White paper

The Future of Wind

Met Office analysis of European wind variability over 140 years to help policymakers, developers, owners, turbine manufacturers and investors
The Future of Wind

This briefing is intended to highlight the areas where the Met Office is investing in the research and development required to be able to offer reliable weather and wind predictions on all timescales. The Met Office provides a range of forecasts – from hourly and daily through to annual and decadal timescales and beyond, as depicted in Figure 1.

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<thead>
<tr>
<th>Hour</th>
<th>Day</th>
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<th>Month</th>
<th>Season</th>
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<td>Operators</td>
<td>Engineering/construction</td>
<td>Traders</td>
<td>Grid management</td>
<td>Turbine manufacturers</td>
<td>Planning policy</td>
<td>Investors</td>
<td>Developer/owner</td>
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![Figure 1: Timescales for the future of wind](© Crown copyright Met Office)

The dark grey area of Figure 1 highlights the shorter-term wind and weather forecasts, which are well serviced by current operational weather forecast models. However, significant improvements in the accuracy of these forecasts is still required as they are critical to the support of a variety of operational requirements including health and safety, asset optimisation, energy trading and to satisfy short-term regional, national and international electricity supply and demand balancing.

Importantly, increasing development and operational costs, together with high levels of uncertainty in revenue projections associated with limited current understanding of future weather and wind risks, are becoming increasingly critical to the longer-term success and profitability of all onshore and offshore renewable wind energy projects. More reliable longer-term predictions will therefore potentially transform the management of weather and wind risks – and therefore profitability – for all industry stakeholders including developers, operators, engineering companies, technology manufacturers, investors and traders, as well as planners and policymakers of national government and regulatory bodies.

Longer-term timescales, from monthly onwards, as depicted in light grey in figure 1, require new research methods. These methods include using more sophisticated, coupled atmosphere and ocean climate
models, linked with an understanding of the behaviour of large-scale weather phenomena, such as the North Atlantic Oscillation in the northern hemisphere and El Niño/La Niña events in the southern hemisphere.

Such weather and wind climate research forms an ongoing programme within the Met Office in all of the above timescales, on a global basis, under the title of ‘The future of wind’. Because of more powerful supercomputers in combination with our world-class science, we are now beginning to make some real progress into many of these new areas of research.

‘The future of wind’ briefing papers present current and planned Met Office research into all of these timescales. The briefings are designed to provide the basis for engagement at all levels of business and technical management.

This is an exciting time for the renewable wind energy industry as it battles for priority with other energy generation options, including gas and nuclear sources, with the objective of providing long-term security of energy supply for the UK and other countries around the world. We are confident therefore, that our research into the future of wind will result in the additional intelligence required to underpin long-term successful growth.

In this first paper, we focus on some initial research into the decadal timescales, highlighted in blue in Figure 2. We also summarise the analyses of wind data over the last 140 years as the basis for projecting forward over the decadal timeframe, the life time of a typical wind asset.
The benefit of hindsight

This first short paper provides a summary of the full research paper entitled ‘European wind variability over 140 yr’ produced by Drs. Philip Bett, Hazel Thornton and Robin Clark of the Met Office Hadley Centre for Climate Prediction and Research.

Introduction

An accurate and detailed understanding of the likely electrical power yields over the lifetime of a wind asset, of typically 25 years, is becoming increasingly important, as development and operational costs continue to rise and power generation subsidies and incentives continue to fall, putting more pressure on business profitability.
Such detailed understanding comes from combining knowledge of the underlying physical processes with reliable historical data, enabling us to describe both the wind climate and the processes that can cause it to vary. The vast amount of useful information available from existing historical data means that we can build up a very detailed picture of the distributions of wind speeds, including the underlying patterns, cycles and drivers. This paper describes how the wind speed distribution varies on decadal timescales, giving an indication of the kind of variability that we might experience over the lifetime of wind farms.
Using a newly available data set, we have characterised the long-term distributions of wind speeds over 140 years in the UK and Europe. This has enabled us to better understand the form and variability of their distribution, and to demonstrate some of the benefits of using long baselines for such analyses.

Reanalysis data sources

One way of using historical data is to combine the results from direct observations with the physical understanding encoded in a computational weather and climate model to produce a gridded data set called a reanalysis, which remains tightly bound to describing the observed world. Reanalyses represent major projects in data analysis, modelling and quality control, and produce data sets most suited for assessing the long-term historical climate. They aim to provide an optimal combination of observations and numerical model data, giving the best representation of the “true” situation at any given point and a dataset that is homogeneous in space and time.
We use the Twentieth Century Reanalysis data set (20CR, Compo et al., 2011) produced by the US’ National Oceanic & Atmospheric Administration (NOAA) as the basis for this research project. The 20CR
spans an unprecedentedly long period of 140 years (1871 to 2010) by including sea level and surface pressure observations alone in order to produce a homogenous data set over that period. This source data comes largely from the ACRE project, led by Met Office Hadley Centre scientist Dr Rob Allan in collaboration with many UK and international partners (Allan et al., 2011). Since observational records become increasingly scarce as one looks further back in time, there is greater uncertainty in the earlier data. This is quantified in the reanalysis by running an ensemble of 56 different realisations of the atmosphere at each time step.

**Methodology and results**

While it is relatively straightforward to calculate the long-term mean wind speeds over Europe, some care is required when considering the wind variability. The averaging involved in the ensemble-mean time series would erase much of the true variability in the early years of the data, so it is important to calculate the standard deviations from the ensemble members directly, and produce an ensemble-mean as the last step.
Figure 3 below shows the geographic distribution of the long-term mean and standard deviation of daily wind speeds over our selected European domain. We also show the trends from linear regression on the time-series of 5-yearly average wind speeds and standard deviations, with regions shaded out where the trend is not significantly different from zero.

Figure 3: The geographic distribution of wind speeds over Europe from the 20CR data. The 140-year mean and standard deviation are shown in the top row, with linear trends in the time series of 5-yearly averages in the bottom row. Areas where the trends are not statistically significant are shaded out, although the trends everywhere are so small that their physical significance is dubious.
It is apparent that areas of complex topography (such as the Alps) show extremely low wind speeds. This is actually an artefact of the relatively poor spatial resolution of the data (2° in latitude and longitude) and is a common feature in wind speed modelling. At this resolution, the relatively modest height of terrain over the British Isles means that it does not suffer from this problem.

Figure 4: Mean wind speed in five-yearly bins for a region around eastern England
We continue our analysis by looking in detail at a time series of five-yearly averages, highlighting the decadal-scale variability; for example, as shown in Figure 4, Eastern England clearly had higher wind speeds on average during the 1990s, although they were no more exceptional than the period around 1920. All of the long-period variability seen here is relatively small compared to the much larger day-to-day variability in wind speeds. We also investigated how the form of the distribution changes, in terms of the deciles of the distribution and the best-fitting Weibull distribution function.

Figure 5 below is a colourful illustration of how the 140 years are distributed in terms of their wind speeds. In each panel, the years are shown in rank order of their annual mean wind, with the vertical extent of the bars showing the 10th and 90th percentiles of daily-mean winds each year. Each decade is coloured separately and the lack of any long-term trend results in an unordered mixture of different colours. This also demonstrates how the day-to-day variability (shown by the length of each bar) is much greater than any trend or the interannual variability.

The different panels below highlight different decades: in this case, the 1980s have years with both very high and low average winds, whereas the 1990s are mostly in the top-half of the 140-year distribution. There is a fairly evenly spread in the 2000s, reflecting a decade with near-average wind speeds – but 2010 (also included in the last panel) is the year with the lowest wind for this region, corresponding to the very cold winters at the start and end of that year. This type of analysis is important for showing the variability on different timescales (daily, yearly, decadal), and puts recent experiences into the context of the full 140-year data set.

**Figure 5:** Ranked annual mean wind speeds. The large top panel shows all years (coloured by decade), and the lower panels highlight the 1980s, 1990s and 2000s.
Interpretation and conclusions

Our analysis of the 140-year 20CR data set has highlighted both the average large-scale wind climate for Britain and Europe and also the decadal-scale variability of wind speeds, thus putting high-wind periods (such as the 1990s) and low-wind years (such as 2010) into their proper long-term context. Just as there is little sign of any long-term trends in the data, we can also see that the variability in recent decades is typical of the general wind climate.

These results have only been possible because of the long baseline of the 20CR data. While other data sets can provide much higher resolution, they will tend to extend back only 10 to 30 years. Using such data alone would severely limit our understanding of the long-term variability and trends in wind speeds, and could bias our perception of likely future behaviour. Using a long-term data set has meant that we can provide a much more accurate understanding of the wind speed distribution and long-term variability in a region, which is critical to understanding the wind speeds expected over the lifetime of any specific wind farm.

Finally, while this study does not directly address the question of climate change, the absence of any strong historical long-term trends is relevant in that regard. The importance of wind energy means that the potential impact of climate change is an area of ongoing research at the Met Office Hadley Centre, and in other centres around the world. Current results (e.g. Pryor & Barthelmie 2010, 2011; Pryor et al 2012; Cradden et al 2012; Hueging et al 2013) suggest that wind speeds and the resulting wind power are likely to remain consistent with current natural variability for many decades. While there may be significant changes to the wind energy output by the end of the century, the magnitude of such changes depends strongly on the model used and the location in question. It would take many decades for these weak trends to emerge from the envelope of natural variability.
Next steps

The research discussed in this article represents the initial results of an ongoing Met Office Hadley Centre project to investigate future climate risks to the wind power industry.

The next phase of research into this area will be described in a follow-up Future of wind summary paper. In this article, we will describe our investigations into the long-term wind speed distribution in more detail, comparing the results from the 20CR data set with those from the higher-resolution ERA Interim (spanning 1979 to the present) and examining possible biases between the two datasets. Correcting for these biases will enable us to generate a more accurate wind speed climatology back to 1871, following the patterns of long-term variability seen in 20CR. We will also perform a more detailed analysis of the time series over Europe, including a closer look at autocorrelation and an investigation into how much historical data is required to obtain an accurate estimate of the long-term wind distribution.

Research in this area will be used to inform future developments of Met Office solutions for the renewable energy industry, such as Virtual Met MastTM, designed to provide the most representative view of the future wind climate at a specific location and hub height on decadal timescales.

The full research paper is available on request by emailing renewables@metoffice.gov.uk

Invitation

We are seeking to collaborate with senior business and technical management from a cross-section of industry stakeholder organisations, to provide strategic guidance and key inputs to our research priorities and objectives. If you would like to be considered for the role of an industry research partner, please get in touch with the Met Office Renewables Team:

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References


