Interannual Variability of the Average Wind Speed in Europe

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Abstract:

Interannual variability of the average wind speed is the main factor for erroneous annual wind park production estimates and therefore can cause serious economical problems to wind park developers from profitability lower than expected. In this study, the magnitude of interannual variability of the average wind speed is assessed in Europe, based on data sets from NCEP Reanalysis II. The areas with the highest values of interannual variability are identified and both average and maximum expected deviations are given as a function of the length of the monitoring period.
Keywords: Interannual variability, wind speed, financing, due diligence.

1 Introduction

When considering onshore facilities, from common sense the most favourable locations for constructing wind parks in complex terrain countries are coastal or mountainous areas. The first step in this process is to install either a meteorological weather station or an anemometric mast and monitor the atmospheric flow for, at least, one year, so that the annual cycle can be taken into account. For practical reasons, wind monitoring periods are much shorter than the mandatory thirty years used to obtain the climatology, hence annual wind speed estimates can vary considerably from the long term average. In this case, the annual production estimates can have significant large errors and therefore economical issues may arise during the lifespan of wind parks.
This work comprises two issues: the first is to assess how local wind reflects large scale flow anomalies; the second issue is based on the hypothesis that there is a clear link between local and large scale flow patterns. Under this assumption and taking advantage of the large meteorological data sets, the ultimate aim of this study is to quantify the interannual variability of the large scale wind field and infer the local flow.

2 Data

2.1 Meteorological Data

The meteorological data used was NCEP/DOE Reanalysis II [1], obtained from NOMADS [2]. The data sets used in this study are the 10 m and the 925 hPa wind speeds, which can be considered representative of low level and medium level sites (altitudes of 750-1000 m), respectively. The data covers the period January 1979 to December 2005, providing forecasted wind speeds four times a day (00, 06, 12 and 18 UTC). The wind speed at 10 m is provided in a Gaussian grid, with a resolution of approximately 1.875º x 1.903º. The 925 hPa data set is provided in a 2.5º x 2.5º lat-long grid point. For both data sets used, monthly and annual averages were calculated.

2.2 Site Measurements

Data sets from nine sites being monitored by INETI are compared against the NCEP Reanalysis data to assess the relationship between the large scale flow and the local wind data. Five of the sites are located in the coastal region and the remaining four are placed in centre of the country, in a mountainous area with altitudes between 700 and 1200 m.
Most of the data used covers the period 1999 - 2004, except in two coastal sites. These anemometric masts are property of INETI and have some of the longest time series in Portugal, as the period spans from 1993 to 2004. All data is provided as ten minutes average and the anemometers are installed between 10 and 60 m above ground, depending on the site.
All data have been quality controlled and, when applicable, gaps in the wind speed records have been filled by multivariate regression, based on data monitored at nearby locations. The selection of the sites depends on whether they are located at areas which have the same characteristics and if the correlation coefficients between the wind speed data exceed a given threshold.
For every data set used in this study, monthly and annual average wind speeds were calculated from the ten minutes records.

3 Reanalysis II *versus* Site Data

In order to address the issue of assessing the interannual variability from meteorological data, a comparison between the global and local data must be made. As a marked example of interannual variability, figures 1 and 2 shows the anomaly wind speed at 925 hPa in January 2001 and 2002, calculated from Reanalysis II, taking the period 1979-2005 as the reference for calculating the climatology. In January 2001 the large scale flow was mainly zonal across the north Atlantic and induced a positive anomaly in the wind speed in Western Iberia as large as 3 to 4 m/s.

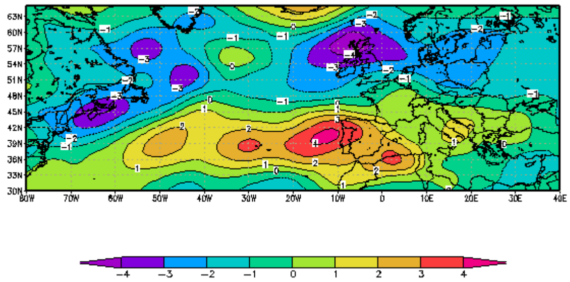

Figure 1: 925 hPa wind speed anomaly (m/s), from Reanalysis II, in January 2001.

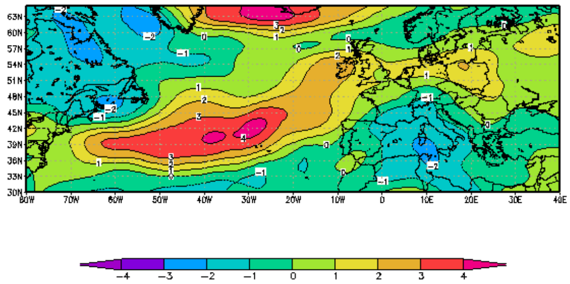

Figure 2: 925 hPa wind speed anomaly (m/s), from Reanalysis II, in January 2002.

In January 2002, however, there was a clear shift to the northeast of the large scale flow, hence the negative anomaly over Iberia and extending over to the eastern Mediterranean, which is characteristic of a strong positive phase of the North Atlantic Oscillation [3]. The measured wind data at several sites expressed clearly the large anomalies observed, with January 2001 being one of the windiest months in record.

To assess the relationship between local wind and large scale flow, the correlation coefficient was calculated between the normalized monthly wind speeds from the Reanalysis data and each of the nine sites. Figure 3 shows the monthly normalized wind speeds from the weather data and two low level sites located very close to the coast, one in the centre and the other in the “southwest corner” of Portugal. The most southern site (IN04 Vila do Bispo) is being monitored daily since 1991 and IN01 São João das Lampas from 1993. Figure 3 spans the period from February 1993 to December 2004. The correlation coefficient between the large scale flow and the wind speed monitored at sites IN01 and IN04 is respectively 0,65 and 0,34. An additional mast (not shown) located on the west coast approximately half way from sites IN01 and IN04 was studied and exhibit a correlation coefficient of 0,54.

Figure 4 is identical but the coastal sites selected here exhibit a somewhat different behavior since they are installed on hilly terrain at altitudes of around 300 and 500 m. The period considered in these sites extends from June 1999 to December 2004 and the correlation coefficients obtained were 0,76 and 0,64.

Figure 5 presents the normalized monthly average wind speed for both the 925 hPa data set and three

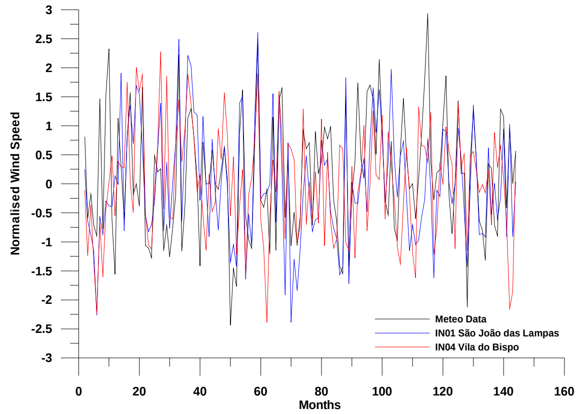

Figure 3: Normalized 10 m monthly wind speed from Reanalysis II data and two low level coastal sites in the southern half of Portugal.

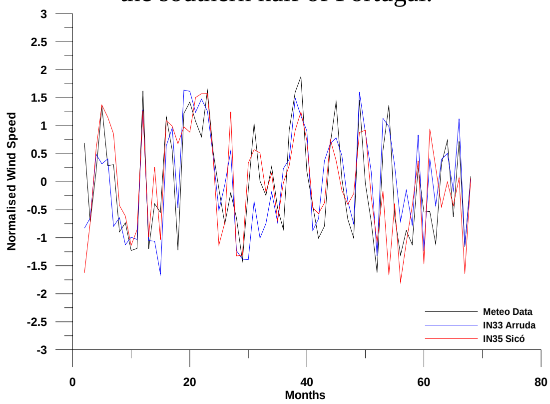

Figure 4: Normalized 10 m monthly wind speed from Reanalysis II data and two coastal/medium level sites in the centre of Portugal.

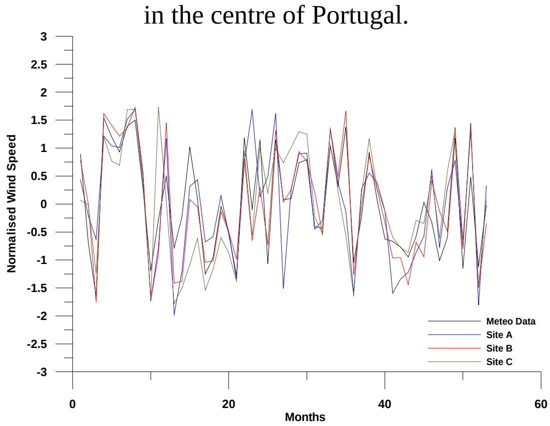

Figure 5: Normalized 925 hPa monthly wind speed from Reanalysis II data and three mountainous sites in the centre of Portugal.

masts located at a mountainous region of the centre of Portugal, at an altitude of 700-900 m. The monitoring period is August 2000 to December 2004. The calculated correlation coefficients between the meteorological data and the local data range from 0,72 to 0,89. An additional anemometric mast, installed at an altitude of 1200 m, was used in this study and covers the period from June 1999 until December 2004. In this case the obtained correlation coefficient is 0,83.

From the results shown above, it seems reasonable to admit that the correlation coefficients obtained between the large scale data and medium level mountainous sites are sufficiently high to suggest that the meteorological data sets are useful to infer local flow. On the other hand, if one considers low level or coastal sites, the correlation coefficients are generally smaller, thus it does not suggest a direct link between large and local flow.

This behavior is expected due to the existence of local circulations such as the sea breeze effect, which is not simulated by General Circulation Models and is even a challenge to Limited Area Models. Another drawback, which may influence any site under monitoring, in a direct link between local and large scale flow is the existence of energy concentrating factors due to local orography.

4 Interannual Variability

4.1 As a function of the monitoring period

Under the assumption that the large scale data is able to provide some insight on local flow, it seems reasonable to use the relatively long data sets of the meteorological data to infer about the annual variability. The assessment of the interannual variability was made using the mean absolute deviation Δ, as given by equation 1.

$$\Delta = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{x-\bar{x}}{\bar{x}}\right| \quad (1)$$

where x stands for the annual wind speed at a given year, $\bar{x}$ is the long term average and N is the number of years of record. Figures 6 to 9 show the mean absolute deviation between the average wind speed and the long term value (calculated from the whole period 1979-2005) as a function of the number of years of monitoring. The results were obtained for both the 925 hPa and the 10 m data sets, in a domain that includes most of Europe and the nearby North Atlantic. Additionally, the maximum absolute deviations of the average wind speed were also calculated as a function of the monitoring period and are shown in pictures 10 to 13.

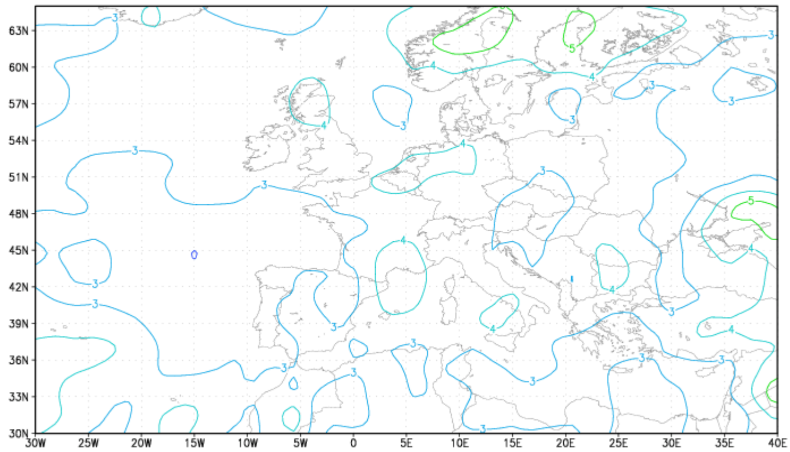

Figure 6: Mean absolute deviation (%) of the 10 m average wind speed of a single year chosen at random, when compared to the reference period 1979-2005.

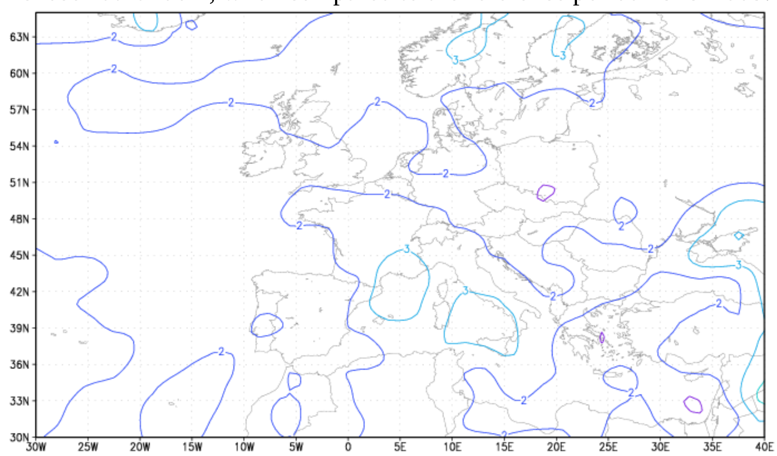

Figure 7: Mean absolute deviation (%) of the 10 m average wind speed of a three year period chosen at random, when compared to the reference period 1979-2005.

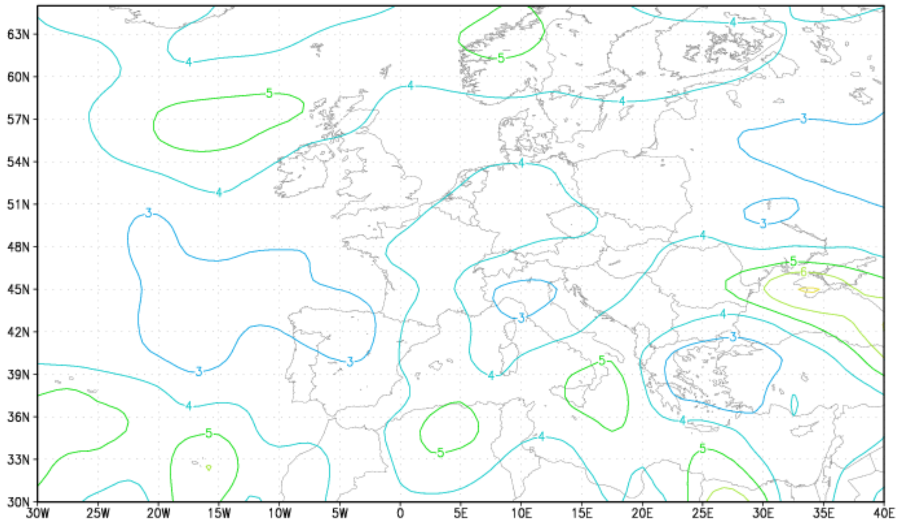

Figure 8: Mean absolute deviation (%) of the 925 hPa average wind speed of a single year chosen at random, when compared to the reference period 1979-2005.

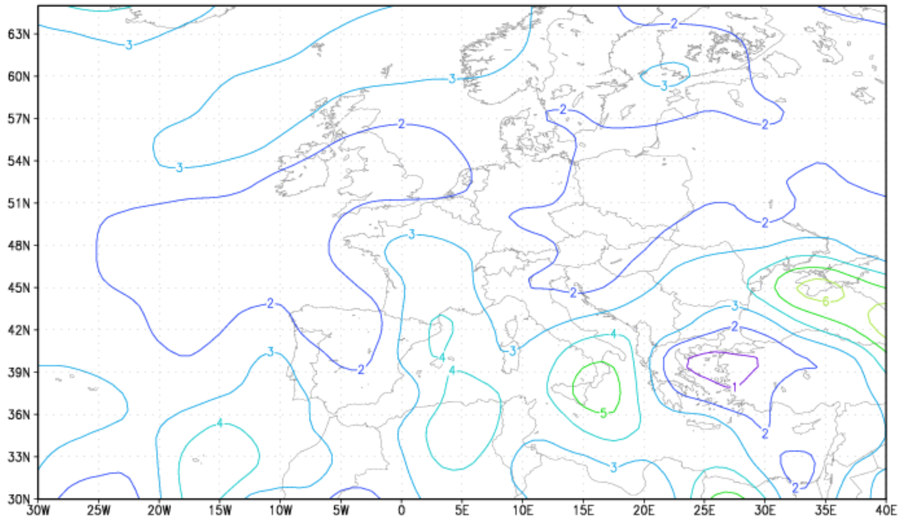

Figure 9: Mean absolute deviation (%) of the 925 hPa average wind speed of a three year period chosen at random, when compared to the reference period 1979-2005.

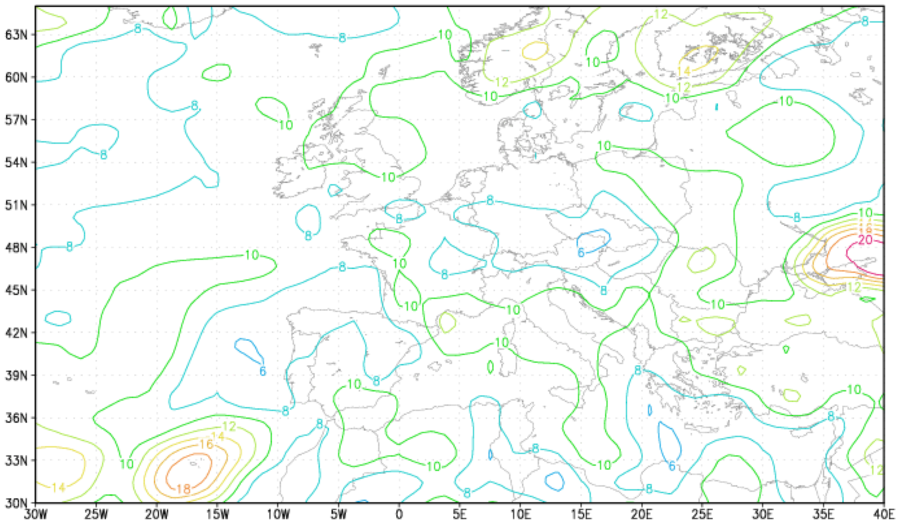

Figure 10: Maximum absolute deviation (%) of the 10 m average wind speed of a single year chosen at random, when compared to the reference period 1979-2005.

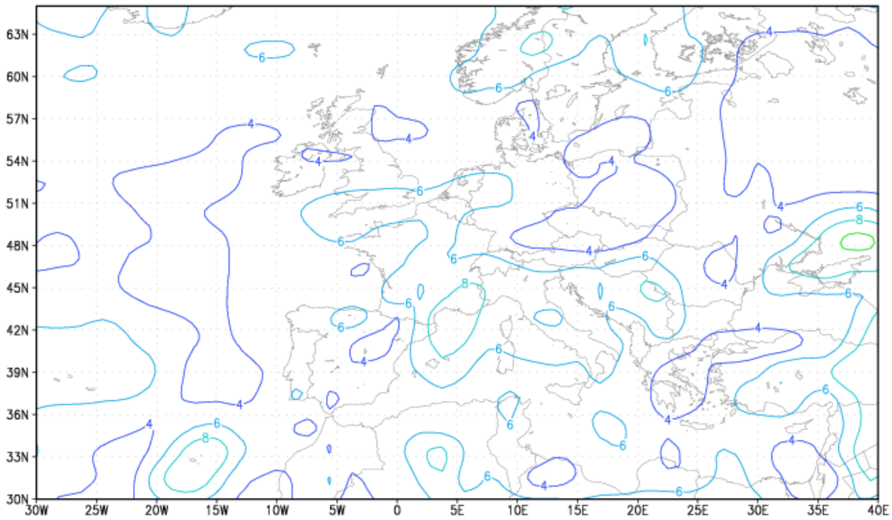

Figure 11: Maximum absolute deviation (%) of the 10 m average wind speed of a three year period chosen at random, when compared to the reference period 1979-2005.

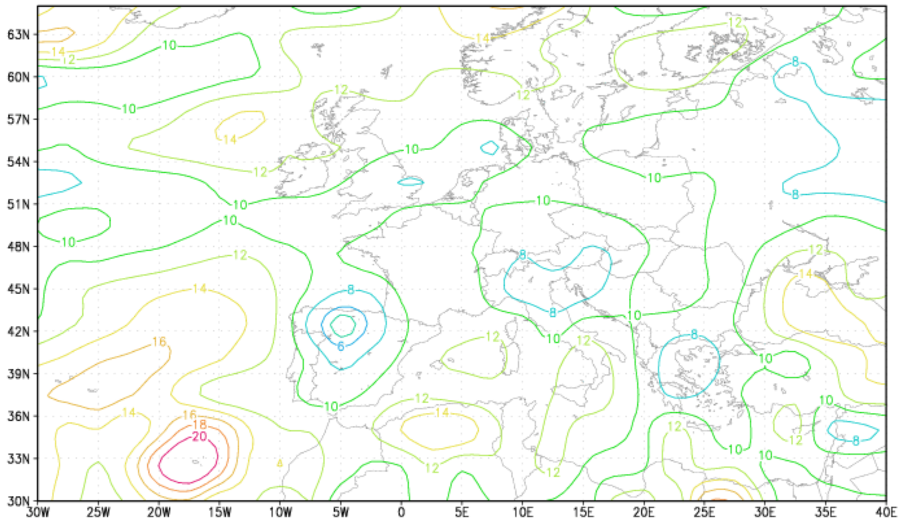

Figure 12: Maximum absolute deviation (%) of the 925 hPa average wind speed of a single year chosen at random, when compared to the reference period 1979-2005.

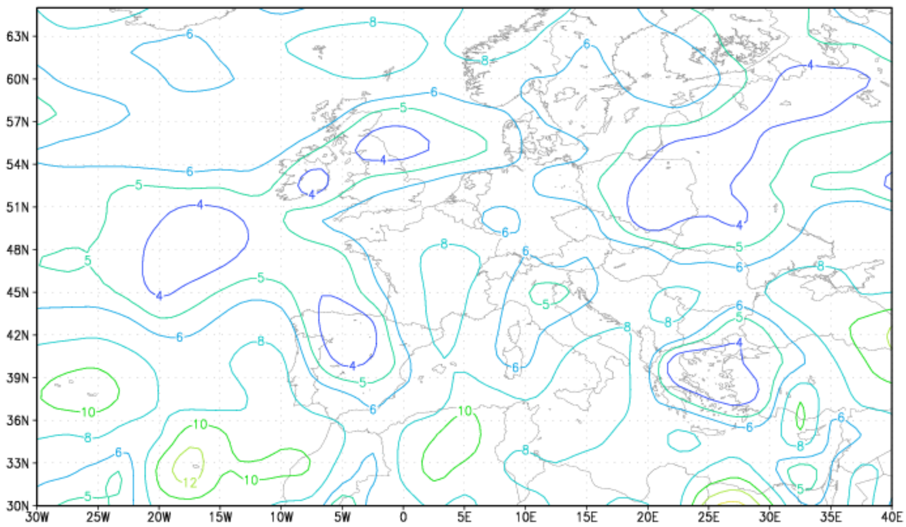

Figure 13: Maximum absolute deviation (%) of the 925 hPa average wind speed of a three year period chosen at random, when compared to the reference period 1979-2005.

When considering the mean absolute deviation of a single year chosen at random one observes that the field is quite homogeneous, with figures around 3-5%. When the period of monitoring increases to three years, which is representative of most monitoring campaigns, the expectable deviations become limited to 2-3%. When considering analogous figures but for the 925 hPa wind field one find similar results, but locally the average deviations are larger.

Regarding the maximum absolute deviations one finds that the figures range between 8 to 12% if only one year is considered and 4-6% if three years are used. In both cases, locally the figures may exceed the cited range of deviation. These results are valid for both the 10 m and the 925 hPa wind fields, but noticeable is the fact that the highest limits of the deviations may increase in the case of the pressure level field.

Figure 14 shows the average absolute 925 hPa wind speed deviation as a function of the monitoring period for seven selected areas of Europe.

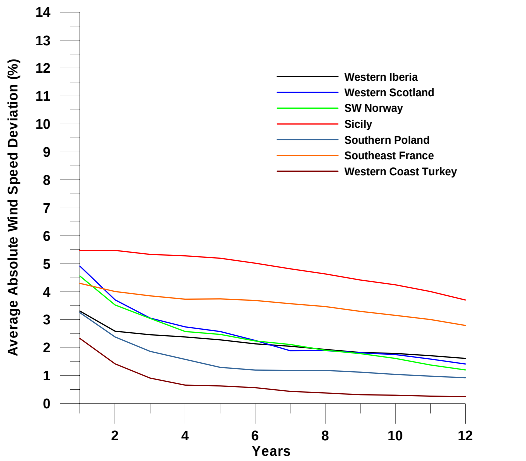

Figure 14: Average absolute 925 hPa wind speed deviation (%) as a function of the monitoring period, over seven selected areas in Europe.

As expected, the deviation in the estimated average of the wind speed decreases as the number of years of monitoring increase. Generally, there is a clear decrease in the deviation in the first 3-4 years, with a subsequent lower rate onwards. This pattern however is not common to all areas, because in both Sicily and Southern France there is not a sharp decrease in the deviation and the figures remain still above 3% after a ten year period.

Figure 15 is identical to the previous, but shows the average absolute maximum deviation of the 925 hPa average wind speed. In this case, all areas exhibit a common behavior as the maximum deviation decreases sharply in the first four to six years of monitoring. From that period onwards, the decrease becomes much lower and there is a tendency for the values to be lower than 4%. The only areas (of the sample) that remain above this threshold are the most northwestern locations. It is interesting to note that the areas that exhibit the lower maximum average deviations are Sicily and Southern France, which on the other hand present the highest average absolute wind speed deviations. From these results one may argue that the wind speed anomalies are more persistent in western and central Mediterranean than in the rest of selected areas, but on the other hand the anomalies have a lower amplitude.

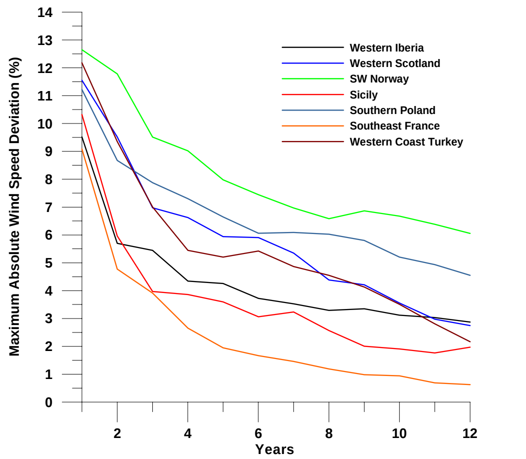

Figure 15: Maximum absolute 925 hPa wind speed deviation (%) as a function of the monitoring period, over seven selected areas in Europe.

4.2 Variability in the period 2000-2005

The period 2000-2005 is one of most interest because of the boom of the wind energy deployment, particularly, over Europe. As such, many field campaigns have been made in order to assess local wind energy resource and, with additional studies, to obtain wind park yearly power production estimates. As the profitability of wind parks is highly dependable on these estimates, regardless of other contributing factors, errors in the assumed average wind speed at a given location can lead, at extreme cases, to large differences between real and estimated yearly wind park energy production estimates.

In order to identify the anomalies observed, figures 16 and 17 show the 925 hPa average wind speed deviation, respectively, for the period 2000-2004 and in the last year, when compared to the reference period of 1979-2005. In 2000-2004 the wind speed deviations were low in most of the north and central Europe, with figures ranging between -2% and +2%. However in southern Europe, from Iberia to the Black Sea, there was a positive anomaly, with large areas exhibiting deviations above +4%.

When considering the last year, there was a positive anomaly over the British Isles, extending towards Scandinavia and Western Russia, with large areas experiencing deviations above +6%. Most of Europe exhibits a slight negative anomaly, except in western Iberia/nearby Atlantic and the eastern Mediterranean/ Black Sea, where deviations exceeded +6%.

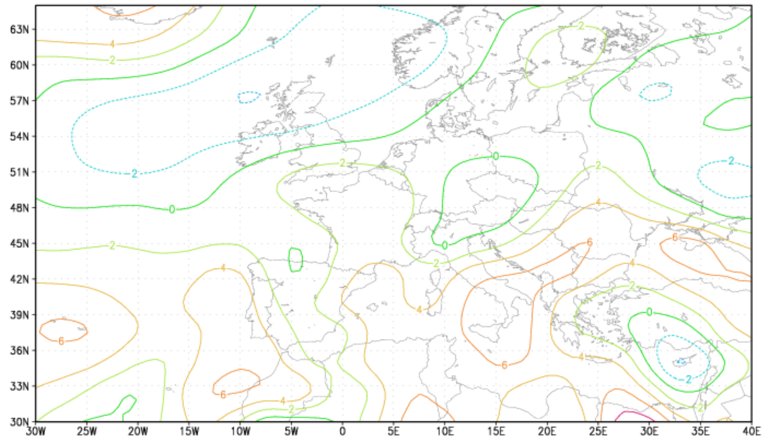

Figure 16: 925 hPa average wind speed deviation (%) in 2000-2004, when compared to the reference period 1979-2005.

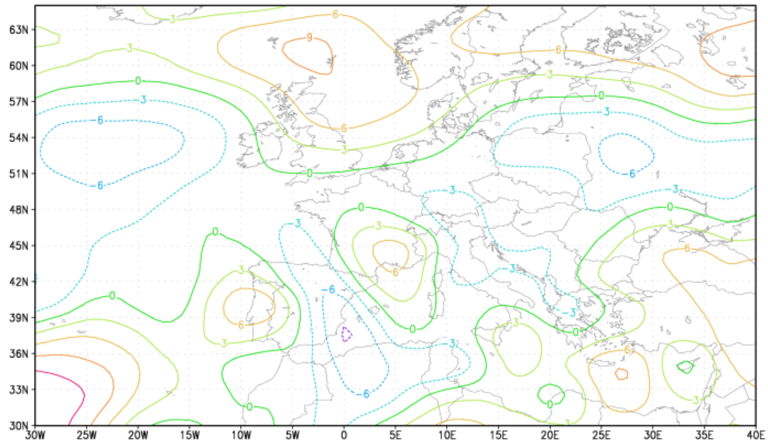

Figure 17: 925 hPa average wind speed anomaly (%) in 2005, when compared to the reference period 1979-2005.

5 Concluding Remarks

A comparison between the monthly average wind speeds from a meteorological data set and several sites being monitored in Portugal was made to assess the links between the large and local scale flow. From the results obtained, one can suggest that the monthly wind speed anomalies in the meteorological data can be used mainly to infer local deviations in mid-level and/or mountainous areas. Under this assumption, a study on interannual variability over Europe, based on large scale meteorological reanalysis data, is presented. The main results suggest that in the period of most interest to the wind energy industry there have been positive wind speed anomalies in most of southern Europe, while most northern and central Europe exhibited either an average wind speed close to the reference period of 1979-2005 or even a slight negative anomaly.

This study requires further work such as an increase in both meteorological and anemometric stations data to be the most representative as possible, but nevertheless provides some insight on an issue that clearly influences the financial revenues of the wind park industry.

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