ESTIMATING WIND ENERGY POTENTIAL OFFSHORE IN MEDITERRANEAN AREAS.

Alfredo.Lavagnini [1], Anna M. Sempreviva [1,2], and Rebecca J. Barthelmie [2]
[1] Istituto di Scienze dell'Atmosfera e del Clima, sezione di Roma CNR, via Fosso del Cavaliere 100, 00133 Rome, Italy,
Tel +39 0649934272 - FAX +39 0620660291
a.lavagnini@isac.cnr.it
[2] Dept. of Wind Energy and Atmospheric Physics, Risø National Laboratory, 4000 Roskilde, Denmark.

SUMMARY. Relatively few studies have been performed on the evaluation of offshore wind resources and these have been conducted mostly in North Europe. In Mediterranean areas the lack of such studies is mainly linked to: 1) the difficulty of meteorological monitoring in deeper waters; 2) the complex orography, frequently extending down to the coasts; 3) the sea breeze wind regimes and 4) local winds such as Bora, Mistral or Sciroc. In the North Adriatic Sea, a shallow basin of the Mediterranean, the first reason is not applicable, but the others are sufficient to make evaluating wind speed methods challenging. In the present paper we estimate the wind climatology at a platform located 15 kilometres offshore of Venice based on seven-years of data and compare it with the wind climatology obtained using five different methods using the long-term data from four coastal meteorological stations: Venezia Tessera, Venezia San Nicolò, Ronchi and Rimini. We discuss the applicability of those methods and find that WAsP® model of Risø National Laboratory is still the best tool for wind climate estimates. The results of new methods are promising but still require some development.

Keywords: Offshore, Coastal sites, Statistical Analysis, Climatic conditions.

1 Introduction

Relatively few studies have been performed on the evaluation of offshore wind resources and these are mainly concentrated in North Europe. The main difference between wind climatology of North Europe and Mediterranean coastal areas is that, in the latter, stability conditions other than neutral and strong sea breeze regimes are more frequent. If conditions offshore deviate significantly from near neutral (either on average or by season), the effect of stability on the wind speed profile can be substantial. Another additional difficulty of meteorological monitoring in the Mediterranean waters is their depth.

Various methods are available for predicting long-term wind speeds in offshore areas, which rely on long-term measurements at nearby land sites in comparison with short-term records offshore. In this paper, we have chosen three methods that have been used in the evaluation of wind resources at Danish offshore sites and have shown to give promising results there [1], [2], [5]. In addition to the above approaches we have also used two new methods.

The performance of these approaches is evaluated in the North Adriatic area. Here 7 years of hourly data collected on an oceanographic platform 15 km offshore of Venice and climatological data at four coastal stations (Venezia Tessera (VT), Venezia S. Niccolò (VSN), Rimini and Ronchi) are available. Figure 1 shows the North Adriatic Sea area and the location of the stations. In Table 1, the coordinates of the stations, altitude a.s.l (H), the height of the anemometers a.g.l. (Ha), and the period of measurements are shown.

2. Methods

An overview of the different methods used to estimate the wind climatology offshore is described.

1) The standard measure-correlate-predict (MCP) [3] [4] [5] method. It assumes a linear relationship between paired site acts where one site with a long-term record acts as predictor and the wind speed at short-term measurement sites as the predictand. Once a regression equation has been conditioned based on the measurement overlap period, the regression parameters can then be used to derive an extended data record for the site of interest. This method is generally applied using one regression analysis for each wind sector. At the Danish sites [1], [2] and [5], MCP tends to under-predict wind speeds in comparison with offshore data, which appears to be the result of a shift in the wind speed distribution between on - and offshore.

2) Risø's Wind Atlas Application and Analysis program WasP 7.0® [6]. It calculates the wind climatology at one site from the wind climatology of long-term representative stations. WAsP is a physically based model and uses a mean value for heat flux on- and offshore to calculate a mean stability correction and the change in roughness to adjust the momentum flux. WAsP typically gives good results except at sites that are less than five kilometres from the coast where wind speeds are predicted to be a few percent higher than those observed.

3) The Weibull correction method [1] for extrapolating wind data series is based on the concept of modifying the Weibull parameters of the short-term data series to characterise a longer data sampling period. It compares sector-based wind speed distributions at the on - and the offshore sites considering the on-shore long-term time series as representative of the area. The Weibull shape (A) and scale (k) factors are determined for 12 sectors at both sites considering a common period and their ratio is used to modify the long-term wind speed direction distribution to represent the off-shore station. The Weibull method gives good

results provided sufficient data are available to accurately characterise the wind speed distribution in each sector and the distribution conforms to a Weibull distribution.

4) WAsP applied to geostrophic wind distributions (GeoWAsP). Geostrophic wind speeds were calculated from a sea level pressure data set for the period 1985-1997. WAsP was applied to each $0.5^o x 0.5^o$ grid of the waters of the European Union assuming any nearby land had roughness length $z_o = 0.03$m. Wind profiles were predicted for the centre of each grid for heights between 10m and 150m.

5) The Coastal Discontinuity Model (CDM). Geostrophic wind speeds and directions are calculated from the same sea level pressure data set as in 4). The CDM works in a slightly different way to WAsP in that geostrophic wind speeds are used to estimate friction velocity assuming a neutral atmosphere for each data point. Hence, instead of applying stability and land-sea corrections to the mean wind speed distribution as in WAsP, the CDM uses air and sea temperature, together with the geostrophic wind speed to calculate the stability parameter (the Monin-Obukhov length) for each grid point at each time step (input data are six-hourly). Air and sea temperatures were given for each $1^o x 1^o$ grid, for the period 1985-1997. Equilibrium land and sea wind speed profiles are corrected for stability. Finally the program uses the fetch distance to land at the centre of the grid point to determine the internal boundary layer (IBL) height and interpolates between equilibrium wind speed profiles over land and sea to the fetch distance accounting for the discontinuity caused in the profile by the IBL.

3. Data and climatology

The platform measurements are hourly values with a calm threshold of 2 ms^{-1}. In the other four selected meteorological stations data were taken in integer knots at the synoptic hours (0, 3, 6, 9, 12, 15, 18, 21 GMT). The mean wind speed **M** (m/s) and the frequency **f** (%) for each of the twelve sectors considered in this paper are shown in Table 2.

In Figure 2a and 2b the mean hourly velocity and the mean monthly velocity are shown respectively for 4 stations. VSN presents behaviour similar to VT. From Figure 2a we note that in the central part of the day the wind is enhanced in the coastal areas and reduced at the platform distance. Inverted diurnal cycles with highest wind speed at night have been noted in other offshore locations [7]. The sea breeze regime might produce this effect. In Figure 2b a maximum wind speed during the spring and minimum during summer and winter time is observed. The monthly climatology of Rimini is slightly different from the climatology of Venice and Ronchi that are in better agreement.

4. Results.

We have applied the methodologies outlined above. The results of the application of these methods are shown below:

1) MCP. This method is clearly not applicable in this area since we could not find satisfying correlations amongst stations. Figure 3 shows scatter plots of wind speeds measured at VT and Venice platform for sectors 60° and 150° during the seven-year period of overlapping measurements. Data are not well correlated in either of the sectors. Comparing the two scatter plots, we can note that from the 60° sector the winds measured at the platform are typically higher than the winds measured over land due to the Bora type winds that blow from northeast. In the 150° sector, data from platform are lower and comparable to the measurements over land. Unfortunately no overlapping data periods were available between the Platform and VSN.

2) WAsP. The program is not able to reproduce the wind climatology of the platform using Rimini and Ronchi stations due to the long distance between stations and different positions along the coast, which have the effect that the two sites are subject to different meso-scale situations and different local circulations. We focus on the results obtained using data from VT (Figure 4 and 5) and VSN (Figure 6). Due to the large amount of calms (around 40%) at the two stations we have removed them in order to estimate the wind distribution. In WasP, the calms are uniformly distributed in the 12 sectors. In a region with large percentage of calms this procedure might modify the sector wise frequency distribution especially in the sectors with a low percentage. An alternative approach of distributing the calms according to the frequency distribution of the wind speed without calms was evaluated. A study has been performed on this subject and no noteworthy differences have been found. In Figure 4 and Figure 5, the comparison between predicted and experimental mean wind speed and frequency at the platform from VT for 7 years (VT7) and for 35 years (VT35) are shown respectively. Using VT35, wind distribution improves the prediction but still WAsP overestimates the mean wind speed by 15 %. Ratios between predicted and observed data are between 0.8 and 1.2. In Figure 6, the prediction of mean wind speed and frequency at the platform using data at VSN are shown. The frequency distribution is in better agreement than for VT35 especially in the sectors where the wind blows from the sea sectors (150°-210°). However, VSN under predicts the mean wind speed in the sea sectors (60° -210°) and overpredicts in the land sectors (240° - 360°). Generally, WAsP underestimates the wind at the platform in the sea sectors and overestimates in the land sectors.

3) The Weibull correction method. This method has been applied using the 7 years overlapping time series of VT and correcting the Weibull A and k parameters using the 35 years of VT. The results are shown in Figure 7. The method reproduces the frequency distribution in all sectors well, except for the two land fetch sectors. The wind speed is overestimated between 60° and 240 °. This is a weakness of the method, which uses a long-term experimental wind distribution including its own characteristic climate.

4) The GeoWAsP. The sector wise wind speeds obtained from the model are in good agreement with the experimental values as shown in Figure 8. The agreement between the predicted and observed wind speeds is surprising for three reasons. First the GeoWAsP was applied without orography and it is expected that wind speeds in the north and east sectors are influenced by the topography and by meso-scale winds such as the Bora. This might explain the difference between the observed and predicted sector frequency in these sectors. Second, it is expected that the relationship between the geostrophic wind speed and the near-surface wind speed is more difficult to be predicted in the Mediterranean area where thermal forcing plays a larger role (GeoWAsP does not account for sea breezes). Third, the location is relatively close to the coast - GeoWAsP predictions are made for 0.5^o by 0.5^o grid squares.

5) The CDM. In the results given below the CDM was run using input data for grid 45.5N 12.5E but using the fetch distances to the platform calculated by WAsP and given in Table 2. The mean geostrophic wind speed at the grid is 8.64 m/s with mean air and sea temperatures of 283.9K and 283.6K respectively. This gives a mean wind speed profile, which is close to neutral but slightly stable with a predicted wind speed of 6.35 m/s at 15 m height (Figure 9). The air-sea temperature difference tends to be large and either positive or negative driving the Monin-Obukhov to small (i.e. non-neutral) values. This is a consequence of using the temperature difference to define stability because it is very sensitive to calibration errors or to errors in the databases such as the use of a coastal (mixed land/sea) air temperature with a sea surface temperature. This could be improved using a finer grid but differences in the datasets used for air and sea temperatures would remain. Similarly, geostrophic wind speeds and predicted near-surface winds are highly correlated. The correlation coefficient is >0.99

(Figure 10) indicating strong association between geostrophic and near-surface wind speeds, which is not realistic for the Mediterranean environment.

The sector wise M and f obtained using CDM, compared to the experimental values are shown in Figure 11. The model overestimates M but the results are promising.

Stability at the platform is estimated based on air-sea temperature data sets for the 0.5 by 0.5 ° grid in which the platform is located. Unfortunately this can give errors at the coastline when both land and sea are incorporated into the grid square for the air temperatures. Figure12 indicates variations of stability on different timescales and by wind speed and direction. This distribution of stability conditions between the highly stable and highly unstable classes with a very low occurrence of the near-neutral class is rather unusual even for a site with relatively low mean wind speeds. In Figure 13, the monthly average wind speed from the model is compared to the experimental averages at the platform. The two curves are in agreement showing a minimum in the summer months but the average wind speed from CDM is over-predicted, especially in winter.

4. Final remarks.

We have applied five methods to estimate wind climatology offshore by long-term data sets. In Table 3, the ratios between predicted and experimental mean wind speeds are reported for the WAsP model considering VT 35 years (WAsP VT 35) and VT 7 years (WAsP VT 7) time series, the WAsP model considering VSN, the Weibull correction method applied to VT35 and finally the Geo WAsP model and the CDM model. The methods based on WAsP (WAsP and GeoWAsP) are found to give the best results. WasP 7.1 works well provided that the predictor station lay in an area with similar local circulations. Also the CDM shows promising results.

The major problems in our Mediterranean study area are: the large amount of calms and the local wind regimes such as the sea breeze that strongly influence the wind distribution. Because of the latter problem it is not possible to use long-term time series located in a different sea breeze regime as were tried with Ronchi and Rimini. Furthermore, although for M > 4 ms^{-1}, a significant correlation could be found, it is not possible to apply the MCP method to the whole dataset. The main drawbacks of using either the CDM or GeoWAsP are that both models rely on the relationship between the geostrophic wind and the near-surface wind to calculate near-surface wind speeds. If this relationship cannot be predicted using the drag law (i.e. conditions close to the surface are stable, or as in this case, because meso-scale circulations such as the sea breeze dominate the local wind climate) then the prediction method will not provide a true representation of the near-surface wind resource.

5. Acknowledgements

The platform measurements were supplied by Luigi Cavaleri from the Institute of the Dynamics of Large Masses of the Italian National Council of Research (CNR) in Venice. The other four selected meteorological stations belong to the Italian Military Meteorological Service. The sea-level pressure data set for the period 1985-1997 used for the CDM were supplied by Tom Holt of the Climatic Research Unit, UK and WAsP runs were conducted by Gillian Watson of the Rutherford Appleton Laboratory, UK under the European Union JOULE program project ‘POWER, Predicting Offshore Wind Energy Resources’ Contract # JOR3-CT98-0286. We would also like to thank Mr. Claudio Transerici of IFA-CNR for the data quality control of the Meteorological database.

6. Bibliography

[1] Hoejstrup, J., M., Lange, B., Barthelmie,R.,J., Pedersen, A.,M.,J., Olsen, F. and Svenson, J. Offshore Wind Resources at selected Danish sites. Risø-I-1339 (EN), 1996, Risø National Laboratory, Roskilde, Denmark.

[2] Barthelmie, R.J., Courtney, M., Lange, B., Nielsen, M., Sempreviva, A.M., Svenson, J., Olsen, F., and Christensen, T. Offshore Wind Resources at Danish measurements sites. Risø-I-1339 (EN), 1998. Risø National Laboratory, Roskilde, Denmark.

[3] Landberg, L. and Mortensen, N.G., 1993: A comparison of physical and statistical methods for estimating the wind resource at a site. In: K.F. Pitcher (Editor), Proceedings of the 15th British Wind Energy Association Conference. Mechanical Engineering Publications Ltd, York, pp. 119-125.

[4] Woods, J.C. and Watson, S., 1997: A new matrix method of predicting long-term wind roses with MCP. *Journal of Wind Engineering and Industrial Aerodynamics*, **66**, 85-94.

[5] Barthelmie , R.J., M., Lange, B. and Nielsen, M.. Wind Resources at Roedsand and Omoe Staalgrunde. Risø-I-1456(EN), 1999. Risø National Laboratory, Roskilde, Denmark.

[6] Mortensen, N.G., L. Landberg, I. Troen and E.L. Petersen. Wind Analysis and Application Program (WAsP), Risø-I-666 (EN), 1993. Risø National Laboratory, Roskilde, Denmark.

[7] Barthelmie, R.J., Grisogono B. and Pryor S.C. Observations and simulations of diurnal cycles of near-surface wind speeds over land and sea. Journal of Geophysical Research (Atmospheres), 1996, 101(D16): p.21,327-21,337.

Table 1. Coordinates of the stations

Station	Lat. (deg.)	Long. (deg.)	H. asl (m)	Ha (m)	Period
1. Venezia Platform	45.31N	12.51E	0	15	1976-1982
2. Venezia Tessera	45.50N	12.33E	6	10	1961-1996
3. Venezia SanNiccoló.	45.43N	12.38E	5	10	1951-1977
4. Rimini	44.03N	12.61E	13	10	1951-1996
5. Ronchi	45.61N	13.50E	17	10	1967-1996

Table 2. Experimental mean wind speed, frequency and shortest over water distance to the platform calculated by WasP for each sector.

	Over-water distance (km)	M (m/s)	f (%)
0:	18	4.2	1.89
30:	17	5.5	12.7
60:	14	6.6	18.16
90:	15	6.4	15.35
120:	17	4.8	9.96
150:	20	4.2	8.29
180:	30	4.4	4.91
210:	20	4.2	5.05
240:	17	4.3	4.01
270:	15	4	7.54
300:	15	4.03	6.92
330:	17	3.53	5.22

Table 3. Ratios between mean wind speed M at the platform (Mplat) and predicted values from VT and VSN and applying the different methods (Mpred). The WAsP predictions have been obtained running the model by first removing all calms from the data set.

Method	M (m/s)	A (m/s)	k	(Mplat/Mpred)
Platform experimental	4.6	5.5	1.28	1.00
WAsP VT 35	5.4	6.1	1.69	0.85
WAsP VT 7	4.1	4.6	1.53	1.12
WAsP VSN	5.1	5.7	1.66	0.90
Weibull Correction VT35	5.1	---	---	0.90
GeoWAsP	5.2	5.6	1.33	0.88
Coastal Discontinuity Model	6.3	---	---	0.73

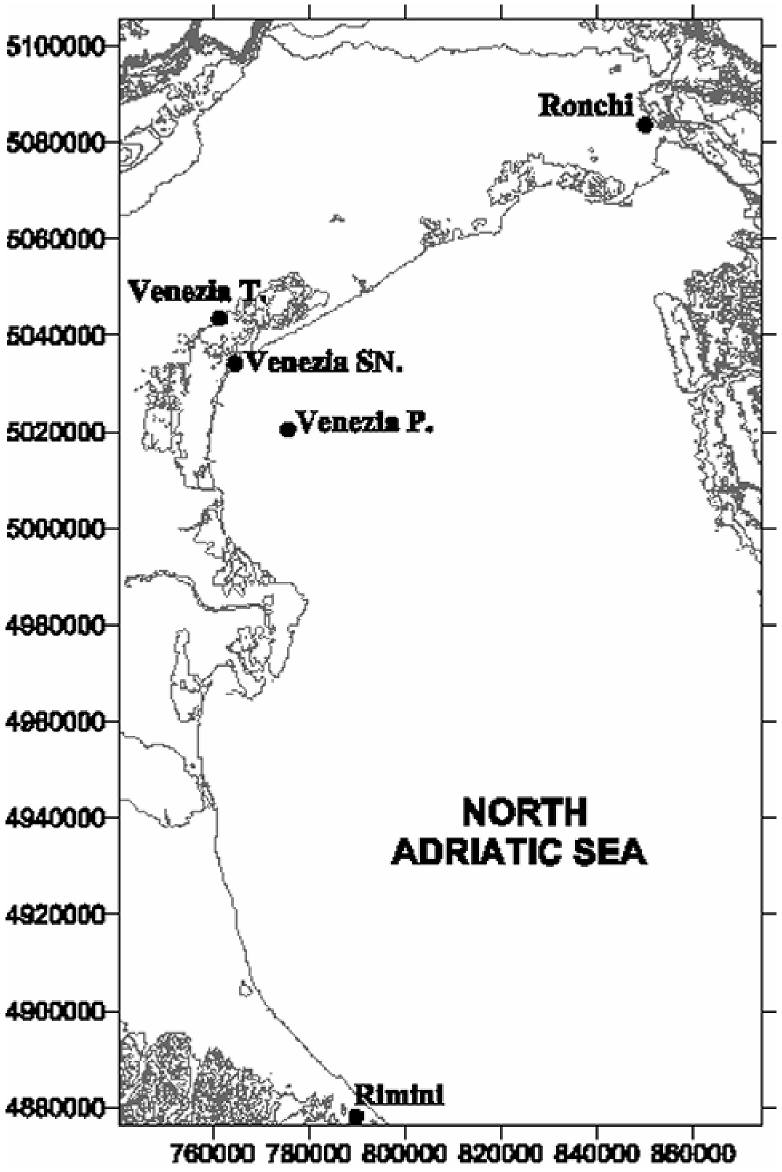

Figure.1. North Adriatic Sea, location of the stations.

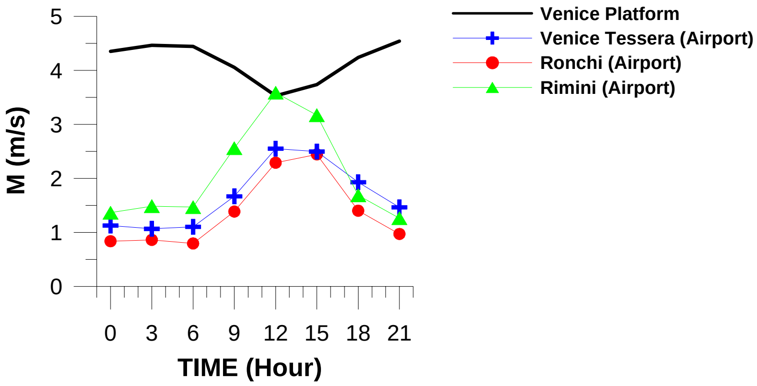

Figure 2a. Mean hourly wind speed.

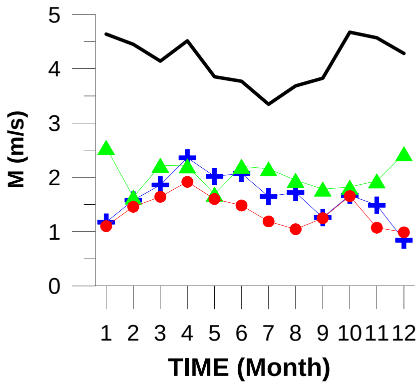

Figure 2b. Mean monthly wind speed

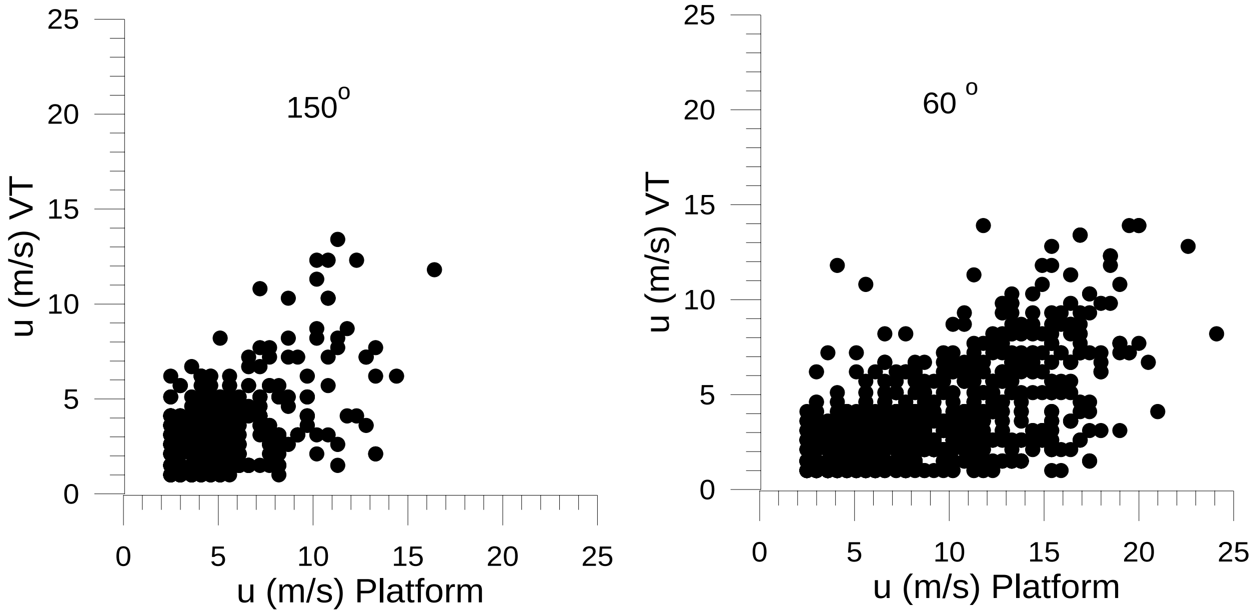

Figure 3. Scatter plot of wind speeds measured at Venice Tessera and Venice platform for wind blowing from 60° (left) and from 150° (right), during seven-year overlapping data.

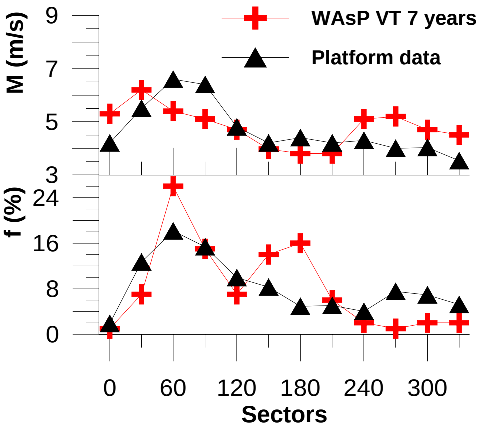

Figure 4. Predicted and experimental wind speed and frequency for each sector using seven years overlapping data from VT.

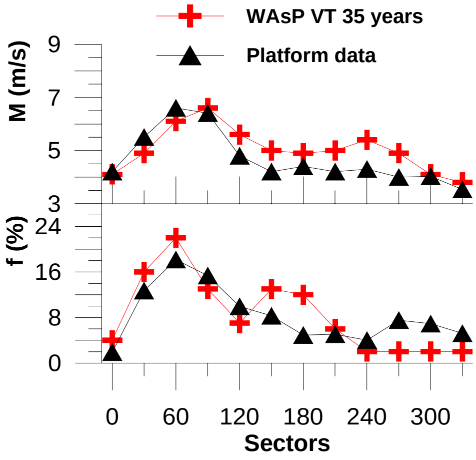

Figure 5. Predicted and experimental wind speed and frequency for each sector, using 35 years data from VT.

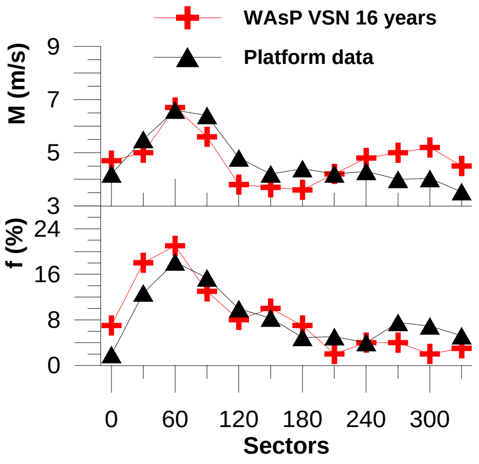

Figure 6. Predicted and experimental wind speed and frequency for each sectors using Venice S.N.

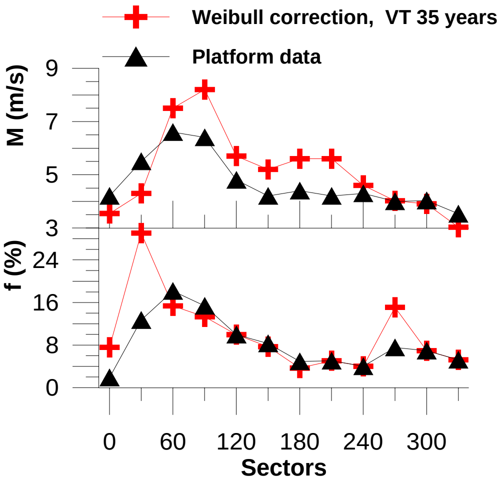

Figure 7. Predicted and experimental wind speed and frequency for each sector, using the Weibull method.

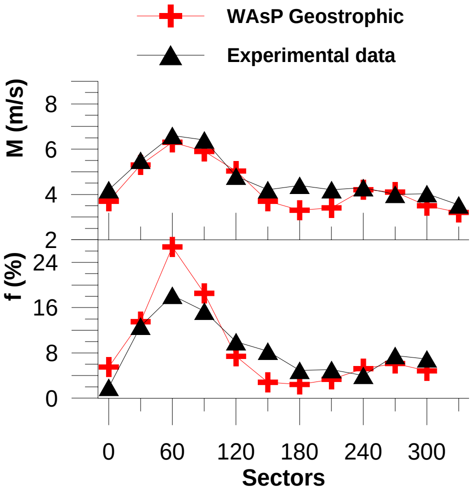

Figure 8. Predicted and experimental wind speed and frequency for each sector, using GeoWAsP

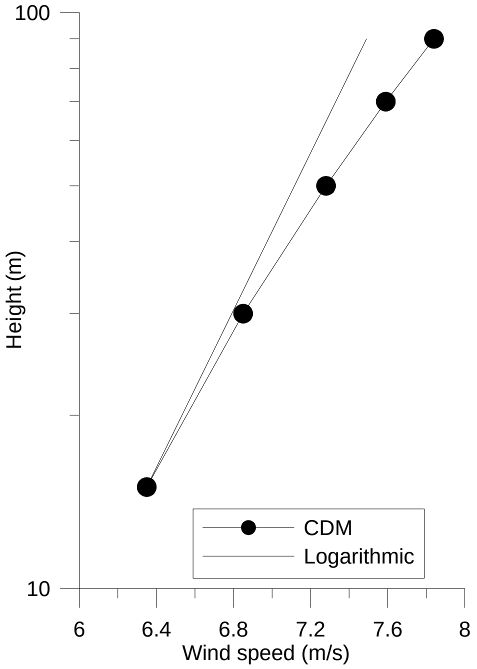

Figure 9. CDM predicted wind speed profile

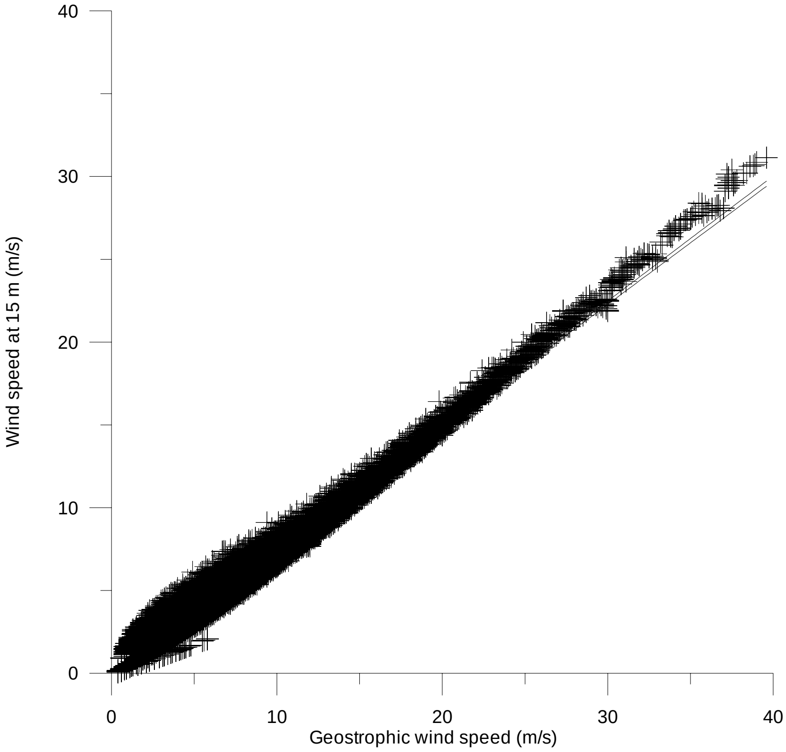

Figure 10. Scatter plot between geostrophic wind speeds and predicted near-surface winds at 15m height at the platform site using the CDM. The two fit lines represent a linear fit and a fit passing through the origin: very little difference amongst the two is found.

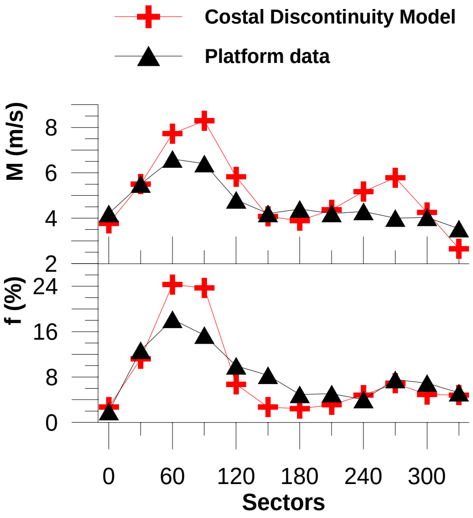

Figure 11. Predicted and experimental wind speed and frequency for each sector, using the CDM model.

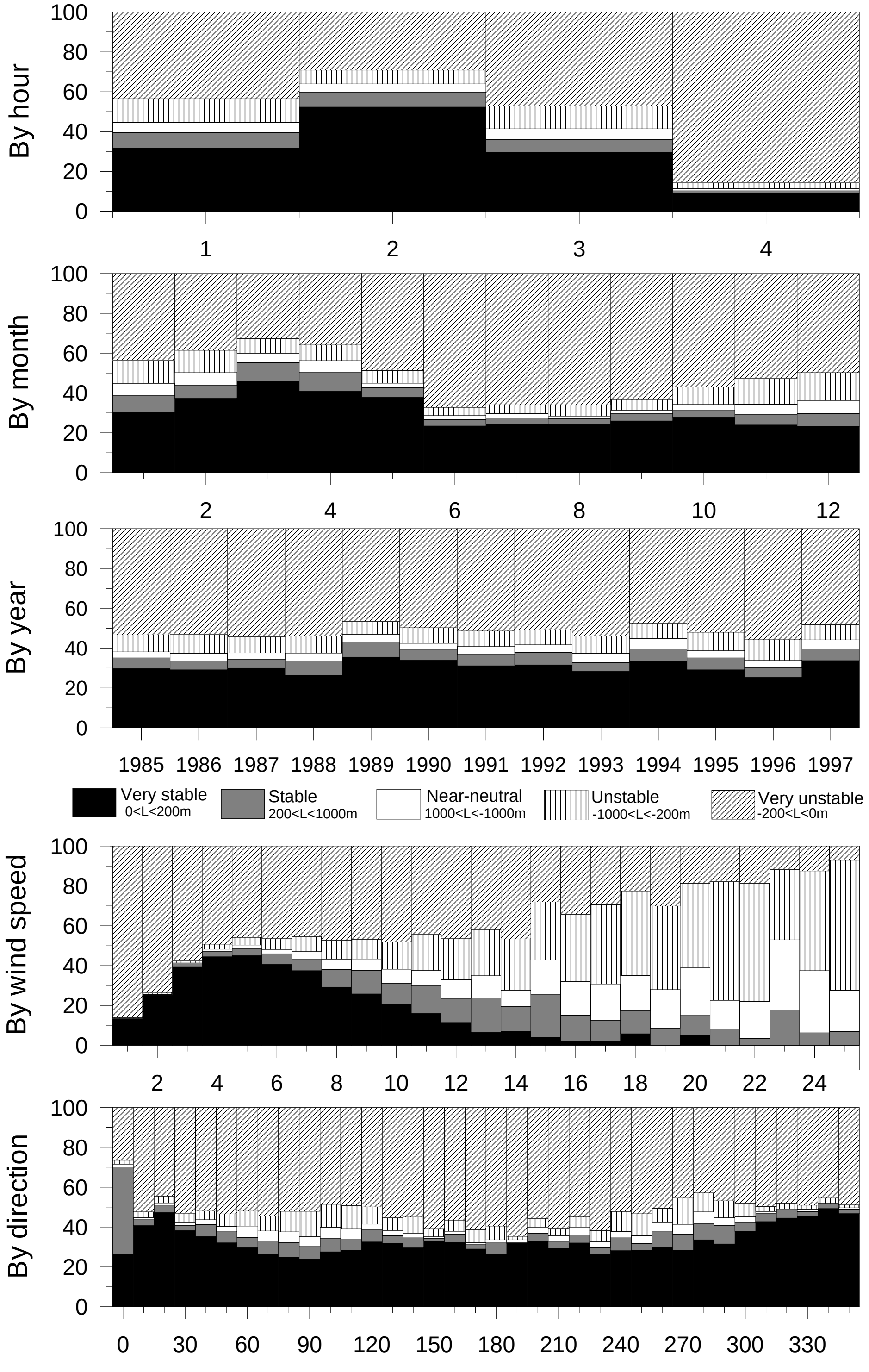

Figure 12. Frequency of different stability conditions by hour, month, wind speed and wind direction.

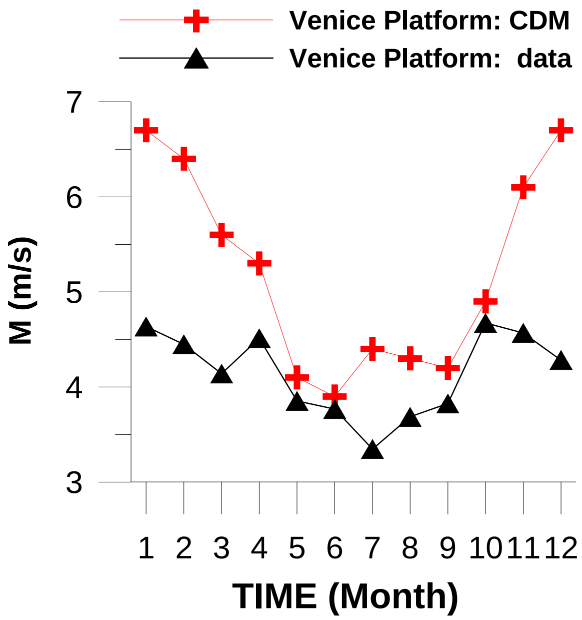

Figure 13. Comparison between monthly mean wind speed from CDM and experimental values.