Analysis and forecast of wind speeds measured and modelled (by the Modern-Era Retrospective analysis for Research and Applications (MERRA)) at a site in the UK

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BSc Statistics Thesis

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1 Introduction

1.1 Background

To stabilise the global temperature increase of 1.5 °C, it is crucial to reduce greenhouse gases emissions to a minimum. This requires the proportion of electricity supplied by renewable sources to increase to 60.24% by 2050 from the current global total of 14.9% (Rogelj et al., 2018, p.132). Of that, the power generated by wind is projected to increase from 1.81% to 21.13%.

Wind power generation presents many challenges such as high variability in supply that follows seasonal and daily wind patterns. In statistical theory variation is understood as a distance away from the mean value. For wind speeds, trend, seasonality and any remaining cyclic patters could contribute to variation. In particular, when looking at the seasonal pattern, higher wind speeds are observed in winter than in summer (Danish Wind Industry Association, 2003). This applies to temperate climates such as the one in the UK. Also, the diurnal wind pattern constitutes of higher wind speeds during the day than at night (Danish Wind Industry Association, 2003). Finally, any potential effects of climate change on wind speeds are likely to be linear and need to be considered.

Power forecast is calculated using wind speed and time, where the power generated by wind is directly proportional to the cubic power of wind speed:

$$Power = \frac{Energy}{Time} = \frac{1}{2}A\rho v^3 \quad (1.1.1)$$

where
ρ = density of air
v = wind speed

Wind-generated power is not dispatchable meaning it is impossible to generate on demand. In 2020, energy storage remains expensive and inefficient. For this reason, there is a need for short-term wind forecasts that can predict the power output from a wind farm and can match it with real-life demand, omitting the issue of storage. Within the paradigm of wind speeds forecasting, forecasts can be classed as very short-term (up to an hour), short term (1 hour up to a few days ahead) or long-term (seasonal and yearly). This project focuses on short-term forecasting of wind speeds, particularly up to 24 hours ahead.

Short-term forecasts are an essential tool for electrical grid to operate effectively. The grid operators need to ensure the demand for electricity is met with that from renewable resources, such as those from wind farms, and that the cost of electricity generation is minimised. This requires short-term forecasts of wind power and load to schedule a power dispatch. Short-term wind power forecasts are also used for grid congestion management (deciding on which power sources are going to be used), as well as grid maintenance (such as preparation of power reserves in response to unforeseen rises in load demand, falls in wind speeds or damage resulting from extreme wind speeds).

There are two types of models currently in use for weather predictions. Physical models use partial differential equations to model the behaviour of the global physical systems and make a prediction based on that for any around around the globe at a particular time. These models fall under the name "Numerical Weather Prediction (NWP)". The problem with NWP is that they are usually deterministic and do not always provide information on the forecast accuracy. The second type, probabilistic models use probability theory and regression. They can quantify the uncertainty in the forecast. The problem with the probabilistic models is that they only provide a prediction for a particular site as opposed to global prediction. Nevertheless, prediction uncertainty is essential for decision-making at wind farms and hence probabilistic models are of interest.

This project is going to investigate and forecast wind speeds measured at an unknown location in the UK and wind speeds obtained from Modern-Era Retrospective Analysis for Research and Applications (MERRA) done by NASA. MERRA is a physical model that provides estimates of weather conditions at numerous locations around the globe. MERRA is a climate reanalysis meaning it uses techniques of data assimilation and numerical weather prediction to obtain a picture of the weather at numerous locations around the globe in recent past (The European Centre for Medium-Range Weather Forecasts, no date). MERRA is useful in context of wind power production since it can provide an estimate and prediction of the weather at any location and time on the globe without placing any measuring equipment there.

1.2 Objectives

1. Evaluate the cyclical and seasonal patterns, linear trends, as well as identify any extreme values in wind speeds measured and modelled by MERRA.
2. Evaluate the performance of the MERRA model for the particular location within the UK that our data is obtained for.
3. Build a probabilistic model that will predict hourly wind speeds in a 24 hour ahead forecast. The remaining MERRA variables (MERRA.U, MERRA.V, MERRA.RH, MERRA.P, MERRA.T and MERRA.WD) are going to be considered as potential explanatory variables.

1.3 Plan

Chapter 2 of this report contains a more detailed description of the materials used for the project. This will include plots and summary statistics of the variables from the data. Chapter 3 consists of statistical and mathematical methods used to answer the question of interest. Chapter 4 outlines the results from the report. Chapter 5 concludes and discusses the content.

2 Materials

2.1 Data

Data for this project consists of wind speed measured hourly at an unknown location in the United Kingdom over a two-year period. The first measurement was taken on the 1st of January 2011 at 1 am, and the last one on the 31st of December 2013 at 1opm. This gives a total of 26,302 observations.The rest of the data was produced by MERRA. The variables from the data are described in Table 1.

Table 1: Variables under consideration

ï..Variable	Abbreviation	Description	Type	Unit.or.Category
Time	DateTime	Hourly measure of time	Continuous	Day/month/year hour:minute
Wind speed	WS	Wind speed as measured at the UK location at the UK location	Continuous	Meters per second (m/s)
MERRA wind speed	MERRA.WS	Wind speed as modelled by MERRA for the UK location	Continuous	Miles per hour (mph)
MERRA zonal wind speed	MERRA.U	Zonal wind speed	Continuous	Meters per second (m/s)
MERRA meridional wind speed	MERRA.V	Meridional wind speed	Continuous	Meters per second (m/s)
MERRA relative humidity	MERRA.RH	The ratio of humidity in the air to the maximum humidity the air can hold multiplied by a hundred.	Numerical	Percentage (%)
MERRA pressure	MERRA.P	Air pressure	Continuous	Pascal (hPa)
MERRA temperature	MERRA.T	Air temperature	Continuous	Kelvin (K)
MERRA wind direction	MERRA.WD	Wind direction	Numerical	Degree Celsius

2.2 Exploratory analysis

Objective 1

In this section the underlying patterns in the variables under consideration are going to be investigated. Plots of measured and modelled wind speeds, as well as the remaining MERRA variables are going to be examined.

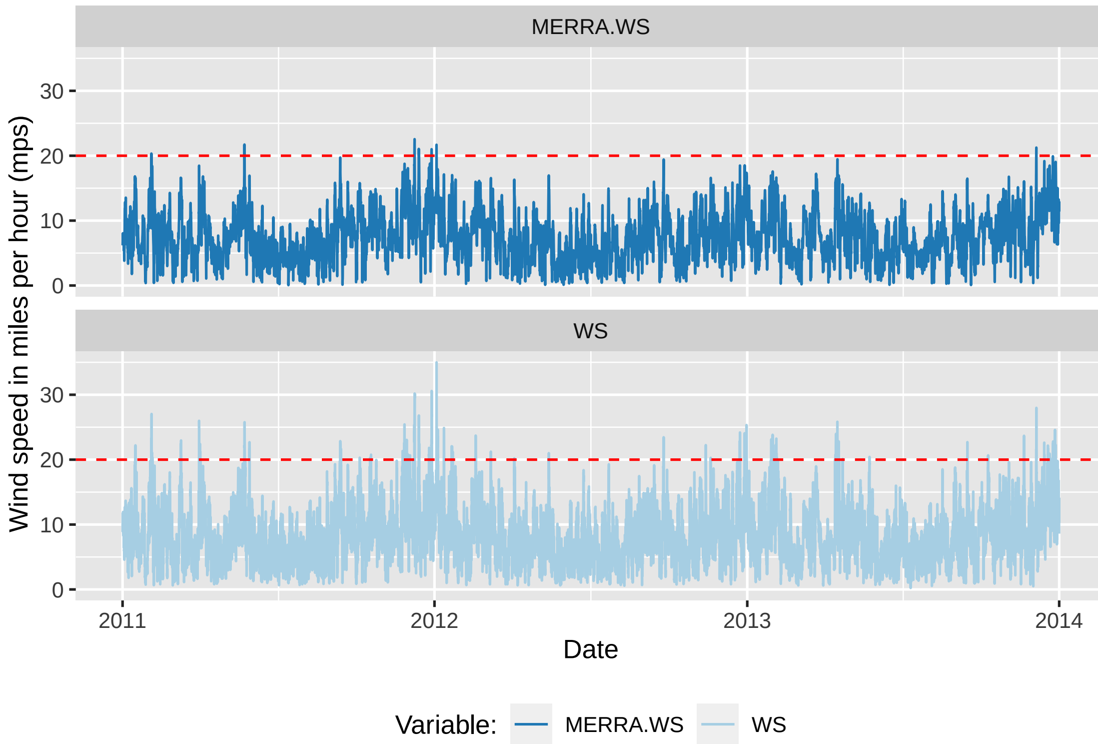

Figure 1: Time series plot of measured (WS) and modelled (MERRA.WS) wind speeds at the location in the UK with 20 m/s highlighted in red.

In Figure 1, we can see the pattern in measure (WS) and modelled (MERRA.WS) wind speeds at the unknown location in the UK. At first sight, it appears as if the two time series exhibit relatively similar wind speeds over time. The WS has a higher variability with plenty speeds exceeding 20 mph (highlighted by the red dashed line in Figure 1) ,while in case of MERRA.WS the speeds are mostly within 0 to 20 mph limit. There is no obvious linear trend for either time series. Both variables seem to follow a seasonal pattern with higher wind speeds at the start of each year, gradual dip to reach lowest values in the middle of the year (June), and then an increase to higher wind speeds towards winter. That seasonal pattern is more evident in Figure 2, where the median wind speeds are clearly lower in the summer months, than they are in the winter months. Additionally Figure 2 gives some indication of potential extreme values in January and December.

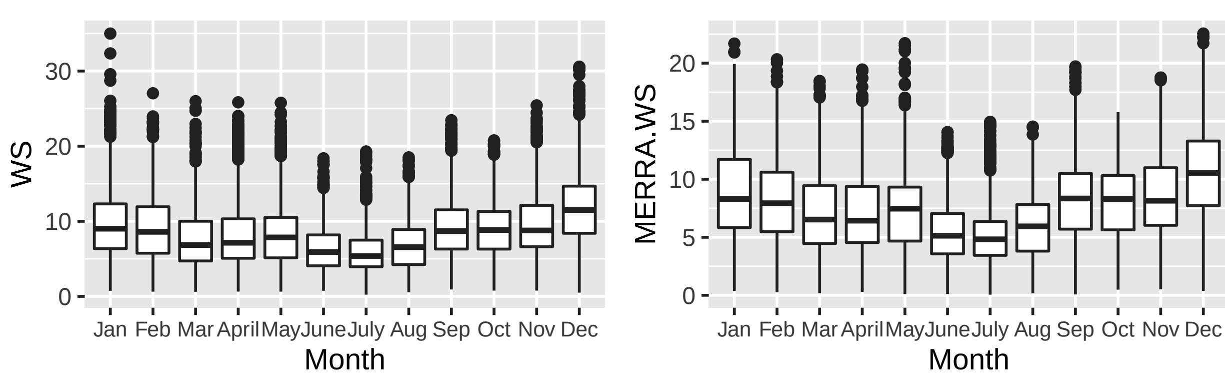

Figure 2: : Boxplots of wind speeds distributions for the WS variable (left) and MERRA.WS (right) for each month during the two-year period from January 2011 till Decemeber 2013

Objective 2

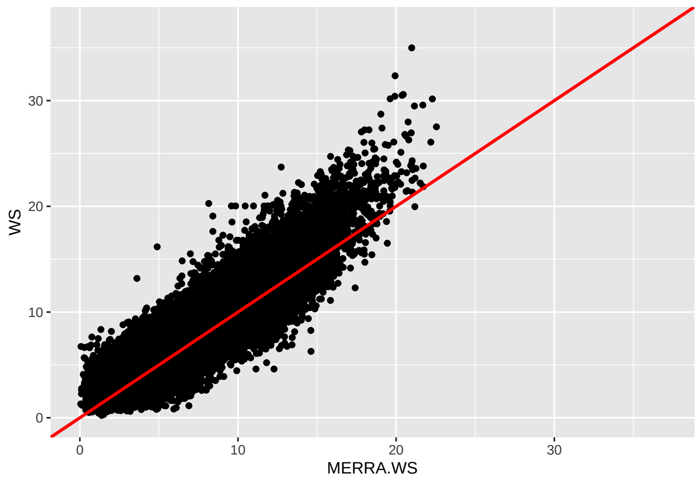

Figure 3: Scatter plot of WS against MERRA.WS with line a equality y=x plotted in red

From Figure 3 it can be seen that WS and MERRA.WS seem to exhibit fairly similar values of wind speeds at most time points. It seems like there is more disparity between the two variables at wind speeds exceeding 15 m/s. It seems like the measured wind speeds were actually higher on many occasions than predicted by the MERRA model.

Objective 3

From Figure 4 we can examine the relationships between the measured wind speeds and the remaining MERRA variables. The scatter plots show data for 2011, but it can be assumed that atmospheric variables exhibit very similar patterns every year. The most obvious relationship, strong and positive, is between WS and MERRA.WS since MERRA.WS tries to model WS. Some liner relationship also occurs between WS and MERRA.U, MERRA.V, as well as MERRA.P. These relationships however are not to strong. Nonetheless, MERRA.U, MERRA.V and MERRA.P could be potential predictors for WS.

From the wind rose plot if Figure 5 it can be concluded that the wind mostly blows towards SW and West. The highest % of the measured wind speeds blows towards WSW (approximately 19%). It appears like there is no evident relationship between the wind speeds and wind direction since the percentage of lower wind speeds is approximately the same for all wind directions. The percentage of lower wind speeds at 4 to 6 m/s is a bit higher for West, WNW and WSW. However, this increase is likely proportional to the % of total wind blowing in that direction.

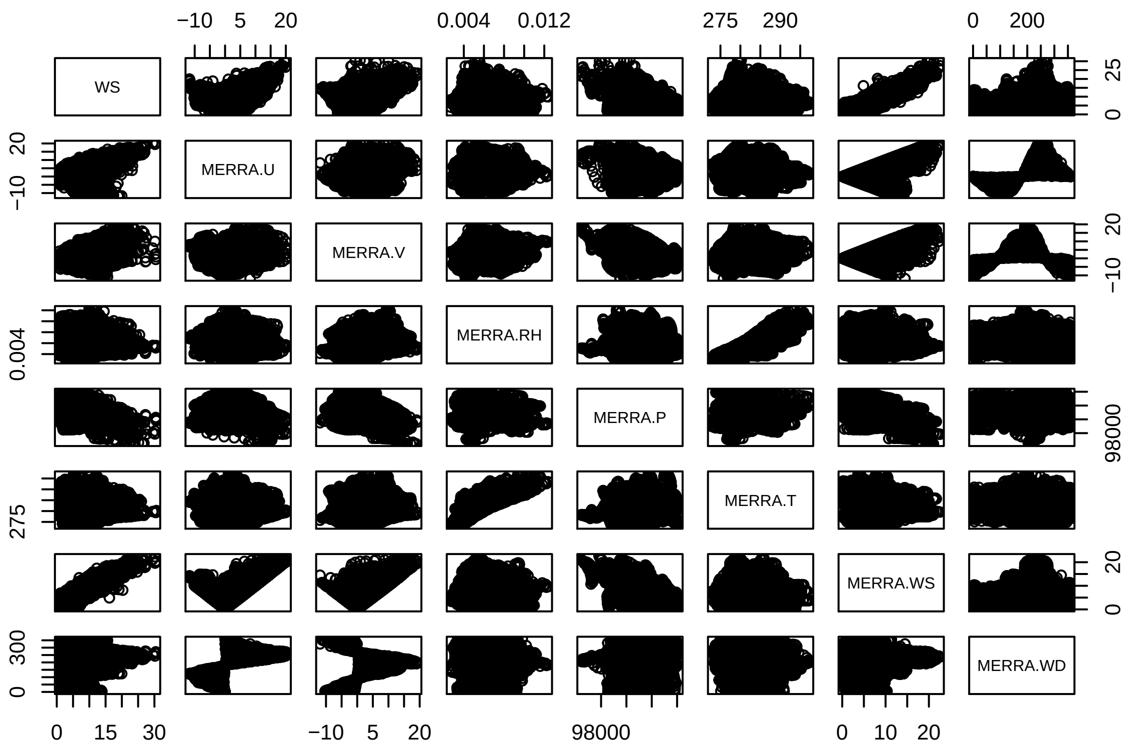

Figure 4: Scatter plots of WS and the MERRA variables for 2011 only

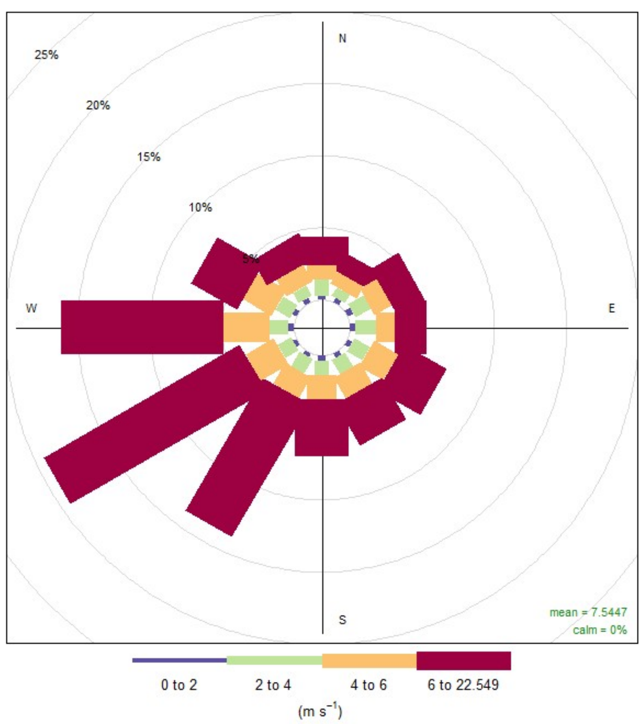

Figure 5: Wind rose plot for the measured wind speeds (WS) and wind directions from MERRA.WD

3 References

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