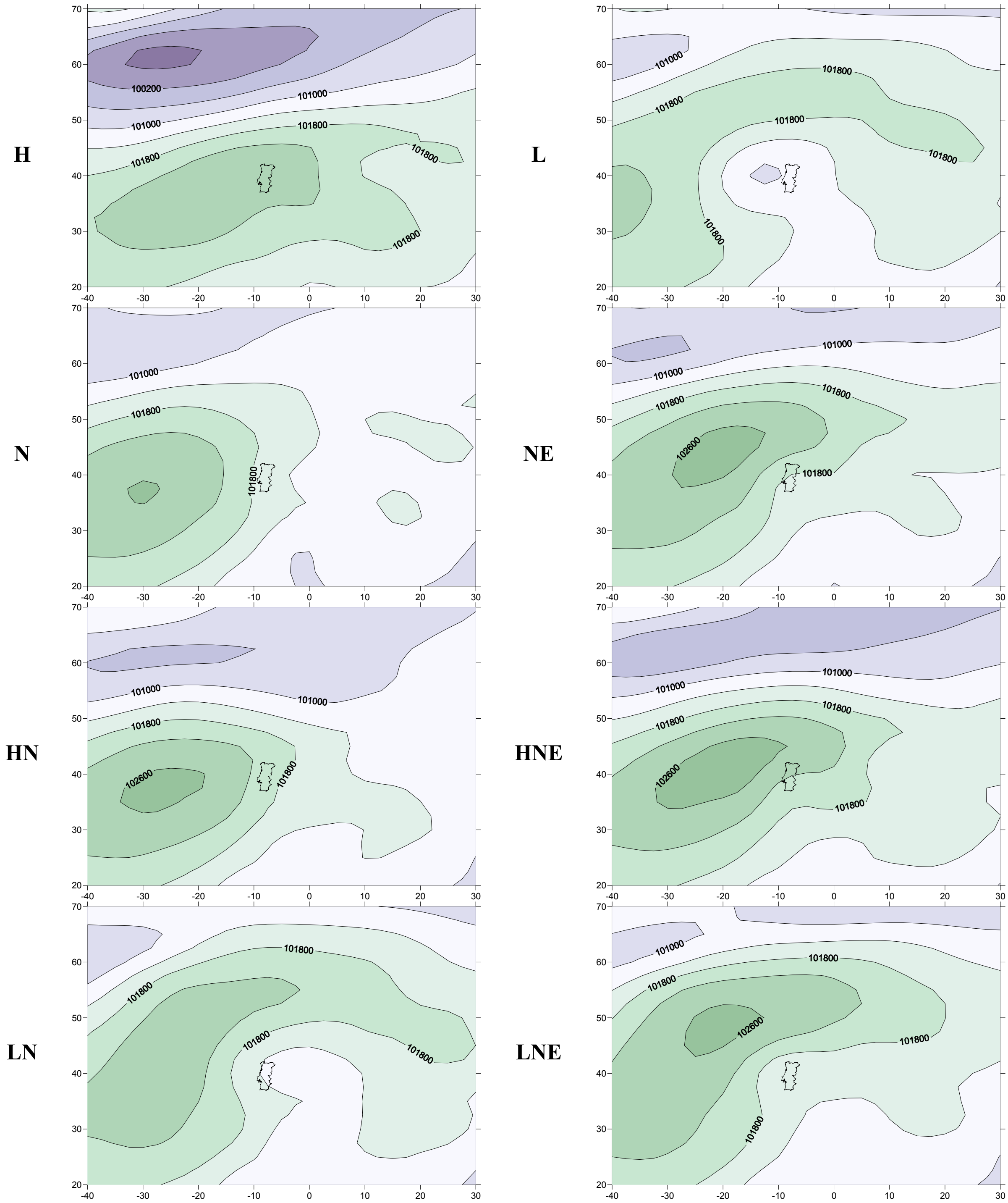


Figure 3: mean sea level pressure fields obtained for some of weather types classified in period with 7 years of data

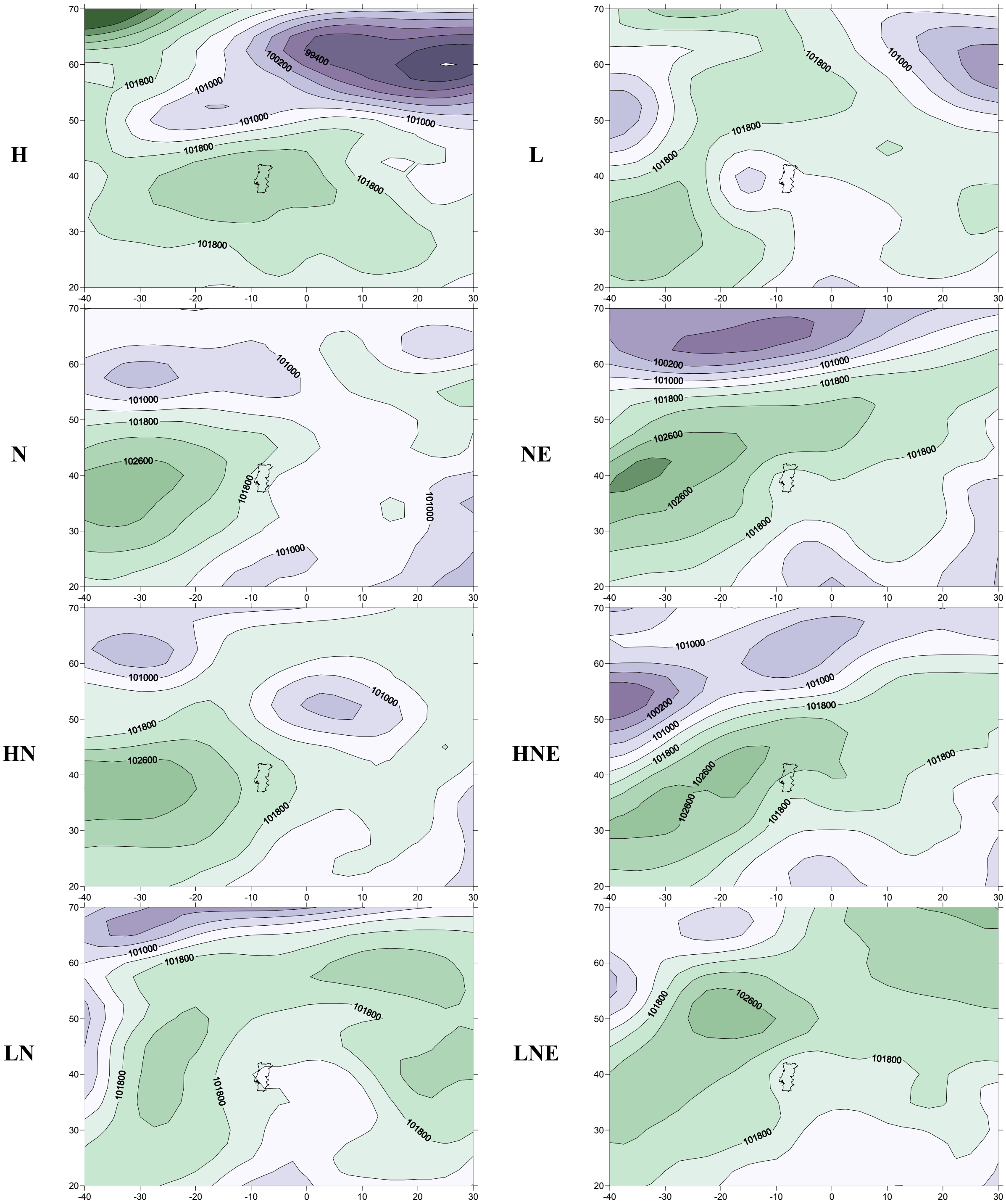


Figure 4: mean sea level pressure for the most likely “representative” day (see table 3) for some of weather types classified in period with 7 years of data 7

3. Numerical Mesoscale Model

To construct the wind atlas for mainland Portugal by this classification weather type methodology, the well known atmospheric mesoscale model MM5 was used. Four one-way nest domains were constructed with spatial resolutions between 81X81km up to the highest resolution of 3X3km. Parameterization schemes were previously selected by performing control simulations for 4 selected days in order to minimize the differences between observed and simulated wind speed and direction values. Parameterization schemes like Gayno-Seaman (PBL), RRTM (radiation), GRELL (cumulus) SIMPLE ICE (microphysics) and NOAH soil model were chosen since wind data simulated is in better agreement with the observed wind data. Figure 5 shows the high resolution domain (3X3km) used in weather type simulations and table 4 shows the grid point dimensions as well as spatial resolutions and model step time for all four one-way nested domains.

Figure 5: High resolution MM5 domain (3X3km) used for weather type simulations.

Domain	Grid dimensions nx×ny×nσ	Spatial resolution	Model Step (s)
D1	52×63×32	81 km	240
D2	54×72×32	27 km	81
D3	111×96×32	9 km	27
D4	171×276×32	3 km	9

Table 4: Domain dimensions and model step of the simulations.

Boundary conditions for both MM5 and soil model were ingested with data from Reanalysis Project (17 vertical levels plus 4 soil levels) for each classified 26 days (see table 3).

3.1 Numerical experiments

Two types of *numerical experiments* were created for the purpose of this work. The first one is the weather type simulation. For this case, all 26 days (table 3) were simulated with MM5 and the output of the wind field for each day was multiplied by the respective frequency factor as shown in figure 2. The classification obtained for the 7 years of data was used to enable validation of results against wind data from INETI's anemometric reference stations. The final wind and energy density fields were obtained by the sum of all simulated days weighted by the respective frequency factor.
The second type of experiment consists on a *long term* simulation: INETI had previously simulated a complete one year of reanalysis data (1999 year) in order to simulate a complete annual wind cycle. The same MM5 parameterisations described above were also used in this long numerical simulation. The whole one year simulated results were also corrected by an intra annual factor computed using the data of four long term wind stations located in mainland Portugal presented in figure 6 where table 5 shows the name of each station and also the position and sensor's height.

STATION	STATION ALTITUDE (A.G.L)	HEIGHT OF SENSORS	
		Velocity	Direction
IN_01 S. João Lampas	152m	10m	10m
IN_04 Vila do Bispo	104m	10m	10m
IN_32 Gardunha	1210m	10m	20m
IN_33 Arruda	398m	10m	20m

Table 5: Wind stations used by INETI

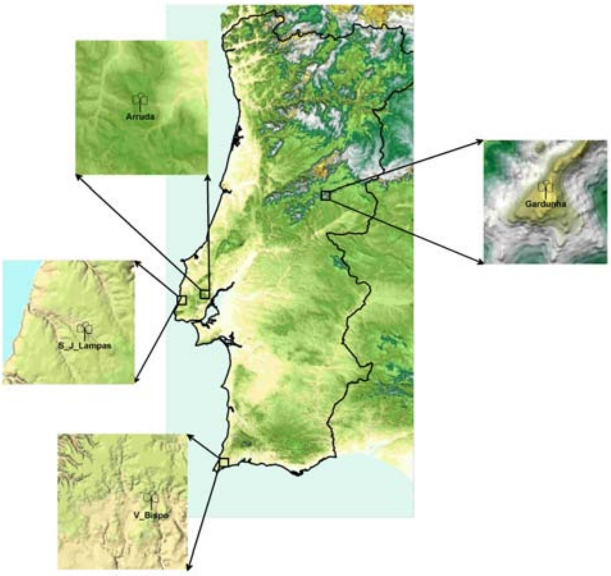


Figure 6: Location of INETI's long term stations for wind comparing results and assessing the intra annual variability.

This long term simulation also serves as a spatial wind speed reference to compare with weather type simulation. If both results reveal similarities in wind speed values then the weather type classification scheme presented here is strong enough to be used in order to compute long term wind atlas.

3.2 Validation results

A simple validation procedure between observed and simulated data is applied. The four long term stations monitored by INETI are located in sites where strong speed up effects occur in most part of the annual cycle. Thus, comparing the simulation results with these observed wind speed values enhances the generally good performance of the model in predicting strong mesoscale phenomena in very complex terrain. The occurrence of such intense phenomena in low atmospheric boundary layer is well documented in some mesoscale weather studies [4,5] indicating the existence of deviation errors in wind speed up to 30% using high resolution mesoscale models.

A set of validation results comparing observed and simulated Weibull distributions was performed, as well as: dispersion flow charts; correlation coefficients: wind velocity and direction series; deviations and root mean-squared errors for each day wind direction and velocity; monthly and yearly Weibull parameters; and energy density by each of the 16 wind direction sectors. In this paper only the final results obtained by each type of simulation above described are depicted. In Tables 6 and 7 the observed and simulated mean wind speed values for the reference height of the sensors (10m) and each type of simulation are presented.

	IN_01			IN_04			IN_32			IN_33		
Weather Types	Obs*	Sim**	Dev***	Obs	Sim	Dev	Obs	Sim	Dev	Obs	Sim	Dev
Mean Vel.	4.69	4.49	-4.26	4.97	4.50	-9.33	5.31	4.42	-16.88	5.82	4.25	-26.98

*observed values (m/s); **simulated values (m/s); ***deviation (%)

Table 6: Observed, simulated and deviation values obtained from weather type simulations. Results compared with data from four INETI reference wind masts.

	IN_01			IN_04			IN_32			IN_33		
1999 year	Obs*	Sim**	Dev***	Obs	Sim	Dev	Obs	Sim	Dev	Obs	Sim	Dev
Mean Vel.	4.73	4.54	-4.02	6.11	4.52	-26.02	6.10	4.51	-26.07	6.50	4.45	-31.58

*observed values (m/s); **simulated values (m/s); ***deviation (%)

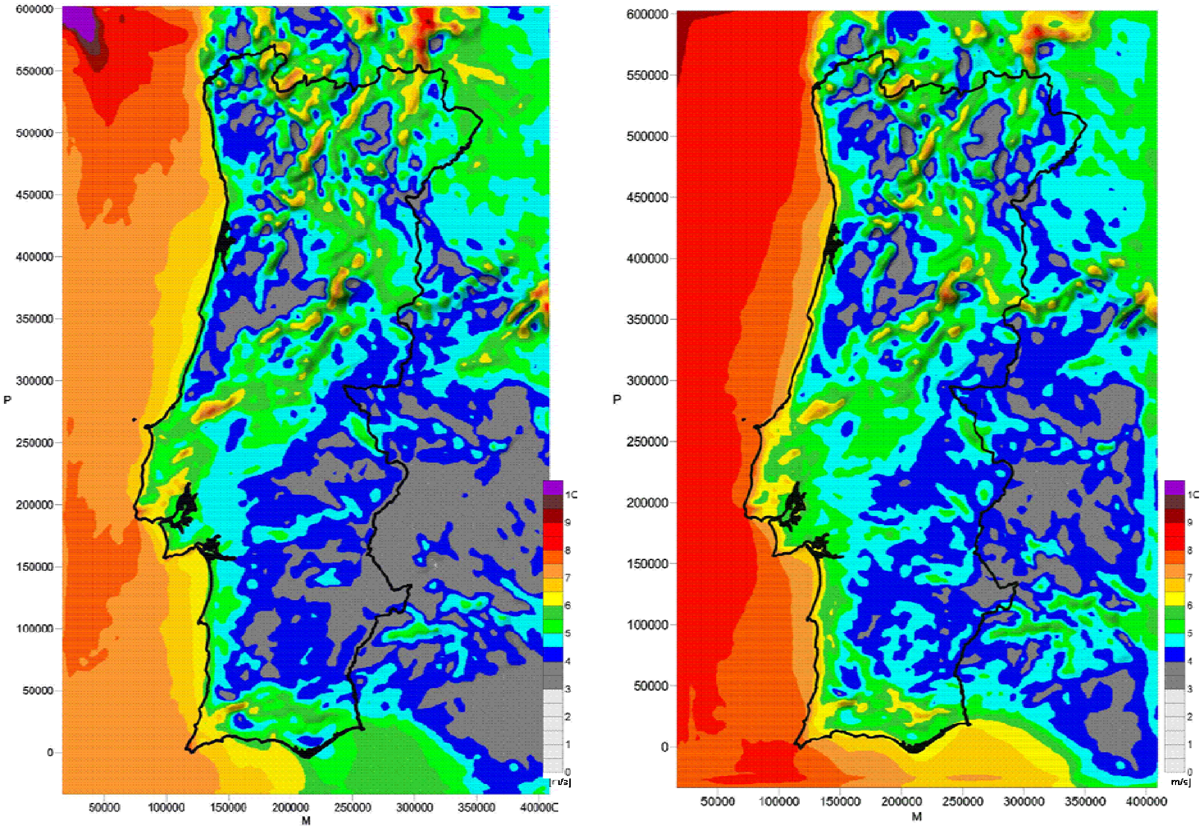
Table 7: Observed, simulated and deviation values obtained by the application of the weather type methodology. Results compared with data from four INETI reference wind masts.

Observing the results one can conclude the existence of deviation error values up to 30% but such deviation is expected, specially taking into account the orography of some of the sites where the existence of strong speed up effects is evident. Another relevant factor for the “wind numerical generated data” for the four stations is the spatial resolution of 3X3km, which may be insufficient to reproduce the flow field in certain type of complex small elevations filtered by the 3X3km grid and quite common in certain areas of mainland Portugal (e.g. the northern region of Lisbon). To reduce these deviations the outputs of mesoscale and microscale models were coupled, being the results for a grid of 1x1km already concluded. The much higher resolution (500X500m) is programmed for a near future.

Correlation values (not presented in this work) for all stations are about to 65% with R-squared values up to 88% between observed and predicted values for both of two types of simulations (3X3km). Once again these values are in agreement with those presented in mesoscale studies [4, 5].

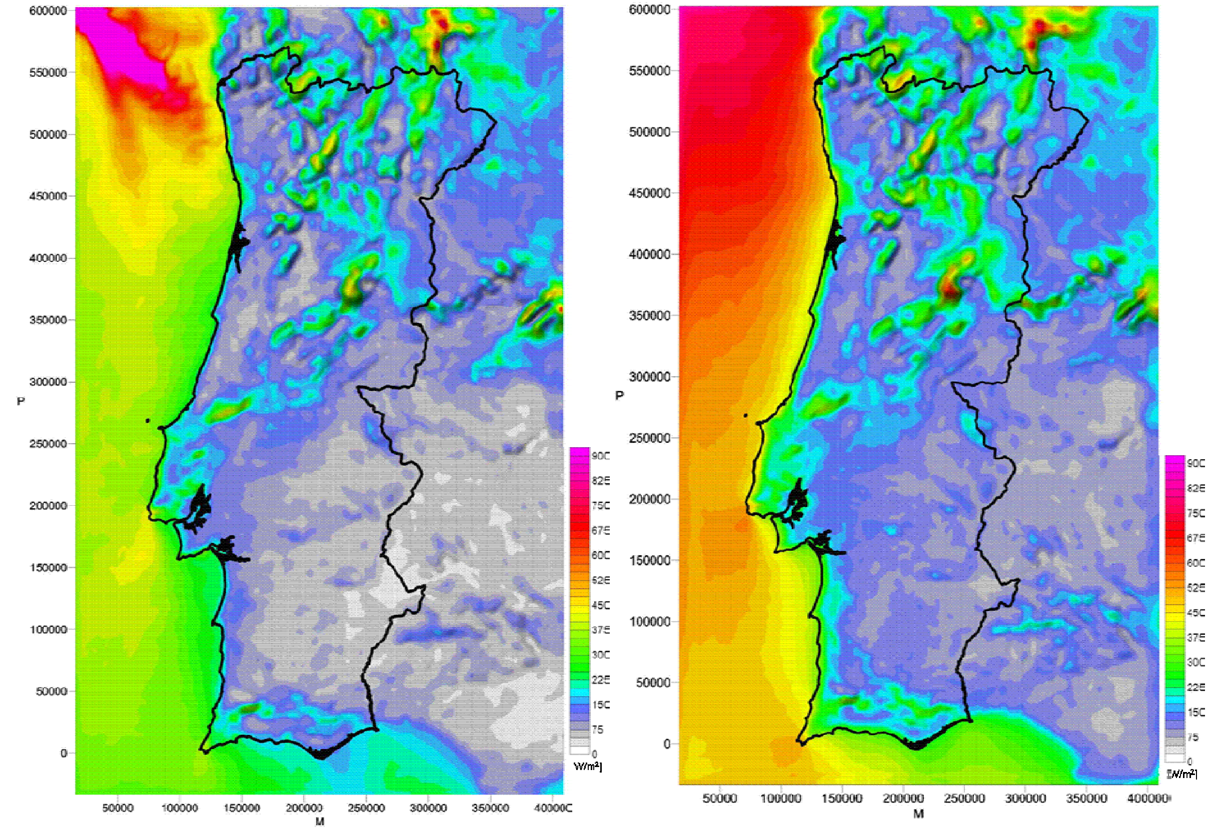
4. Wind Atlas Results

Figures 7 and 8 illustrate the wind speed and energy density maps processed for 80m e.g. (above ground level) for weather type simulation and long term simulation. Comparing numerical results between the two types of simulations (weather types and long term) one can observe the existence of a good consistency wind speed and energy density fields with good similarity for mainland Portugal. These results lead to the conclusion that the weather type classification performed and presented in this study can produce good wind resource assessment maps with the advantage of reducing drastically the computing time effort by eliminating the necessity of long term simulations. A more sophisticated classification is in progress to deal with horizontal wind components to evaluate wind and energy density roses (detailed direction classification) and also the inclusion of other atmospheric parameters such as Richardson number and Stability indices.



(a) (b)

Figure 7: Mean wind speed simulated with (a) – Weather types and (b) – long term simulation corrected by intra annual variability (h=80m).



(a) (b)

Figure 8: Mean energy density simulated with (a) – Weather types and (b) – long term simulation corrected by intra annual variability (h=80m).

5. Concluding Remarks

In this work a weather type classification scheme is presented in order to develop a wind atlas for mainland Portugal. This scheme produces 26 different weather types computed by geostrophic vorticity at mean sea level pressure. A more likely representative day for each weather type identified is also implemented for a period covering 7 years.

Two types of numerical simulations were tested for the purpose of this work. The first one is the weather type simulation. For this case, all 26 days classified were simulated with the popular MM5 ingested by Reanalysis data from NCAR's mass storage systems. Wind field outputs for each day were weighted by the respective frequency factor and the final wind fields are obtained by the sum of all simulated days affected its frequency of occurrence.

A second type of experiment was conduced by a long term test previously simulated at INETI with a complete one year of reanalysis data (1999 year) ingested to boundary conditions of MM5. These simulations were corrected by an inter annual factor computed with help of four stations monitored by INETI. These stations are located in locals where strong speed up effects is present at most part of the annual cycle. Thus, comparing simulated results with these observed wind speed values enhances the model performance in predicting strong mesoscale phenomena in complex terrain

Map results between these two types of experiments show the existence of a good consistency wind speed and energy density fields and good similarity for mainland Portugal. These results lead to the conclusion that the weather type classification presented in this study can produce good wind resource assessment maps with the advantage of drastically reducing computing time effort by eliminating the necessity of long term simulations.

A more sophisticated classification is in progress to deal with horizontal wind components to evaluate wind and energy density roses (detailed direction classification) and also the inclusion of other atmospheric parameters such as Richardson number and Stability indices.

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