

# **Is a Non-linear MCP method a useful tool for North American wind regimes?**

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## **2.0 Introduction**

The goal of a Measure-Correlate-and-Predict (MCP) approach is to produce an accurate prediction of the long-term average wind speed and the wind speed distribution at a given site. This typically involves using long-term measurements at a reference station and correlating them with short-term measurements at a site mast. However in most cases, due to the large relative distances between site mast and reference stations, it is not possible to obtain suitable correlation on a measured record by record basis and often only monthly averages are used.

Given the area covered by a large wind project and complex terrain issues, inter-site mast correlations are playing a much larger role in assessing the long-term wind regime across a project site. The relatively short distances between site masts can allow for detailed record by record correlations which are typically binned by direction. In this situation, it is also advantageous to synthesize a time series from the correlation to extend or augment the measurements at a site mast location. The correlation methods most commonly used for MCP approaches are linear. Although not routinely used, some non-linear approaches have been developed.

This paper compares 6 correlation methods suitable for synthesizing data between site masts using a North-American dataset of 100 pairs of inter-site wind speed correlations.

## **2.1 Linear methods**

By far the most common wind speed correlation method used in the wind industry is linear regression which fits a straight line to the data ( $y = mx+b$ ); where  $y$  is the predicted site wind speed,  $x$  is the reference wind speed, and  $m$  and  $b$  are the slope and offset, respectively. Typically a low wind speed cut-off (e.g. greater than 3 m/s) is also used to avoid representing the scatter from low non-energy producing winds.

When correlation is done from a reference station to a site mast, lower resolution in the reference wind speed data significantly limits the accuracy of the measurements. In this case, applying a standard least square fitting which fixes the independent  $x$  variable and minimizes the vertical distance to the fit as illustrated in Figure 1 is preferred. For inter-site mast correlations however, both the  $x$  and  $y$  variables should be considered as independent having the same level of measurement accuracy. To achieve an equal weighting in both  $x$  and  $y$ , the Method of Moments (MoM) approach minimizes the perpendicular distance to the fit as illustrated in Figure 1.

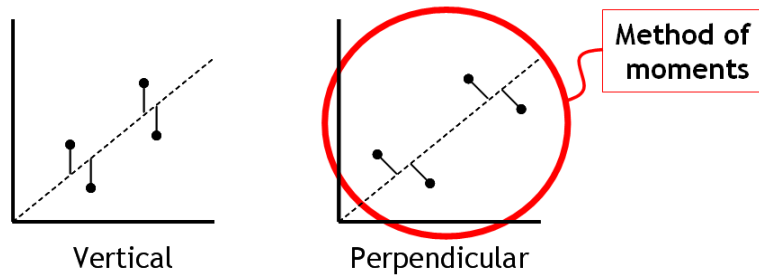


Figure 1: Linear regression optimization

For both of these least-squared approaches, linear fit can be derived with offset,  $b$ , or fitted through the origin.

Variance Ratio (VR) method is an alternative linear correlation method that ensures that the mean and variance of the predictions remain identical to that of the observed data. The variance ratio method defines the slope,  $m$ , as the ratio the standard deviations of each variable,  $\sigma_x$  and  $\sigma_y$ , as  $m = \left( \frac{\sigma_y}{\sigma_x} \right)$  and the offset as  $b = \bar{y} - m\bar{x}$  where  $\bar{x}$  and  $\bar{y}$  are the means of each variable. It has been shown by *Rogers et al* [1] that the variance ratio model produces improved results over linear regression when undertaking wind speed prediction.

## 2.2 Non-Linear methods

Although linear correlation methods generally can provide good predictions in most cases, non-linear trends in wind speed correlations can be resolved using a nonlinear approach. A non-linear relationship between wind speeds is due to several causes including diurnal variation atmospheric stability, measurement elevation differences, complex terrain, and competing meteorological drivers.

One such method is a matrix mapping technique which has been originally developed by *Anderson et al* [2]. Matrix mapping divides the wind speed plot into bins in both the  $x$  and  $y$  axes producing a grid, shown in Figure 2. Each bin or cell in the grid corresponds to one entry in a matrix mapping the frequency distribution. As there is no approximation, the matrix method is a binned representation of the measured wind distribution relationship. While this method can be quite useful for mapping frequency distributions from the reference to the site, a matrix mapping method cannot effectively be applied for synthesizing data between site masts without a random  $y$  variable selection from the binned frequency distribution. Given this additional complexity, the matrix mapping method has not been considered in this study.

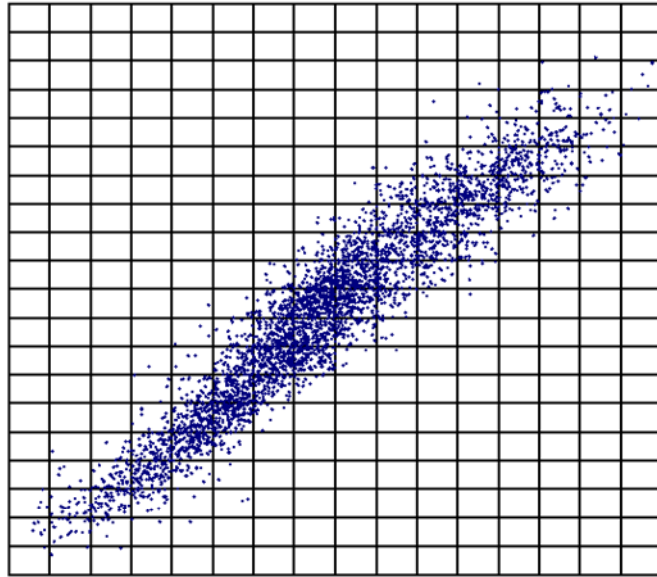


Figure 2: Matrix method bins

Inspired by the matrix mapping approach, two non-linear methods which allow for wind speed synthesis have been developed: Vertical Slice and Non-Linear Method of Moments.

For the Vertical Slice method, the wind speed domain is split into vertical bands or slices and a piecewise linear fit is derived from the  $y$  variable mean of each slice. An example of this is provided in Figure 3. If the data count in a given bin is too low to resolve a  $y$  mean, the fit is determined using a standard linear regression.

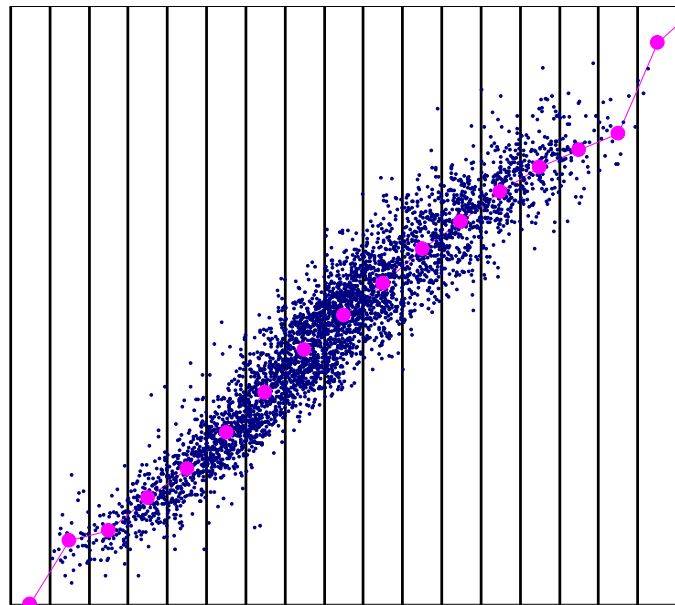


Figure 3: Vertical Slice method with bins and resulting piecewise linear fit

The second development method, Non-Linear Method of Moments (NL-MoM), is similar to the Vertical Slice method in that NL-MoM also divides the wind speed plot into bands or slices. However, the slices are set perpendicular to a MoM linear fit of the data as shown in Figure 4. The fit point at each bin is calculated by transforming the  $(x,y)$  coordinates to  $(l,d)$  coordinates, where  $l$  runs along the MoM linear fit (Figure 5). If the data count in a given bin is too low to resolve a representative  $d$  mean, the fit is determined using the MoM results.

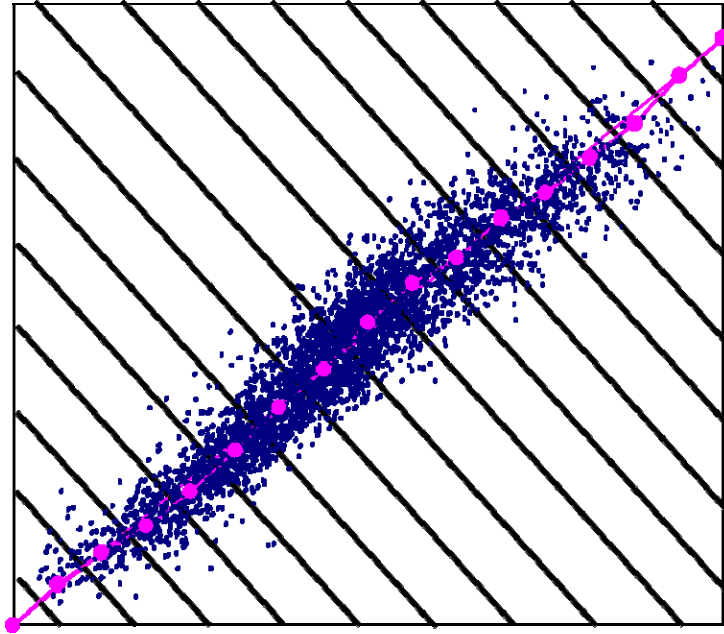


Figure 4: NL-MoM method with bins and resulting piecewise linear fit

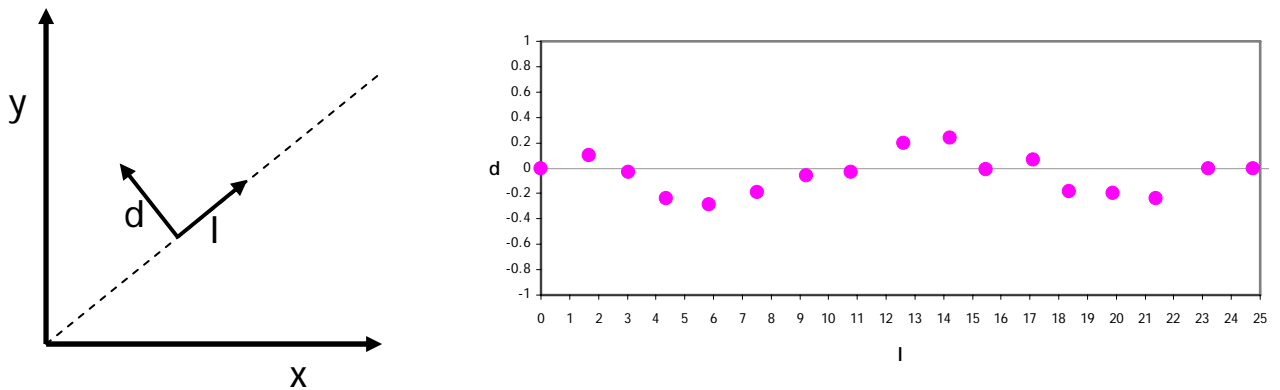


Figure 5: Transforming to  $(l,d)$  coordinates

### 3.0 Method Comparison

A comparison of linear and non-linear methods has been done using a North American regional database. The cases used to compare the methods come from a database containing site wind data from 100 sites in USA and Canada. The case distribution of site regions spans a large portion of North America as shown in Figure 6.

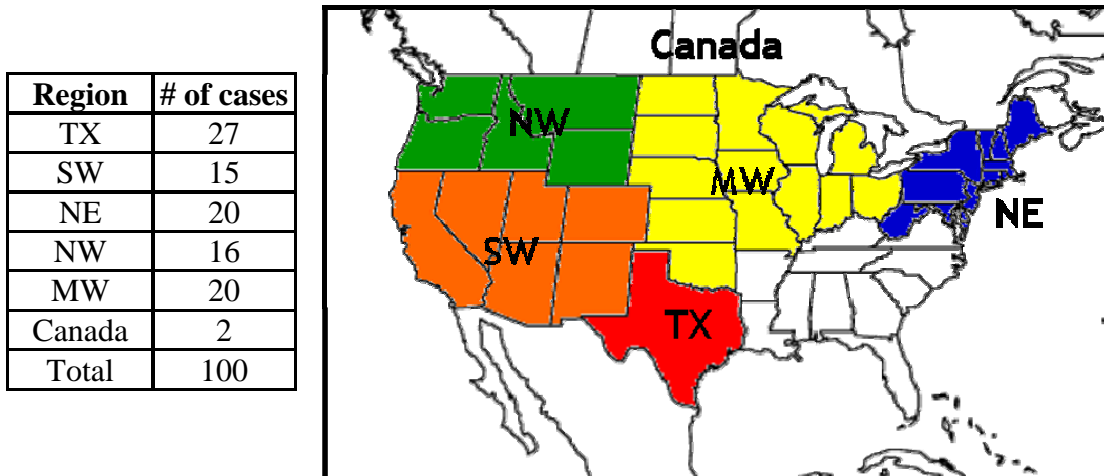


Figure 6: Regions represented in the North American database

Each of these cases is composed of a pairing of site masts with a 10-minute wind speed correlation of  $R^2 > 0.9$ . The overlapping data for both masts are divided in 2 equal parts. The first half of the data from one mast is correlated to the second mast for each 30 degree direction sector. The resulting fits by direction are used to produce a synthesized prediction for the second half. These predictions are compared using the mean absolute error in wind speed and the absolute difference in wind speed frequency distribution. A generic turbine power curve is also used to determine the resulting wind speed frequency distributions to compare the correlation methods in terms of absolute difference and bias in energy.

The results have been divided into two categories – correlation derived from overlapping data sets shorter than 6 months (45 cases), and longer than 6 months (55 cases) – and are shown in Figures 7 through 10.

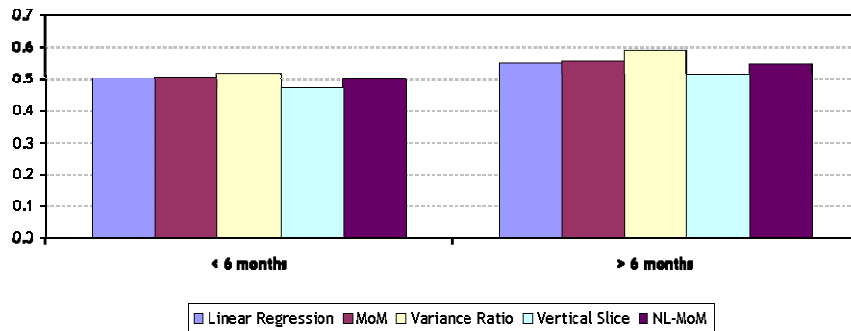


Figure 7: Record by record mean absolute wind speed error comparison

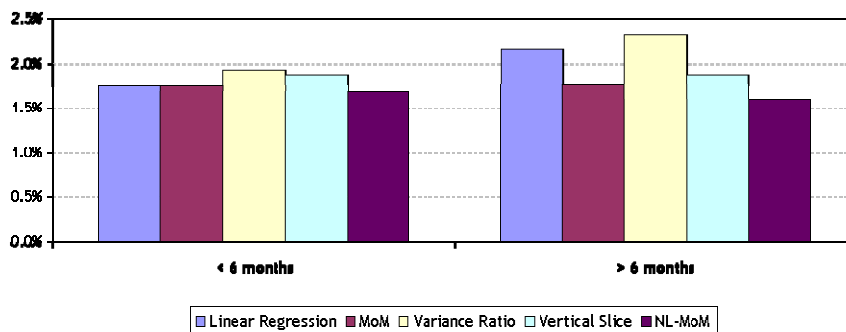


Figure 8: Record by record mean absolute wind speed difference comparison

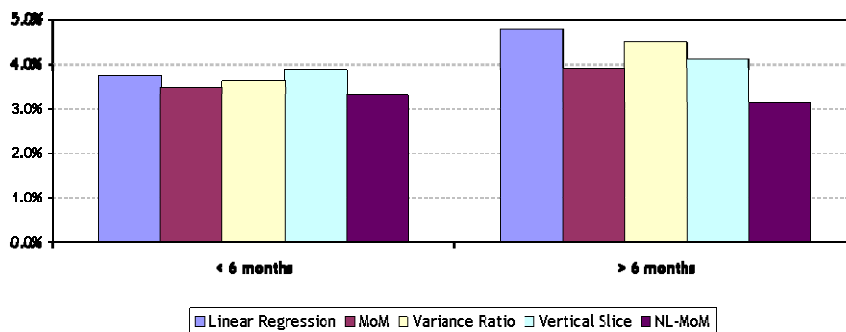


Figure 9: Record by record mean absolute energy difference comparison

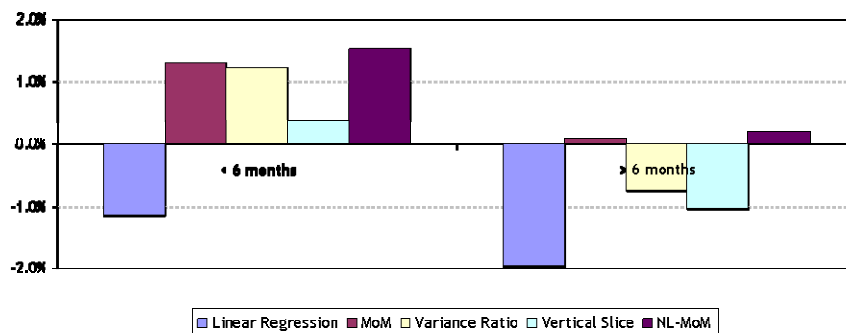


Figure 10: Energy bias comparison

Graphically comparing the wind speed absolute differences for all cases, shown in Figure 10, illustrates that there is strong dependence with increasing data points.

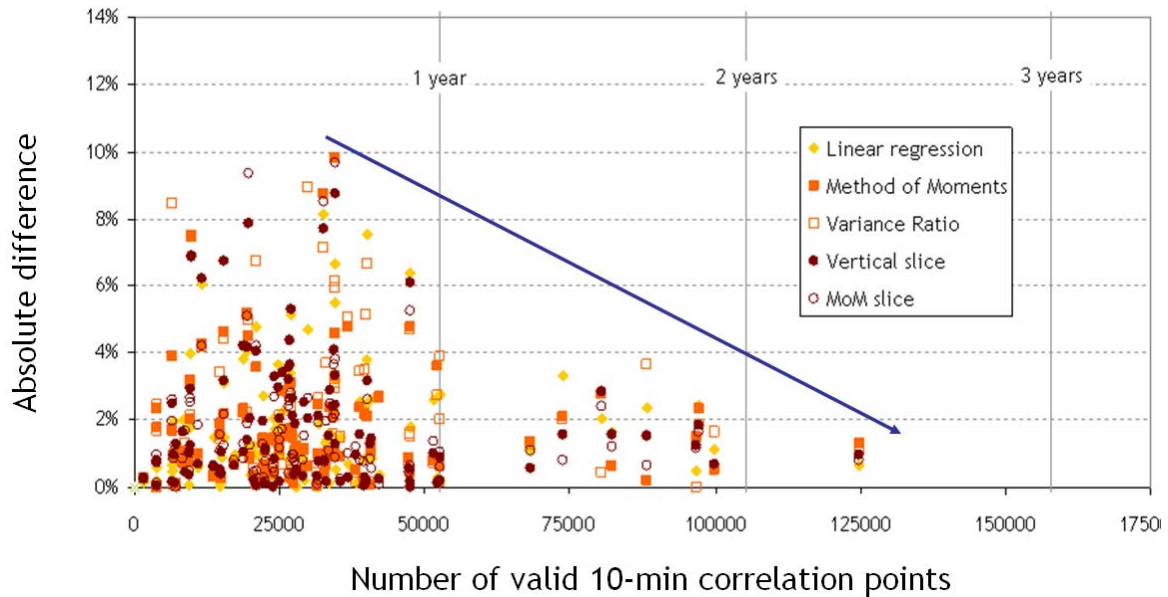


Figure 10: Variation of absolute wind speed difference with number of data points

## 5.0 Conclusions

Two newly developed non-linear correlation methods have been compared to common correlation techniques as applied to a North American database of inter-site mast cases to investigate the usefulness of a non-linear correlation approach to MCP.

The linear methods perform well for the cases examined and comparing all methods using the shorter term data sets (<6 months), only relatively small differences are found. For the database of test cases Non-Linear MoM shows the best overall results. Therefore, a non-linear method may well be a more useful tool than a linear MCP technique and certainly warrant further investigation.

In considering the various correlation methods on 100 test cases, there is a distinct relationship between the accuracy and the length of the measurement campaign. While some individual cases for a given method may show low levels of error for less than 1 year of data, the overall results clearly indicate the importance of having one year or more of measured on-site data in a measurement campaign to minimize correlation risks to a project.

## 6.0 References

[1] L. Rogers, J. W. Rogers, J. F. Manwell, "Comparison of the Performance of Four Measure-Correlate-Predict Algorithms", *Journal of Wind Engineering and Industrial Aerodynamics*, 93, No. 3, pp. 243-264, March 2005.

[2] M. Anderson, J. Bass, "A review of MCP Techniques", *Renewable Energy Systems Ltd*, Report No. 01327R00022, Issue No.3, 1 December 2004.