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Extreme 50 year return wind speeds from the USAF data set

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Introduction

Information on extreme wind speeds is an important design parameter for survivability of exposed engineered structures, in particular bridges and wind turbines (Palutikof et al., 1999). The issue has recently come into focus in the wind energy industry after several cases of the destruction of wind turbines in coastal wind farms in east Asia by severe cyclones (Li et al., 2013; Chen and Xu, 2016). These events have led several research groups in the United States to assess wind turbine survivability at offshore sites along the U.S. Atlantic coast and Gulf of Mexico where future wind farms will be located (Rose et al, 2012; Worsnop et al., 2017). Many of the areas can expect multiple hurricane occurrences over the 20 year operating lifetime of a typical wind farm. Most wind turbines have been designed for meteorological conditions in Europe where the industry is most advanced, but these may not be adequate for hurricane regions. While the most robust turbine design (i.e., Class 1 turbines according to the IEC guidance document IEC 61400-3) can survive hurricanes of Category 1 or 2, they would have a high probability of damage or destruction in hurricanes of Category 3 and higher (i.e., at wind speeds of >45 m/s). This issue prompts questions about the extreme wind speeds that can be expected at other potential wind farm sites. This contribution uses the USAF data set to assess extreme 10 m wind speeds at the 50 year return interval for long-term station records around the world.

Procedure

The USAF data set is a compilation of meteorological observations from different measurement networks over the time interval 1901–2017. The full data includes information on standard meteorological variables, and for the present analysis only the 10 m wind speed was considered. The data are unevenly distributed in time and space with more data available from the late 20th century than in the earlier part of the record, and a pronounced data sparsity in certain areas of Africa and South America. For this analysis, stations from the full data set were selected based on certain network types: WMO (World Meteorological Organization), ICAO (International Civil Aviation Organization), AFWA (Air Force Weather Agency), and CMAN (Coastal-Marine Automated Network). This yielded ~12000 stations in the first count.

Extreme wind speeds at the 50 year return interval were evaluated using the annual maximum method with Gumbel distribution (Palutikof et al., 1999). The data quality for each year of each station were assessed and only complete years of data (i.e., at least 360 data measurements in a year with each month represented) were retained. To avoid possible climatological interannual biases associated with short data sets, station records had to have at least 20 years of data. There were ~7100 stations remaining after this sifting process. The USAF data set has not been quality controlled, the task of assessing the maximum wind speed in each year was complicated by the presence of data outliers. These isolated data points were factor of approximately two (but sometimes a factor of 10 or more) higher than the data points recorded before and after. The origin of the problem is uncertain but might relate to problems of unit conversion from the initial source to metres per second by the US archival authority. Valid maximum annual wind speeds were therefore assessed if the measured values before and after the identified maximum were not less than 50% of the maximum value. This test assumes that the high wind speed event would last across three synoptic measurements. Tentative maximum values that failed this check were rejected, and the next highest value was tested for validity. Up to ten rejections could be made before the full year of data was removed from the analysis. To calculate the extreme wind speeds at the 50-year return interval, the maximum annual wind speeds were arranged in descending order and plotted against the Gumbel reduced variate, which is calculated from the index position and linked to the return period (Palutikof et al., 1999).

Results

Figure 1 highlights the features of the wind speed data and presents worked examples of how the extreme 50-year wind speed is assessed. Selected time series of the annual maximum wind speed are shown in Fig. 1a–m for selected stations around the North Sea and also two offshore stations on the Norwegian petroleum platforms Ekofisk and Gullfaks. The stations were selected for the large number of annual maximum wind speed values available for the statistical analysis of the 50-year extreme value. Most of the time series have significant data gaps. It is assumed that the missing years of data are not linked with the highest values of annual wind speed maxima, which would introduce a bias to the results. When the data are ranked and plotted versus the Gumbel reduced variate (i.e., a proxy for the return period), there is a linear distribution of data as shown in Fig. 1n–z. The 50-year extreme wind speed is calculated from a straight line fit to the plotted data.

The spatial distribution of the 50-year wind speeds is shown in Fig. 2a with a histogram summary of all the stations is shown in Fig. 2d. The most significant feature of the map is that it emphasizes the global station distribution that is mostly based on land stations with some offshore platforms. Most stations show a 50 year return wind speed on the order of 10–30 m/s, and the mode in the histogram distributions occurs at ~18 m/s. Extreme wind speeds greater than 40 m/s are not common on the global map in Fig. 2a and are found mainly in certain coastal and offshore areas. These include the northern North Sea, coastal Greenland, and certain coastal and island sites around Japan.

The highest measured wind speed (Fig. 2b and Fig. 2d) is comparable to the calculated 50-year extreme value (Fig. 2a), an expected result given that only long station records greater than 20 years have been used in the analysis. Figure 2c and 2e gives information on the length of the data series (i.e., number of years of data) used to calculate the extreme wind speeds. The length of the time series ranges from 20–80 years, and most of the longer datasets occur in North America and Eurasia.

Discussion and Conclusion

Wind speed data from the USAF data has been extracted processed to yield information of the extreme winds at the 50-year return interval. The advantages of the USAF data set is that it provides long time series for a large number of stations with a global distribution. The extreme wind speed results are in qualitative agreement with other statistical investigations of extreme wind (e.g., Gatey and Miller, 2007; Outten and Esau, 2013).

The analysis has highlighted some shortcomings of the USAF data set that make it non-optimal for assessing design wind speeds for engineering purposes. Data outlier values are possibly based on unit conversion errors and were addressed by eliminating suspect annual maximum values in favour of next highest values that met the quality control standards. Gatey and Miller (2007) identified a similar problem in a related data set, and found that there were long segments of data for some European stations where there was confusion in the conversion from knots to metres per second. This type of error generates a wind speed outlier value that is approximately twice as high as it should be and introduces significant offsets in the Gumbel fit statistics that are used to assess the 50-year extreme wind speed. Gatey and Miller (2007) recommended the use of an automatic error detection procedure to overcome the problem, and the preliminary analysis of the USAF data set supports this assessment. The best way to approach this quality control would be to check for outliers within the time series of a single station, and also to compare the values adjacent nearest stations. An additional check would compare the reported wind speeds with the horizontal pressure gradients, which should be related through geostrophic wind theory.

A second identified problem with the USAF data set was the presence of significant data gaps in the station time series. For an extreme value analysis, it is best to have complete data series. Where gaps exist sporadically in a time series, questions arise if the measuring anemometer failed during an extreme meteorological event, such as a hurricane. This has the potential to introduce significant bias to the extreme value analysis if the measuring instrument malfunctions consistently above a certain wind speed threshold. Future work aims to exploit this feature of the USAF data set to use clusters of stations to ensure complete data time series across regional storms.

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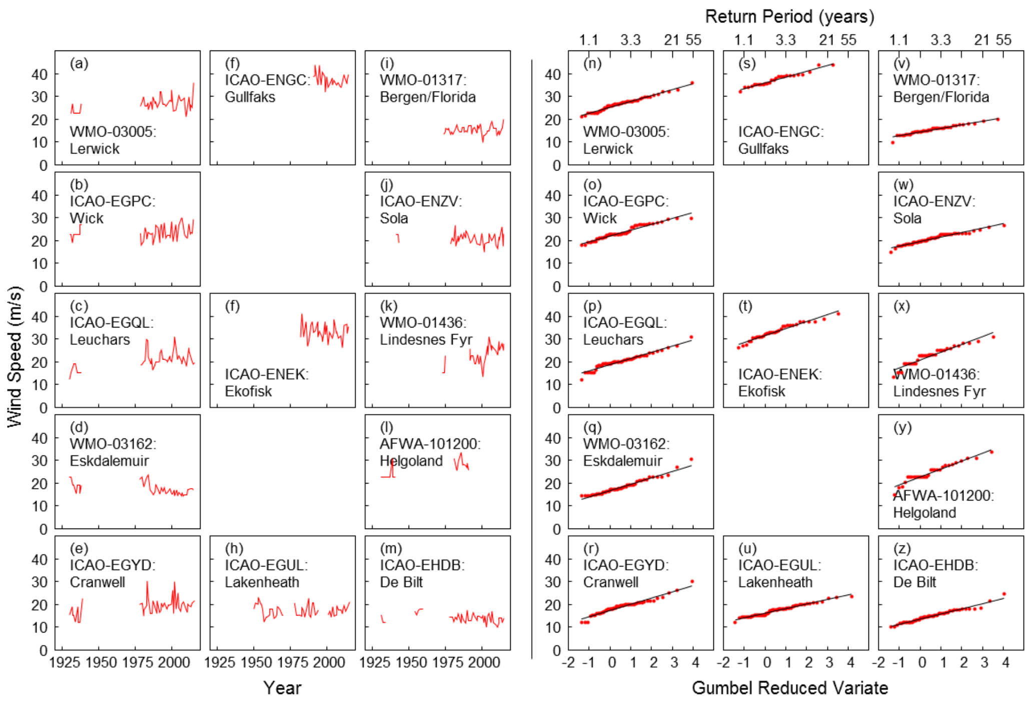

Fig. 1. (a) to (m): time series of maximum annual wind speed for a selection of stations around the North Sea; and (n) to (z) the ranked annual wind speeds (red points) plotted versus the Gumbel reduced variate with the corresponding return periods shown along the top panel. Fitted black lines are fitted to the distribution and used to calculate the 50 year return period wind speed.

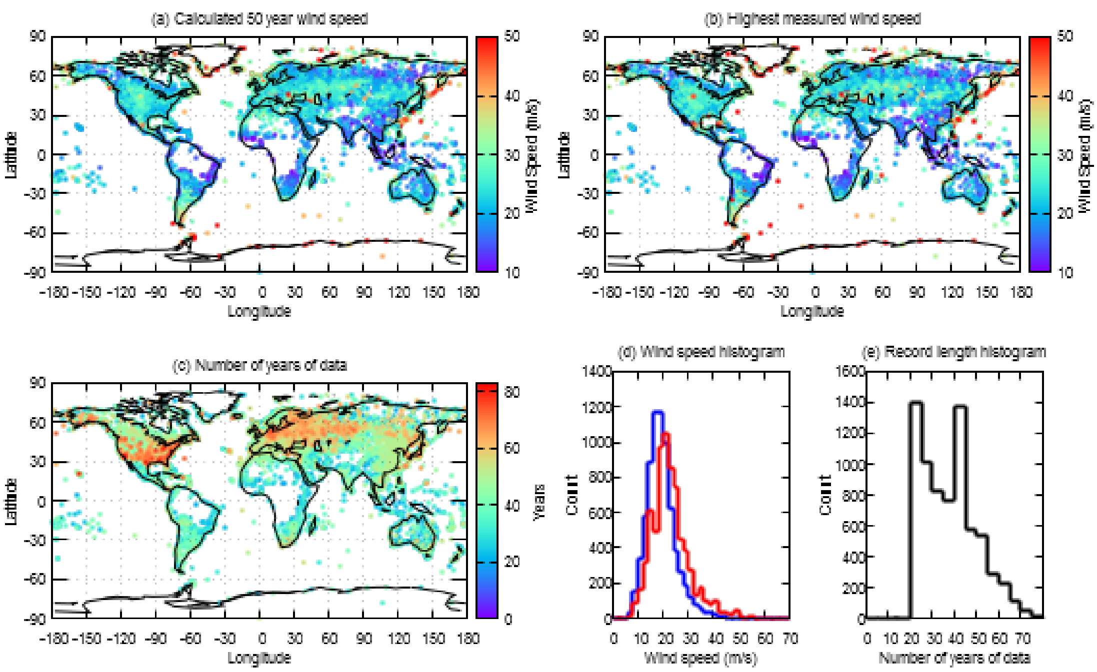

Figure 2. (a) Calculated 50 year return wind speed, (b) highest measured wind speed in the USAF dataset stations, (c) number years of data available for the extreme value analysis, (d) histogram of the calculated 50-year wind speed (blue) and maximum measured wind speed (red), and (e) histogram of the number of years of data available for the extreme value analysis.