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A comparison of physical and statistical methods for estimating the wind resource at a site

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SYNOPSIS This paper will attempt to cast some light on the ever ongoing dispute between the followers of physical methods for wind resource estimation such as WA^{s}P (Wind Atlas Analysis and Application Program), and the followers of statistical methods such as Measure-Correlate-Predict (MCP).
It is demonstrated that, for sites in complex terrain with only a few months worth of data, the outcome of the estimate of the wind resource when using MCP is very sensitive to which months and how many the correlation has been calculated for.
It is also shown that WA^{s}P is performing quite well, despite the fact that the assumptions underlying the flow model are violated.

1 INTRODUCTION

When one wants to estimate the wind energy resource at a given potential windfarm site, with no or few measurements, one has to link these measurements to measurements of a long duration from another (near-by) site. The idea behind this being that within a certain distance - given by the local meso-scale conditions - the overall wind climate is the same. To obtain this link, two methods can be used:

1. A physical method, i.e. a method based on a physical model of effects affecting the two sets of measurements.

2. A statistical method, i.e. a method based on statistical correlations between the two time-series.

Here we will make some general statements with respect to the two types of methods. We have chosen to concentrate on one representative of each of the two types of methods: for the physical method WA^{s}P (Mortensen et al, 1993a) is used and Measure-Correlate-Predict (see eg Derrick, 1993) is used for the statistical method. Both these methods are widely used in the wind resource estimation community.

2 GENERAL REMARKS

Since this study is based on a specific set of data from an area with complex terrain we would like to start out with a few general remarks about the two models under discussion, a summary is given in Table 1.

2.1 WA^{s}P (Wind Atlas Analysis and Application Program)

WA^{s}P is a PC-program used all over the world to estimate wind resources. Its major advantage is that it can generalise a long-term meteorological data series (collected at e.g. an airport) to be valid not only at the site where it has been measured, but in an area around the measuring site. The size of this area depends on the gradients in the geostrophic wind (such as eg in northern Europe) and on the local flow regimes (such as eg in southern Europe). The way the generalisation is done is by correcting the data series for effects which only affect the measuring site, but are not of more general nature. These local effects are: shelter from near-by obstacles (as houses, wind breaks etc), the effect of roughness and changes in roughness (e.g. from water to land), and the effect of orography (e.g. speed-up on hill tops).

The major disadvantage is that the program does not (at present) include thermally driven local effects, as see-breezes (caused by the different heating of land and water), ana- and katabatic winds (winds caused by heating and cooling of the surface, respectively). Another disadvantage is that it is not possible, beforehand, to give a solid estimate of the size of the region where the calculated wind climate is valid. Hence one has to base the estimates on prior knowledge obtained from the terrain type one is operating in.

2.2 MCP (Measure Correlate Predict)

MCP can like WA^{S}P be run on almost any PC, and it is used in many places, especially in the UK. The advantage of the method is that one can put up a mast (preferably 30 m high) at the proposed wind turbine site for only a few months, correlate the measured time-series with a near-by long-term time series (measured at e.g. a synoptic station), and then, when the correlation has been established, use the long-term time-series to estimate the wind resource at the proposed site.

The disadvantage is that if the long-term and the on-site time-series do not have a high correlation coefficient then the resulting estimate is not very reliable. Another disadvantage is that the resource is only valid at the location of the on-site mast and at the height of the measurements. So to use this sort of technique at eg a wind farm a program that can calculate the wind resource at different places (as WA^{S}P) must be used anyhow.

3 AN EXAMPLE

As an example of the use of the two methods, data from 10 meteorological masts located in the northernmost part of Portugal will be used. These data have been measured as part of the University of Porto's contribution to the CEC-funded JOULE project "Wind measurement and modelling in complex terrain". A detailed description of the stations and their surroundings, the instrumentation used and the data obtained so far is given by Restivo and Petersen (1993), a map is shown in Figure 1.

For the purpose of this investigation six stations were selected, representing three different degrees of topographical complexity along a 50-km long profile: from the Atlantic coast in the W to the more than 1000-m high mountains of Arada-S. Macário in the

Table 1: An overview of the two methods' pluses and minuses.

WA^{S}P	+	works with no on-site measurements
	+	works at any height
	+	works at any place
	–	may give inexact results in very complex terrain
	–	does not include local thermally driven effects
MCP	+	can generalize a short on-site measured time-series, if a long (climatological) is available
	–	if on-site data are wrong, generalization is wrong
	–	can only predict at the height of the measurements of the on-site mast
Both	–	if long time-series is wrong (or non-representative) on-site resource is wrong

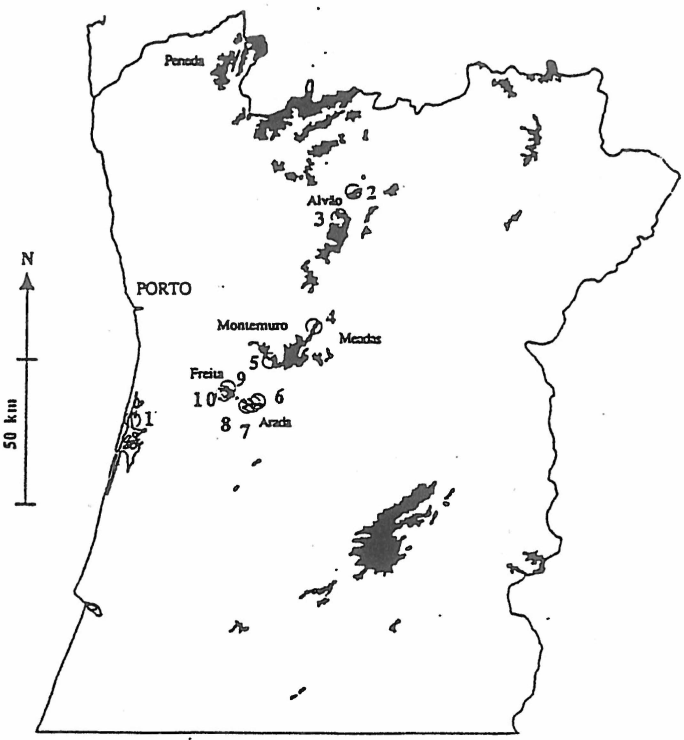

Figure 1: A map of the stations used in this study from Restivo and Petersen, 1993.

E. In the following we will refer to the stations by the numbers 01, 10, 09, 08, 07, and 06 (going from W to E). It must be stressed that in this type of terrain (like the one chosen here) the assumptions behind the flow model in WA^{S}P with regard to the slopes of the terrain involved are severely violated at some of the sites. For the MCP, simple guidelines as to where to use the method do not exist, but it is expected that this case also is very close to the scope of validity of MCP. The purpose of this exercise is thus to see how well the two methods perform in a real case, *in spite* of these violations.

3.1 The data

At each station the wind is measured at 10 m agl. The instrumentation is as follows

- A cup anemometer (Risø 70) measuring 10-minute averages and 3 sec gusts, consecutively. Each anemometer has been individually calibrated.
- A direction sensor (Aanderaa Instruments 2750) giving the 'instantaneous' wind direction.

The data are collected using an Aanderaa Instruments 2990 data storage unit. The measuring period is from June 26th 1991 to July 23rd 1993, ie more than two year's worth of data are available.

3.2 WA^{S}P

The WA^{S}P analysis is much along the lines of the analysis presented in Mortensen et al (1993b); except for the fact that more data are now available. As can be seen from Table 2 - where data from each of the 6 stations have been used to predict the wind climate over a flat grass field at 10 m height - there is more or less the expected agreement between the different predictions (in the case of identical overall wind climates they should all be identical). The reasons why there are the minor differences, especially between stations 6 and 7 and the rest, can be any of the following: 1) The masts are situated in different wind climates, 2) the WA^{S}P-model is not able to simulate properly the flow in the very complex terrain around stations 8, 7 and 6, and/or 3) the maps used in WA^{S}P are not covering an area big enough to include all orography having influence on the flow at the sites. In the following sections we will discuss some of these aspects.

Table 2: Estimated mean wind speeds (ms^{-1}) and mean wind power densities (Wm^{-2}) 10 m a.g.l. over a uniform, flat surface of z_0 = 0.03 m (roughness class 1).

Station	01	10	09	08	07	06
Wind speed	3.7	3.9	3.9	3.8	2.9	3.1
Power density	72	82	83	85	33	39

3.2.1 Inter-predictions

To see whether the masts are situated in different wind climates the data from the stations are used to predict each other, see Table 3 and cf. Mortensen et al (1993b). As can be seen from this table stations 1, 10, 9 and 8 predict each other quite well, but turning to stations 6 and 7 different results are obtained. It is very hard to find an explanation for this, one could be that the two stations, which are located furthest away from the coast, are actually in a different wind climate (eg one dominated by other thermally driven local flows than the rest of the stations). This has the consequence that station 8 which is only 5.6 and 3.2 km away, respectively, from stations 6 and 7 is in the wind climate ranging all the way from the coast and 50 km inland. This means thus, that the wind climates generated by WA^{S}P in this example are valid as far as 50 km away. In some cases, however, the climate is valid out to only 3 km. This stresses the fact that when in complex terrain the WA^{S}P model should be used with utmost care.

Table 3: Measured and estimated mean wind speeds (ms^{-1}) and mean wind power densities (Wm^{-2}) at 10 m a.g.l. for the six stations. The power densities have not been corrected for the influence of different air densities (which is of the order of 10 %).

	01	10	09	08	07	06	Meas.
01	**4.1**	4.2	4.3	4.2	3.2	3.4	4.3
	108	105	120	111	48	53	115
10	5.6	**5.4**	5.5	5.5	4.2	4.5	5.5
	278	**218**	243	262	99	130	215
09	5.6	5.9	**5.8**	5.5	4.2	4.6	5.8
	275	311	**271**	236	125	136	269
08	6.5	6.7	6.4	**5.9**	4.7	5.2	6.0
	511	518	410	**295**	213	225	290
07	6.3	6.9	7.0	6.9	**5.2**	5.4	5.3
	351	499	514	555	**194**	223	195
06	5.3	5.8	5.8	5.6	4.3	**4.5**	4.6
	217	293	281	281	115	**128**	128

3.2.2 Sensitivity to the size of the map

In complex terrain it is very important that all terrain significant to the flow model is present in the maps used as input to WA^{S}P. To see the sensitivity to this, it has been tried to vary the size of the maps from 1×1 km to 8×8 km in steps of 1 km. The result is shown in Figure 2. As can be seen from this figure it is necessary for the maps to cover areas at least 6 × 6 km for the calculations of WA^{S}P to converge. The explanation of why stations 6 and 7 have a much higher decrease (and as a consequence, a higher sensitivity to the area of the map) can also be found in the paper by Mortensen et al (1993b) Table I, where it is seen that the change in 'orographic complexity' (σ_z) is much more rapid for stations 6 and 7.

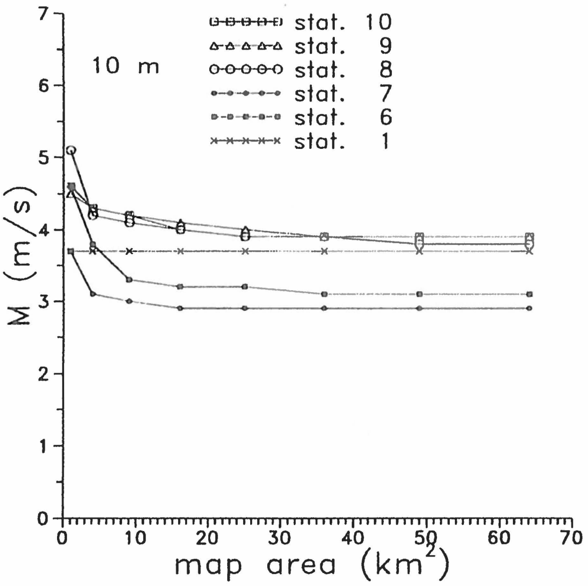

Figure 2: The calculated mean wind, M, at 10 m agl over a flat grass field, cf Table 2, plotted versus the area of the orographic map used in the WA^{S}P program for the 6 selected stations.

3.3 Measure-Correlate-Predict

Several have applied the Measure-Correlate-Predict (MCP) method to the resource estimation problem (see eg Derrick, 1993). Basically what the method does is that it establishes a relation between a short on-site time-series and a long time series eg from a near-by synoptic meteorological station. This relation can then be used to estimate the long-term wind climate at the new site. Normally the relation is taken to be linear, ie

$$u_{\text{on-site}} = a + b u_{\text{long-term}} \tag{1}$$

Sometimes the relation is a simple scaling, ie without an offset ($a = 0$).

To use the MCP method a good correlation between the on-site and the long-term data is cardinal. In the following we will therefore investigate this matter.

3.3.1 Cross-correlations

Studying the 15 possible cross-correlations (assuming westerly flow) between the 6 stations it is found that the general shape of the correlation function is as shown in Figure 3. The correlation function is defined as the cross-correlation between the two time-series with different lags plotted against the lag. The cross-correlation is given by

$$r_{xy}(k) = \frac{c_{xy}(k)}{\sigma_x \sigma_y} \tag{2}$$

where

$$c_{xy}(k) = \frac{1}{N} \sum_{t=1}^{N-k} (x_t - \bar{x})(y_{(t+k)} - \bar{y}) \tag{3}$$

and x_t the value of the time-series at time t, σ_x and σ_y are the standard deviations, $\bar{x}$ and $\bar{y}$ the mean values, and $k (= 0, 1, 2, \ldots, K)$ the lag.

In this study we only consider wind speeds (or rather 10 minute averages) higher than 3 m/s, to exclude the very weak winds with ill-defined directions, since they are often very site-dependent (and therefore uncorrelated) and insignificant for wind energy purposes. The cross-correlations are also calculated with all wind directions in the same bin. Since all the correlation functions generally decrease it is concluded that when calculating the linear regression it is not necessary to take any time-of-flight lag into account. The correlations are shown in Table 4, and as can be seen the correlation between the coastal station (station 01) and the rest of the stations is low, but indicating, none the less, that some correlation exists between the stations. This can most likely be explained by the fact that the distances vary from approx. 40 to 50 km.

3.3.2 The regression

To study the sensitivity of the regression two experiments have been carried out:

1. Each of the stations have in turn been considered as the station with the long term time-series. The data from the other stations have then been used as the on-site data. At each

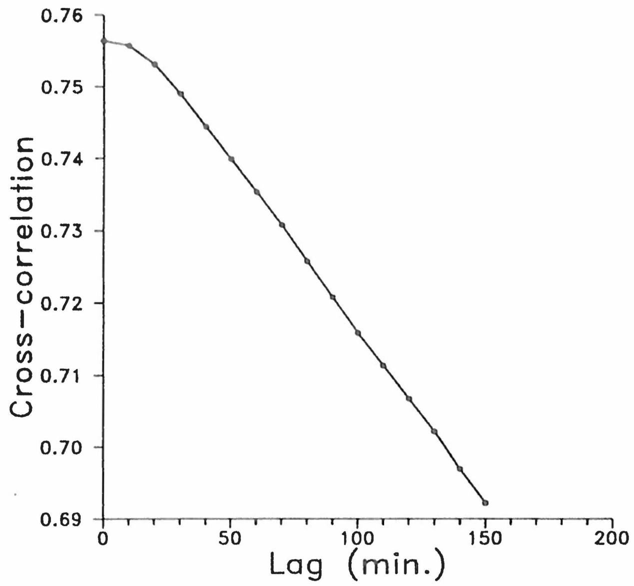

Figure 3: The cross-correlation function for station 10 and 07.

Table 4: The cross-correlations for the selected stations (lag 0 min). The stations are listed from west to east going from left to right.

	01	10	09	08	07	06
01	1.00	0.67	0.63	0.71	0.60	0.56
10		1.00	0.70	0.82	0.76	0.80
09			1.00	0.86	0.87	0.89
08				1.00	0.88	0.91
07					1.00	0.91
06						1.00

of the 'on-site' stations 7 'measurement campaigns' have been carried out, the campaigns lasted for 1, 3, 5, 7, 9, 11 and 12 months, respectively. The idea of this experiment is to see the sensitivity to the length of the measuring period and also the dependence on geographical location.

2. At each of the stations the measuring campaign described under item 1 is shifted in time with step lengths of one month. As an example consider the 3 months measuring campaign. The first 3 months period spans months 1 to 3, the second spans months 2 to 4, the third months 3 to 5 etc. The idea here is to see the annual variation of the result of the regression.

In all the calculations above, the linear regression is calculated sector by sector in 12 sectors.

The results for station 10 (a mountain station) using data from station 01 (the coast station) are shown in Figure 4. A number of conclusions can be drawn from this figure:

1. As the length of the measurement campaign increases the scatter of the MCP estimate is reduced.

2. For a measuring campaign lasting one year the scatter is still ± 0.5 m/s. Note, that in practice, campaigns lasting from 3 to 8 months are used.

3. The actual mean value at station 10 is never reproduced by the method, the method seems to converge to some other value (approx. 5 m/s). This is quite puzzling (and it is found for all the stations), the explanation being that the correlation coefficients are calculated using only winds higher than 3 m/s, which means that if the wind below 3 m/s do not fall on the calculated regression line, differences can be expected. When using all wind speeds in the regression the actual mean (5.5 m/s) is found as the convergence value. This case - contrary to normal procedure - suggests that all wind speeds should be used when calculating the correlation.

For reference, the mean of the predictions, using station 1 as the long-term reference, where the correlation has been calculated over a period of 12 months, are shown in Table 5.

4 DISCUSSION and CONCLUSIONS

This study has shown that both WA^S^P and MCP are able to make useful predictions of the long-term

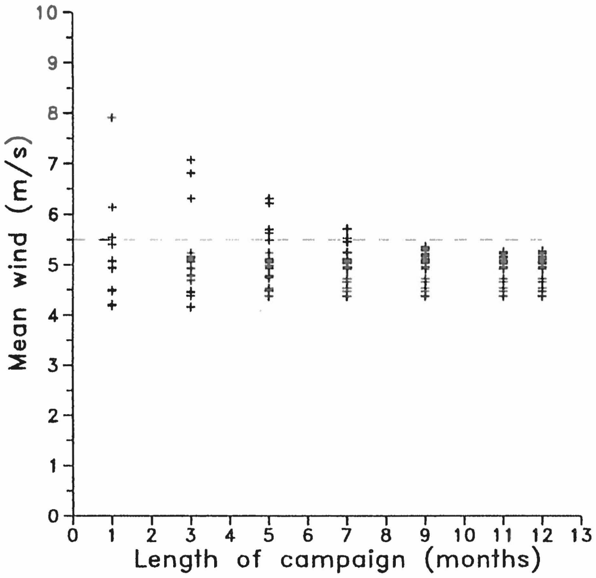

Figure 4: The predicted mean wind (m/s) at 10 m agl for station 10 using station 1 as the long-term reference station plotted against the length of the on-site measurement campaign at station 10. For each of the campaigns several parts of the time-series have been used.

Table 5: The mean wind speed (m/s) and the standard deviation (m/s) of the MCP-predictions using station 1 as the long-term reference for each of the stations, where the correlation has been calculated over a period from 3 to 12 months compared to the measured mean speed.

	10	09	08	07	06
mean, 3 months	5.1	5.6	5.7	4.9	4.2
std. dev. 3 months	0.8	0.7	0.8	0.7	0.7
mean, 5 months	5.0	5.5	5.6	4.9	4.2
std. dev. 5 months	0.6	0.5	0.6	0.5	0.5
mean, 9 months	5.0	5.4	5.5	4.7	4.0
std. dev. 9 months	0.3	0.3	0.3	0.3	0.3
mean, 12 months	5.0	5.4	5.5	4.7	4.0
std. dev. 12 months	0.3	0.3	0.3	0.3	0.3
Measured	5.5	5.8	6.0	5.3	4.6

wind climate at the selected sites in the studied area. The uncertainties for each model can, however, be quite large, especially for MCP. It must be borne in mind that the area under study is quite complex, and most likely dominated by other effects than just the complexity of the terrain. These effects could be thermally driven circulations on the meso- scale, and none of the two methods are able to include this. It is therefore necessary to take other models and concepts into account. The most obvious is to run a meso-scale model such as the KAMM (KArlsruhe university Meso-scale Model). This is now being done at University of Karlsruhe, Germany, in co-operation with Risø National Laboratory, Denmark, in the CEC-sponsored project mentioned in the beginning of this paper. The results of the very preliminary studies are very promising. In these studies KAMM is run with a horizontal resolution of 5 × 5 km^2 for northern Portugal (the area where the stations discussed in this study are located). More firm results from this model are expected in the middle of 1994.

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REFERENCES

Derrick, A, 1993: *Development of the Measure-Correlate-Predict strategy for site assessment.* In proceedings of the European Community Wind Energy Conference, Travemünde, ed AD Garrad, W Palz and S Sheller. p 681-685.

Mortensen, NG, L Landberg, I Troen and EL Petersen, 1993a: *Wind Atlas Analysis and Application Program (WA^{s}P). Vol. 2: User's Guide.* Risø-I-666(EN)(v.2). Risø National Laboratory, Roskilde, Denmark. 133 pp.

Mortensen, NG, EL Petersen and L Landberg, 1993b: *Wind resources, part II: Calculational methods.* In proceedings of the European Community Wind Energy Conference, Travemünde, ed AD Garrad, W Palz and S Sheller. p 611-614.

Restivo, A and EL Petersen, 1993: *Wind measurement and modelling in mountainous regions of Portugal, Preliminary results.* In proceedings of the European Community Wind Energy Conference, Travemünde, ed AD Garrad, W Palz and S Sheller. p 603-606.

Troen, I. and E.L. Petersen (1989). *European Wind Atlas.* ISBN 87–550–1482–8. Risø National Laboratory, Roskilde. 656 p.