**LONG-TERM SCALING OF SITE MEASUREMENTS: EVALUATION OF LONG-TERM METEOROLOGICAL DATA IN FRANCE AND COMPARISON OF CORRELATION METHODS**

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**Summary**

The accurate long-term assessment is of crucial importance in the frame of any wind farm energy yield assessment or assessment of operational data. Experiences show that the expected long term energy output can vary, for the same wind farm and measurement data base, in a range of up to +/- 20% depending on the selected long-term meteorological station and the used correlation procedure.

To provide a well founded basis to perform long term assessments in France, the present study analyses the behaviour of different long term data sources and meteorological stations data in France and investigates the importance of the selection of the correct long term correlation procedure.

In a first part, the study focuses on a set of more than 150 meteorological long-term stations in France. Based on a case study, it is shown that a detailed comparative analysis and evaluation of the data connected to the history of each considered long-term station is a prerequisite in the determination of reliable long-term data sources. In a second step, two different correlation procedures, commonly used for energy yield assessments, are tested and compared on a set of 12 pairs of site and reference measurements in France. The quality of the correlation procedures is assessed and the results demonstrate that uncertainties connected to the choice of the long-term station are significantly higher than the uncertainties connected to the correlation procedures, unless a detailed stability analysis is carried out.

## 1. Introduction

1.1 The long-term correlation scheme

The long-term correlation of site data (based on wind measurements or energy yield data) is one of the main steps to be carried out during the process of any energy yield assessment. Indeed, site data is – in most cases – only available for a relatively short period compared to the lifetime of a wind farm and is therefore not independent from the yearly and seasonal variations. Assessing the long-term energy yield of a wind farm therefore requires extrapolating (with regards to time) the site data measured over the short period to site data representative of the long-term wind conditions.

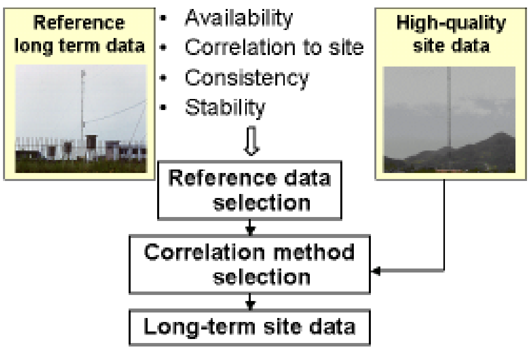



Figure 1: The long-term correlation scheme.

As a consequence, and as shown on Figure 1, this procedure implies:

- To find a reliable long-term data source (at least 10 years, whenever possible) usable as a long-term reference, with a high availability, representative to the site conditions and without inconsistency or any trend over the long-term period.
- To implement a correlation method between the site and the reference data and to determine the relationship between both measurements during the common period and to allow the reconstruction of long-term site data by application of this relationship on the long-term reference data.

In the following, both steps will be considered separately, with a special focus on the available long-term data sources in France.

It is emphasized that assessing accurately the long-term wind conditions of a site also relies on other parameters such as the quality of the (short term) site data. In this context an accurate determination of the long-term wind conditions at the wind farm site can only be performed if the site measurements are of high quality and do fulfil both IEA [1] and IEC 61400-121 [2] recommendations.

1.2 A case study: the difficulty of choosing a long-term data source

Table 1 presents a typical example of the results given by the correlation of 1-year wind measurements at a French site with the closest (in this case seven) long-term meteorological stations, and for different long-term periods (10, 15 and 20 years). These results are presented as scaling factor values e. g. ratio of the predicted long-term wind speed to measured (short-term) wind speed at the site (the procedure that calculates the scaling factor is detailed in section 3.2).

| Ref. stations | LT_A | LT_B | LT_C | LT_D | LT_E | LT_F | LT_G | Scatter (U) |
|---|---|---|---|---|---|---|---|---|
| $R^2$ | 91% | 90% | 94% | 93% | 88% | 89% | 98% | - |
| LT site (10 years) | 107% | 108% | 106% | 106% | 110% | 109% | 104% | 6% |
| LT site (15 years) | 107% | 108% | 107% | 109% | 113% | 111% | 105% | 8% |
| LT site (20 years) | 107% | 109% | 109% | 111% | 114% | 112% | 106% | 9% |
| Distance [kms] | 88 | 69 | 33 | 33 | 52 | 70 | 11 | - |

Table 1: Scaling factors for several reference stations and for different long-term periods.

From this example, which is quite representative of most of the situations encountered for French projects, it can be seen that:

- The scatter on the predicted long-term wind speed is high, from 6% to 9%, depending on the long-term period length.
- The sensitivity of the predicted long-term scatter to the length of long-term period is quite high.

The consequence is, that depending on the chosen long-term meteorological data and on the chosen long-term period, the results in terms of predicted long-term energy yield for this site could differ by up to 20%. This situation – very typical for French and also for most of international projects – clearly shows that a detailed analysis is required for the choice of a reliable long-term data source.

## 2. Long-term meteorological data evaluation

### 2.1 The long-term data sources in France

Depending of the location of the site several long-term data sources are usually available. The most important is composed of the wind speed and wind direction measurements carried out by Météo France all over the country. The network of Météo France [3] meteorological stations is quite dense as shown on Figure 2.

These measurements are carried out at 10 or 12 metres (rarely 30 m) height depending on the pylon type, which means that they are very sensitive to any close surroundings evolution. As well, Météo France is not usually the landowner and there is no administrative constraint around a Météo France mast to prevent from any change of its close surroundings. Therefore, these changes are actually quite frequent. Furthermore, Météo France keeps on trying to achieve the best measurement quality possible, which induces that stations are frequently re-equipped (change of pylon, change of sensors) or relocated.

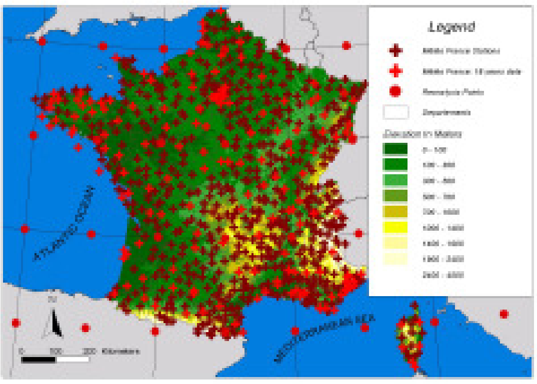



Figure 2: Long-term data sources in France. Red crosses denote the 165 meteorological stations with at least 18 years of existence.

As well, Reanalysis data [4] are available on a grid of 2.5° longitude and latitude spatial resolution (for pressure levels) and 6-hourly temporal resolution. However, using Reanalysis data for the long-term correlation is subject to limitations and should be therefore handled with care (see reference [5] for example).

Other data sources are also available, such as the analysis data from weather forecasting models, but have not been considered in the present study.

### 2.2 Stability assessment of meteorological data

A total of 165 meteorological stations from the Météo France network – those having at least 18 years of existence – have been chosen for a detailed comparative stability assessment. These stations are shown in Figure 2.

For each meteorological station, data have been evaluated in terms of monthly mean wind speed values. A complete testing procedure has been implemented in order to compare the meteorological stations to each other and to evaluate. This procedure investigates the evolution of several parameters over a long-term period such as the relative mean wind speed value, the wind speed standard deviation, the correlation coefficient with the surrounding meteorological stations and the scaling factor, among others. In parallel, the detailed history of the long-term stations has been obtained from Météo France (when available) and compared to the findings derived from the testing procedure implementation. Information from the visits of the meteorological stations performed in the frame of the energy yield assessments carried out in France has also been taken into account.

From this analysis, it appears that the scaling factor evolution can be – at least partly – connected to the history of the meteorological station and can therefore represent a useful tool for selecting a stable long-term data source. On Figure 3 is plotted the evolution of this scaling factor with the long-term period starting year (ending year is 2004) and for the test case presented in section 1.2.

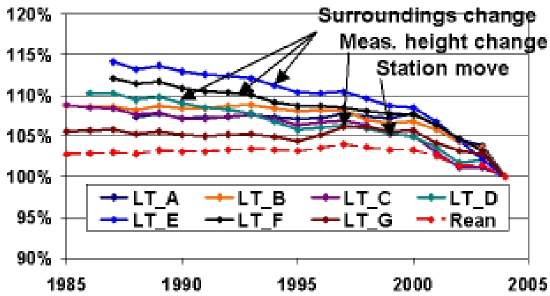



Figure 3: Evolution of the scaling factors deduced from 1-year site measurement data and several meteorological stations (the years in abscises denote the starting year of the long term period – short term period is year 2004).

Filtering out the curves for which distinct trends – induced by changes at the meteorological station surroundings (vegetation growth, buildings…) – or accidents due to major changes such as mast relocation, measurement height or set-up change) yields to the strong reduction of the scatter of the scaling factor evolution, as shown on Figure 4.

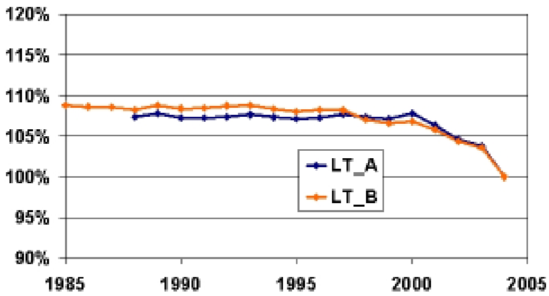


Figure 4: Evolution of the scaling factors deduced from 1-year site measurement data and two meteorological stations without major changes in their history.

In the present case, such an analysis yields to scaling factor values that differ (from one meteorological station to the other) by less than 1% for long-term periods ranging from [1988-2004] to [1999-2004]. It is also shown that for periods longer than 7 years, the scaling factors for each meteorological station differ by less than +/-0.3%. These figures are definitely site-specific but underline the confidence that can be gained in the long-term data source by carrying out a detailed stability analysis.

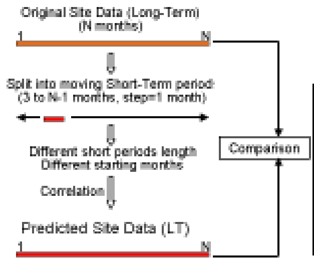
This stability analysis procedure has been carried out for each of the 165 selected meteorological stations shown on Figure 2 taking into account the history of the stations. From this detailed analysis it turns out that only 28 of the considered meteorological stations can be considered as stable over a period of 10 years [1996-2005]. Only 5 to 7 can be considered as stable over an 18-years period. On the other side, the conclusion drawn from Figure 4 regarding the minimum long-term period length to be considered is confirmed: indeed, depending on the wind regime, 7 to 9 years seem to be enough to reach a scaling factor that can be considered as representative of the long-term level.

As a conclusion, only very few meteorological stations can be considered as usable for long-term correlation purposes. If such a stability analysis is not carried out, the risk to misestimate the expected long-term energy yield significantly (by up to 20%) is quite high.

## 3. Comparison of long-term correlation methods

### 3.1 Introduction

In the following sections, two correlation procedures have been applied on 12 pairs of site and reference data, for which two to four years of measurements were available. The aim is first to evaluate the accuracy of a correlation method based on monthly mean values (see section 3.2) and to compare it to a more sophisticated correlation procedure. As well, the evaluation of the errors introduced by both correlation methods will be compared to the error caused by the selection of a non-stable meteorological station.




| $R^2$ | Sites Number |
|---|---|
| 40% - 50% | 1 |
| 50% - 60% | 0 |
| 60% - 70% | 1 |
| 70% - 80% | 4 |
| 80% - 90% | 1 |
| 90% - 100% | 5 |

Figure 5: Correlation methods testing procedure (left) and correlation coefficients of site pairs (right) over the full common period

For each pair of site and reference data, original data (from 2 to 4 years, considered here as the long-term period) have been split into shorter periods, whose starting months moves within the long-term period. A total of approximately 5300 test cases have been thus created. For short periods of 3 months, the number of test cases is 340 and decreases almost linearly to 90 for periods of 24 months. In terms of correlation quality, the correlation coefficients ($R^2$) on the monthly wind speed values range from 46% (very low) to 98% (very high), but the number of sites with very high correlation quality is predominant, as shown on Figure 5.

### 3.2 The monthly mean values approach

This correlation method is based on the monthly mean values of the wind speeds at both site and reference measurement masts. From the comparison between the respective wind speed values during the common period, a linear transfer function is derived, as shown on Figure 6.

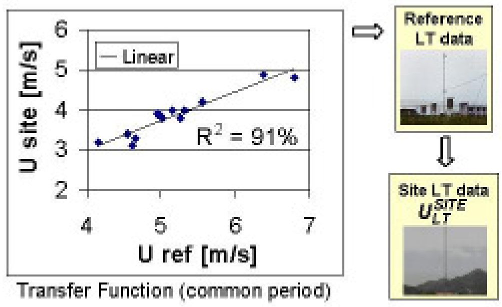


Figure 6: The monthly mean values approach

This linear function is then applied on the reference long-term data to reconstruct long-term site data. From the ratio of the reconstructed long-term mean wind speed at the site to the measured site wind speed (common period), a scaling factor is deduced and applied on the measured wind speed distribution at the site to "scale" the measured wind speeds to the expected long-term level. This method has the main drawback not to correlate the wind direction distribution and to require high data availability.

### 3.3 The MCP-correlation method

The MCP-correlation method as used in the present study is an adaptation of the method presented in [6]. Its main characteristics are that the correlation applies on time series and creates long-term time series of the site data (both wind speeds and wind direction are correlated) and that it is optimised to meet the energy content of the wind speed distribution at the site. This method has manually adjustable parameters for the fitting strategy that have not been optimised here. As well, its accuracy is reduced due to the low resolution of the wind speed data (1 m/s for Météo France data usually).

### 3.4 Main findings

The predicted wind speed distributions have been transformed into energy yield values by the use of a standard power curve and then compared to the energy yield values given by the original site data. Figure 7 shows the results of this comparison.

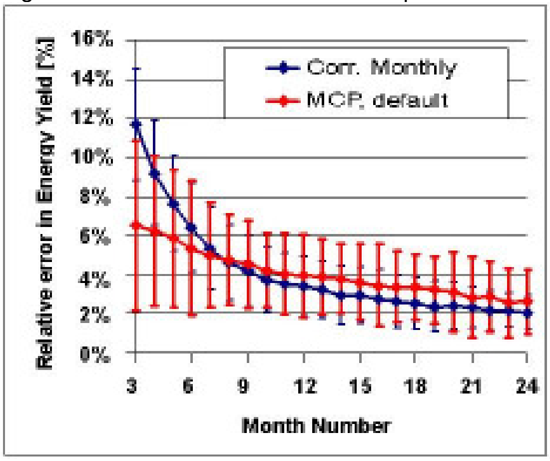



Figure 7: Mean errors and standard deviations on the predicted energy yield for both correlation methods with varying common period lengths

For one year of site measurements, errors on the energy yield are in the range of 4% +/- 2% for the MCP method and are a bit lower (3.4% +/-1.2%) for the monthly mean values approach. Both methods could lead to errors, which are much lower than the errors occurring by a wrong choice of the long-term data source, as seen in section 1.2.

As well, for short measurement periods, the MCP approach has definitely to be preferred since it reduces the uncertainty significantly. The possible errors are very much dependent on the correlation quality between the wind farm site and the reference site, as well as on the atmospheric temperature stratification, as shown on Figure 8. In this figure it is clearly shown that the prediction error is season-dependent. These seasonal variations of the prediction error are actually connected to the seasonal variations of the wind profile, due to the change of the stability: in winters, when the temperature stratification is mostly stable, the wind gradients are high; basing the transfer functions on winter months therefore induces an overestimation of the wind speeds and as a consequence of the predicted energy yields. This error is lower than 2% for common periods of 11 months or more.

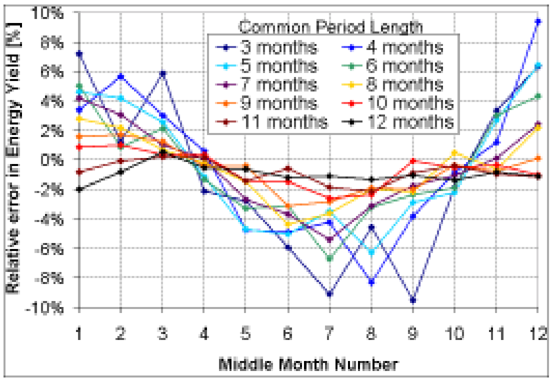



Figure 8: Error on the predicted energy yield for different common period lengths and for varying middle month of the common period.

## 4. Conclusions

The results presented in section 3.4 have to be considered as site-specific and cannot be applied as default uncertainty values of the regarded correlation methods. However, they represent a validation of the use of the monthly mean values approach and highlight that the energy yield prediction error due to the correlation methods is here much lower (within the range 2%-6% for more than one year correlation period) than the error induced by a wrong choice of the long-term data source, as shown in section 1.2.

To draw a conclusion, the detailed stability analysis of any meteorological station selected for the long-term correlation of site data is strictly required and represents the cornerstone of the long-term correlation procedure.

## 5. References


[1] IEA: IEA Recommendation 11: Wind Speed Measurement and Use of Cup Anemometry, 1st Ed., 1999.

[2] International Electrotechnical Commission (IEC): IEC61400-12-1 Wind turbines - Part 12-1: Power performance measurements of electricity producing wind turbines, 1st ed., 12/2005.

[3] www.meteofrance.com

[4] NOAA-CIRES Climate Diagnostics Center: NCEP Reanalysis data, Boulder, Colorado, USA, available at the Web site at http://www.cdc.noaa.gov/.

[5] M. C. Bower: The use of Reanalysis data in MCP. EWEC 2006 Proceedings, Athens.

[6] V. Riedel, M. Strack, H.P. Waldl: Robust Approximation of functional Relationships between Meteorological Data: Alternative Measure-Correlate-Predict Algorithms. EWEC 2001 Proceedings, Copenhagen.