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Data efficient measure-correlate-predict approaches to wind resource assessment for small-scale wind energy

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ABSTRACT

The feasibility of predicting the long-term wind resource at 22 UK sites using a measure-correlate-predict (MCP) approach based on just three months onsite wind speed measurements has been investigated. Three regression based techniques were compared in terms of their ability to predict the wind resource at a target site based on measurements at a nearby reference site. The accuracy of the predicted parameters of mean wind speed, mean wind power density, standard deviation of wind speeds and the Weibull shape factor was assessed, and their associated error distributions were investigated, using long-term measurements recorded over a period of 10 years. For each site, 120 wind resource predictions covering the entire data period were obtained using a sliding window approach to account for inter-annual and seasonal variations. Both the magnitude and sign of the prediction errors were found to be strongly dependent on the season used for onsite measurements. Averaged across 22 sites and all seasons, the best performing MCP approach resulted in mean absolute and percentage errors in the mean wind speed of 0.21 ms^{-1} and 4.8% respectively, and in the mean wind power density of 11 Wm^{-2} and 14%. The average errors were reduced to 3.6% in the mean wind speed and 10% in the mean wind power density when using the optimum season for onsite wind measurements. These values were shown to be a large improvement on the predictions obtained using an established semi-empirical model based on boundary layer scaling. The results indicate that the MCP approaches applied to very short onsite measurement periods have the potential to be a valuable addition to the wind resource assessment toolkit for small-scale wind developers.

1. Introduction

Small-scale wind energy (typically defined as <50 kW [1]) is achieving increasing interest as individuals, organisations and governments seek to decarbonize electricity supply [2]. The UK, which has put in place a legally binding commitment to reduce carbon equivalent emissions in 2050 by 80% compared to 1990 levels [3], is particularly well placed to capitalize on small-scale wind energy as a decentralized, well-established renewable energy technology due to its favourable wind resource and growing expertise in the industry. These factors, along with the introduction of a feed-in-tariff in 2010 which pays a fixed tariff for every kWh of electricity generated from small-scale installations, have resulted in significant growth in the UK small-scale wind energy industry with installed capacity projected to reach 1.3 GW by 2020 [4].

However, in order for small-scale wind energy to reach its full potential, tools capable of predicting the wind energy resource quickly, cheaply and accurately are urgently required [5]. Such tools will allow consumers to make informed decisions regarding the financial viability of a proposed installation as well as the carbon savings that may be achieved.

Thanks to decades of development, wind resource assessment is well established in the large-scale wind industry. To account for the spatial and temporal variability inherent in wind flows, wind speed and direction are monitored at a number of locations across a potential site to establish the statistical characteristics of the wind resource. These data are used in conjunction with wind turbine power curves to predict the long-term wind energy resource at the proposed site. Data collected over 1–3 years [6] along with longer-term correlations to reference sites are typically required to obtain statistics which are robust enough to justify the large financial

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investments involved in such projects. However, in the small-scale wind industry, where investment costs are considerably lower, onsite measurement campaigns on these timescales are often impractical and prohibitively expensive, necessitating the use of indirect methods.

Indirect approaches may be broadly categorized as modelling or data-driven. Any indirect approach must be capable of estimating the long-term average hub-height wind speed and the form of the wind speed distribution as a minimum requirement to predicting the wind energy resource. Building on previous work related to boundary layer meteorology and descriptors of surface roughness, the UK Met Office developed a promising modelling methodology which may be used to estimate the mean wind speed at any UK site without the need for onsite measurements [7]. However, despite the utility of such techniques in identifying potential wind energy locations, the uncertainties present in simple boundary layer scaling approaches may not be tolerable where significant investments are to be made [8]. The UK Met Office are currently developing more sophisticated modelling approaches based on long-term historical weather forecasts which may result in reduced uncertainties [9]. However, since uncertainties increase with site complexity [10], onsite wind measurements may still be required to achieve predictions with a sufficient level of confidence.

In contrast to modelling techniques, data-driven approaches to small-scale wind resource assessment have received relatively little attention. This work is concerned with one such data-driven approach known as measure-correlate-predict (MCP). MCP increases the value of short-term wind speed measurements recorded at a target site by correlating these with concurrent data recorded at a reference site. The correlation is then used to predict the long-term wind resource at the target site using long-term historical data from the reference site [11]. Since long-term wind speed records are routinely held by airports and national weather forecasters, this technique provides a means of reducing the onsite measurement time required at the target site. MCP is already utilized in the large-scale wind industry where the relationship between the reference and target sites is typically estimated from a concurrent measurement period covering a year or more [12]. A number of studies have considered the application of different regression techniques to the MCP approach [13–15] but very little work has been done regarding the application of MCP to measurement periods of much less than one year [16]. While long-term onsite measurements are clearly desirable in reducing uncertainty, the focus of this work is to establish the feasibility of applying MCP approaches to measurement periods of much less than one year. The aim of this is to determine whether data-driven resource assessment can be made more accessible to the small-scale wind industry. In practice, the short-term onsite measurements required for MCP could be obtained using a portable meteorological mast or LiDAR (light detection and ranging) equipment.

In this study, we constrain the onsite measurement period to just three months which is a more practically and economically viable time period in the case of small-scale wind installations. We compare the performance of three MCP techniques, simple linear regression (LR), linear regression augmented by a Gaussian scatter term (LR2) and variance ratio regression (VR). The success of the techniques in predicting the long-term wind resource at 22 UK sites located in a variety of terrains is assessed through comparison with onsite measurements recorded over a period of 10 years. The three month training period is applied throughout the whole data record using a sliding window technique to account for inter-annual and seasonal variability. Metrics are applied to quantitatively assess the average errors in the predicted mean wind speed, mean wind power density, standard deviation of wind speeds and Weibull shape factor.

2. Methodology

2.1. Measure-correlate-predict

The MCP strategy involves three stages: (I) measurement of wind speeds at a proposed installation site (the target site), (II) identifying a correlation between the target site and concurrent measurements at a local long-term reference site such as an airport or meteorological station and (III) predicting the long-term wind resource at the target site using long-term historical data from the reference site.

Typically, a simple correlation is sought whereby the long-term historical reference data may be used to construct a time-series of wind speeds (and possibly wind directions) at the target site. From this time-series, statistical descriptors may be extracted which represent the long-term target site wind resource. In the case of the large-scale wind industry, onsite measurements at the target site covering a year or more may be extrapolated to several decades to predict the likely energy output over the lifetime of the installation. The main purpose of such a process is to take account of inter-annual variation in the wind resource. In the scheme proposed in this study, the analysis is based on just three months onsite measurements and thus a larger burden is placed on the MCP process since it must account for both inter-annual and inter-seasonal variations and it must achieve this using a much reduced data set.

The majority of MCP techniques involve the use of a parametric linear relationship between target and reference site wind speeds [11], although a number of alternatives have also been proposed [15,17,18] with variable results. In this work we have used two established regression based MCP techniques, LR and VR, and a third technique LR2, which employs a Gaussian scatter term in an attempt to improve the predictions of the wind speed distribution compared to simple linear regression. The 10 year wind resource at the target site was estimated using just three months concurrent measurements at the reference and target sites (the training data), and a further 10 years historical measurements at the reference site. In order to account for both seasonal and inter-annual variability, as well as to produce robust error statistics, multiple three month training periods were selected from the 11 year data record using a sliding window technique. The approach is shown schematically in Fig. 1 and can be summarized as follows:

(I) A training window spanning a full year is first defined and this is shifted in steps of one month throughout the 11 year reference and target site data records resulting in a total of 120 steps. The remaining data not covered by the training window is designated as the test data and covers a combined period of 10 years.
(II) At each step, a three month training period at the start of the training window is used to extract the regression parameters for the MCP approaches of LR, LR2 and VR. This represents the short-term onsite measurement period proposed in this study.

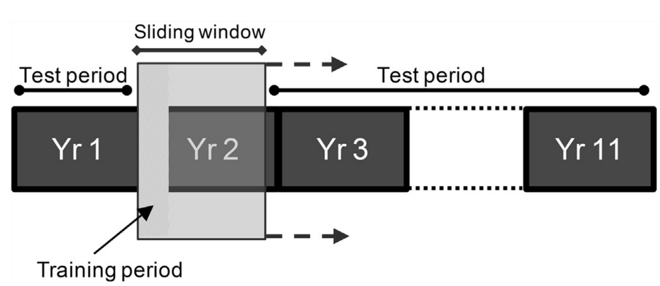

Fig. 1. Schematic diagram of the sliding window technique used to test the MCP predictions across the entire data record. The test periods move with the training window such that the two never overlap.