9th Asia-Pacific Conference on Wind Engineering
Auckland, New Zealand
3-7 December 2017

Preliminary Extreme Wind Speed Estimates for the Auckland Region

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Abstract

Extreme winds can be dangerous for people and cause significant damage to property and buildings. Analysing the historical wind data to gain a better understanding of the space and time distribution of extreme winds is essential to produce appropriate design wind speeds. However, the historical wind data set have not been analysed in New Zealand for the past 2 decades for this purpose. This study is aimed at investigating the historical wind data at six meteorological stations in the Auckland region, correcting them for site exposure and eliminating the discontinuities in the recorded data, in order to estimate extreme gust wind speeds for a return period of 50 years, using three different methods. A contour map for the extreme winds is produced for the selected region. Finally, the results are compared with the current values given in AS/NZ1170.2. It was found that there was considerable variation in the predictions from the different anemometer stations.

Introduction

The damage caused by wind, wind loading on structures, wind energy production, dissipation of pollutants, etc. are a few examples of why the wind flow in the atmospheric boundary layer must be studied. Designing a structure to resist wind forces, requires the assessment of the largest loads which the structure is likely to experience during the expected life-time. This assessment must be done by establishing the appropriate design wind speed, which is a critical and challenging part of the calculation of design wind loads for structures [5].

Wind, due to its great variability on all time scales, and in three-dimensional space, is a difficult phenomenon to define. Due to various systematic errors, long-term wind time histories may be subjected to inhomogeneities. These errors mostly from: station relocations, anemometer height changes, instrumentation malfunctions, instrumentation changes, different sampling intervals and observation environment changes [2]. This is particularly true for gust wind speeds, which are extremely sensitive to factors such as the anemometer response characteristics. The effects of terrain conditions and changing the height of anemometers have long been recognised and taken into consideration. However, the issue of changes in both anemometer type and observation practices that have occurred during the period of the measurements at a particular site have sometimes been ignored [7]. Therefore, in this study, prior to carrying out the extreme value analysis, the historical data from all the stations have been reviewed and subjected to a homogenisation algorithm. Then the unified data are used for further investigation and extreme value predictions.

The historical wind data in New Zealand have not been analysed for the last two decades for wind loading considerations. In 1987, the New Zealand Meteorological Service [8] analysed the wind data recorded from 5 stations in Auckland to determine the wind speeds for the years 1972 to 1986. By fitting the Type I distribution to annual maxima using the Gumbel method, the gust and hourly mean speeds for different return periods were obtained. As a result, it was found that there was considerable variability in the predictions within Auckland city. A comparison was made by Reid in 2000 [10] between estimated extreme winds, based on data recorded from the 1970s to 1990 for a 20-year return period for 50 New Zealand stations, with values given in AS/NZ1170.2 [1]. His results showed that the values obtained based on the data gathered from the stations, lay within 20% of the wind speed in the standard. Another finding of this study was that the hills in large areas of complex terrain affected the airflows in different ways, and since New Zealand has large areas of complex terrain, further development of topographic multipliers may be needed in the standard. After Reid's study, New Zealand's historical wind data have not been investigated for wind loading considerations until now.

Selected Meteorological Stations

Figure 1 shows the locations of the six stations selected in the Auckland region for the present study.

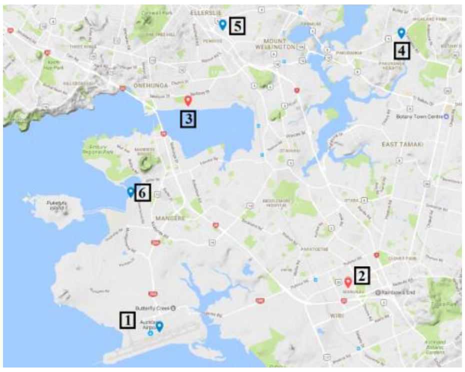


Figure 1. Six selected wind record stations in the Auckland region

Having looked at the instruments and site histories available on CliFlo [9], some of the changeovers, which might have affected the recorded wind data were extracted and are given in Table 1.

Station No.	Location	Anemom. H (m)	Start - End date
1	Auckland Airport	10*	1971 - Now
2	Wiri Rd	10	1995 - 2011
3	Onehunga	10	1994 - 2011
4	Pakuranga	6	2001 - Now
5	Penrose	6	2001 - Now
6	Mangere	10	2002 - Now

* During 1983 to 1986 the anemometer was at a height of 15m

Table 1. History of stations and instruments

Among the selected stations, Auckland Airport has the longest data series, although at this station, many factors such as changes in instrument (1993), anemometer height, and station location have affected the wind data. However, other stations have not experienced any instrument or other major changes. Note that stations 4 and 5 have the anemometers mounted at a height of 6m, instead of the standard height of 10 m. In the following section, the homogeneity of the recorded data is investigated.

Homogenisation Process

In climate research, it is of a great importance to have access to reliable data, which are free from artificial trends or changes. One of the difficulties in analysing wind data is that wind speeds are affected by a significantly larger range of factors than other meteorological variables [2]. Thus, corrections and homogenisation of wind speeds are imperative for climate studies and other applications, particularly for the assessment of observed wind speed trends. The first step in the wind speed homogenisation process is that to make sure the wind data have been recorded at the standard height of 10 m. Otherwise, the wind speeds must be adjusted for non-standard anemometer heights. For this purpose, there are two commonly used wind velocity profiles, the log-law and power-law. In the logarithmic wind profile (Eq. 1) the effects of surface roughness on wind speed are well accounted for by the roughness length Z_0 [16]. Therefore, this model works better for adjusting wind speed data for anemometer height changes than the power-law. In this study, it is assumed that Z_0 does not change over time.

$$U(10) = \frac{\left[\ln\left(\frac{10}{Z_0}\right)\right]}{\left[\ln\left(\frac{h}{Z_0}\right)\right]} \times U(h) \qquad (1)$$

It is common practice in climatology to use statistical methods to detect sudden changes and shifts that are statistically significant, in climate series data. Then the magnitude of the detected shifts can be calculated, and available metadata are used to check the veracity of the identified shifts [16]. In this study, the newly proposed penalised maximal F test (PMFT) ([13,14]) is used to detect the shifts in the data series. The test uses iterative procedures to estimate the linear trend, annual cycle, first-order autocorrelation, and mean shifts of the time series in tandem. The algorithm is used to detect and adjust mean shifts in time series of a constant trend (β) and identically and independently distributed (IID) Gaussian errors. To identify possible shifts in a time series $\{X_t\}$, the null hypothesis (Eq. 2) is tested against the alternative hypothesis (Eq. 3).

$$H_0: X_t = \mu + \beta t + \varepsilon_t \quad , \quad t = 1,2,\dots,N \qquad (2)$$

$$H_a: \begin{cases} X_t = \mu_1 + \beta t + \varepsilon_t & , \quad t \le k \\ X_t = \mu_2 + \beta t + \varepsilon_t & , \quad k-1 \le t \le N \end{cases} \qquad (3)$$

Where ε_t is an IID Gaussian variable of zero mean and unknown variance, also $\mu_1 \neq \mu_2$ [14]. When H_a is true, there is a change at time k, and the magnitude of this change is equal to $\Delta = |\mu_1 - \mu_2|$. More details of this method and algorithm are provided in [13,14]. In addition, Wang, et al. [15] developed an open-source software package in the R and FORTRAN programming languages for implementing this algorithm.

Auckland Airport

As mentioned, the longest historical wind data record in the Auckland region is for Auckland Airport. The importance of this site for aviation would suggest that the instruments are well-maintained. However, the station has experienced a few major changes, such as an anemometer height and instrument change from a cup anemometer, used from the 1960s to 1993, to the new anemometer. Figure 2 clearly shows the effects of these changes on the time series. The first shift, from 1983 to 1985, is due to the anemometer height change, which can be adjusted by using Eq. 1 and assuming flat airport runway type terrain (Terrain Category 1) at the site location (According to [1] $Z_0 = 0.002$ m).

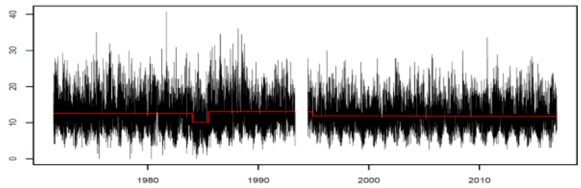


Figure 2. Time series of daily wind gust speeds at Station 1 and the detected statistically significant shifts shown as steps in the red trace.

The other shift in 1993 results from the anemometer change from a Munro cup and vane to Vaisala WAA15. Figure 3 compares the extreme values obtained for periods before and after 1993 by using the Gumbel method. As can be seen, the different anemometers result in significantly different estimates of the extreme winds for the same return period. Therefore, it is essential to understand the characteristics of the anemometers, such as the response length and averaging period, and to adjust the wind data accordingly.

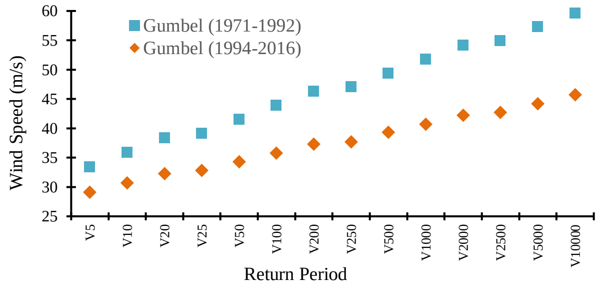


Figure 3. Extreme wind speeds as a function of return period calculated for data recorded before and after 1993 when there was an instrument change

To briefly compare the wind data recorded by both anemometers, a histogram of the daily wind gust speeds from 1971 to 2017 are plotted in Figure 4.

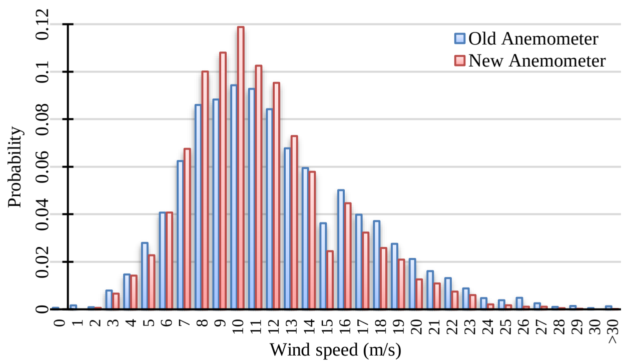


Figure 4. Histogram of daily maximum gust at Station 1 from the two different anemometers

Figure 4 shows that unlike the old cup anemometer, the new anemometer has not recorded any wind speeds below 2 m/s, and also only one speed higher than 30 m/s. The number of recorded speeds between 6 m/s and 14 m/s by the new anemometer is considerably larger than that of the old cup anemometer. The inherent tendency of the cup anemometer to overestimate the wind speed in variable winds has been demonstrated by some researchers, for example in the study carried out by Smith [12]. This perhaps partly explains why there are more measurements above 30 m/s from the old cup anemometer.

To find the magnitude of the shift (Δ), the annual maximum gust speeds and their linear trend lines are plotted in Figure 5. By calculating the difference between the averages of the annual maxima for each period, Δ can be computed and is equal to 2.981m/s in this case.

By assuming that the data recorded after 1993 are of better quality being more recent, the data series before 1993 has been adjusted by adding $\Delta = -2.981\ m/s$ to them. Having adjusted the data series for the anemometer height and changeover, the adjusted data were subjected to PMFT again and the result can be seen in Figure 6, which shows the homogenised wind data for the Auckland airport station.

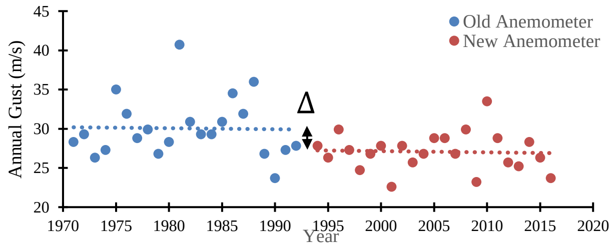


Figure 5. Annual maxima recorded by the old and new anemometers

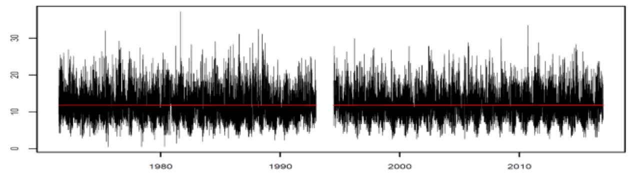


Figure 6. Homogenised wind data for the Auckland airport station

The other Stations

For the other stations, no major changes have been recorded in the history of the sites. However, prior to testing the homogeneity of stations 4 and 5, their data were adjusted to the standard height, by assuming that the surroundings were Terrain Category 3 (According to [1] $Z_0 = 0.2$ m).

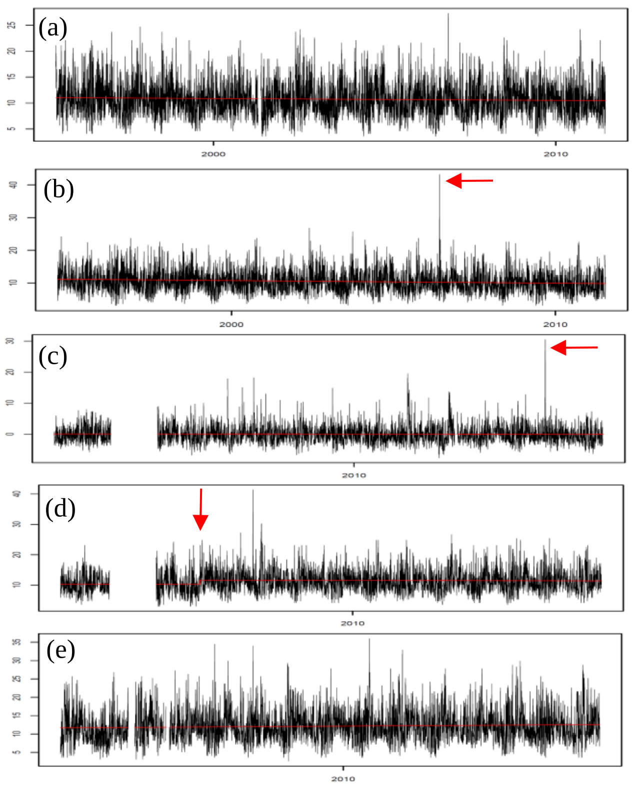


Figure 7. Time series of daily wind gust speeds at Stations: (a) 2; (b) 3; (c) 4; (d) 5; (e) 6

As can be seen in Figure 7, there are no significant shifts in the data, except for one shift at Station 5 (Figure 7(d)). Furthermore, there are 2 data point spikes in the Station 3 and 4 data identified by the red arrows. Due to the considerable differences between these wind speeds and the wind speeds for the next or previous day (about 30 m/s), these two data points were removed from the wind data series before further investigation.

Extreme Value Analysis

The theory of extreme value analysis of geophysical variables is based on the application of one of Fisher and Tippet's asymptotic extreme value distributions [5]. The Generalised Extreme Value distribution (GEV) is a single mathematical form combining all three extreme value distributions (Eq. 4), where the scale factor, a, and the location parameter, U, are parameters in the Fisher Tippet distribution. In this equation, k takes on the values of zero, negative or positive for Fisher Tippet Types I, II and III, respectively. In this study, the Fisher Tippet Type I (FTI) distribution has been used, because previous studies have proved that all extreme winds generated from various mechanisms obey FTI distribution with different modes and dispersions.

$$P = exp\{-[1 - k(V - U)/a]^{1/k}\} \tag{4}$$

To find the parameters a and U, many methods have been proposed. The first and most commonly used method is the Gumbel method [4]. The standard Gumbel method has been used widely, however it has some shortcomings. Firstly, continuous recording of wind is essential to get at least 20 annual maxima for good reliable estimates. Secondly, wind speeds for return periods less than one year cannot be determined. More importantly, this method is biased, due to the allocation of equal weights to each data point.

One method to improve the predictions of the Gumbel method is *q-model*, which was proposed by Cook [3]. He showed that using the dynamic pressure (q) as opposed to the wind speed as the variable of the FTI distribution, gave better estimates than those from the standard Gumbel method, owing to its faster convergence. It was found that using the dynamic pressure reduced the design wind loads by 10% for a 50-year return period. Both the above-mentioned methods are graphical and biased methods. In 1974, Lieblein [6] proposed a numerical method, which gives the correct weight to the data points by applying a set of *Best Linear Unbiased Estimators (BLUE)*. Unlike the previous methods, the BLUE method is unbiased. There are two estimators in this method; A{m} and B{m}, to find the distribution function parameters. In this method, the extremes can be either velocity or the dynamic pressure. In this study the dynamic pressures were used.

Results and Discussion

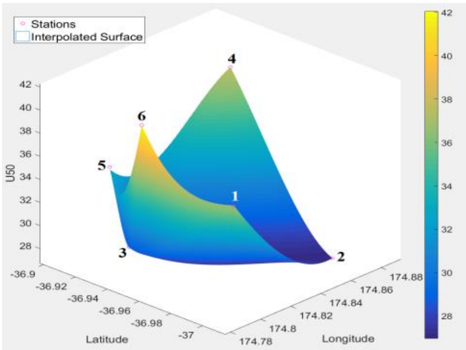
By using the three methods mentioned above, extreme wind speeds for a return period of 50 years were calculated for the selected Auckland region, and the results are shown in Table 2 and compared with the values given in AS/NZS1170.2 [1].

Station	Gumbel	q-model	BLUE	AS/NZS1170.2
1	36.1	35.4	34.5	39
2	28.1	27.7	27.1	
3	28.8	28.2	28.5	
4	43.5	40.4	37.7	
5	37.4	36.6	33.2	
6	43.1	40.4	42.1	

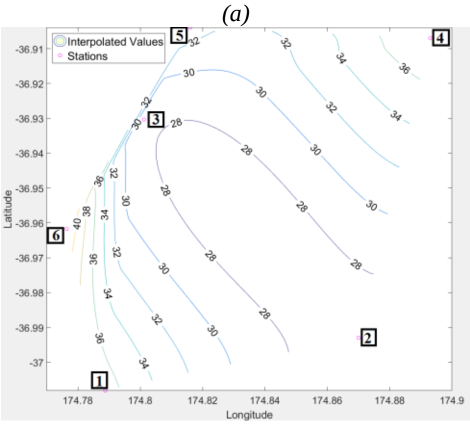
Table 2. Extreme value analysis for a 50-year return period

As can be seen in the above table, for some stations there is good agreement between different methods, but for others there are considerable differences, such as stations 4 and 5. The results from the BLUE method have been used to generate a contour map for the region studied. For interpolation purposes, the triangulation method is employed which uses Renka's algorithm

[11] to carry out a Delaunay triangulation of the observation points. The purpose is to identify a neighbourhood of nearby observation points to be used in the interpolation. There are various methods to apply the triangulation-based interpolation. The one used in this study uses a polynomial fit within each triangle in the triangulation, which involves an intermediate step of fitting a cubic spline on each edge of the triangulation. The interior values are taken as weighted averages of the edge values.



(a)



(b)

Figure 8. Contour maps of extreme winds for a 50-year return period for the selected area in the Auckland region

Figure 8 shows that within the relatively small area considered in this study, the values of the estimated extreme wind speeds change quite considerably, ranging from 28 m/s to 42 m/s. This result shows the considerable challenge of analysing historical wind data to predict extreme values. It should be noted that AS/NZS1170.2 [1] gives a single value of regional wind speed for large areas of New Zealand in order to keep it relatively simple. Despite the fact that for the purpose of interpolation it is desirable to have several data points to achieve more accuracy and high-resolution maps, in meteorological studies, due to the limited number of stations, just a few data points are available within different regions. In this preliminary study, a quite simple method of interpolation was employed. However, further work is underway to attempt to use more sophisticated prediction methods for both the extreme value analysis and interpolation.

Conclusions

The study investigated historical wind data from 6 meteorological stations in the Auckland region. Prior to the extreme value analysis the wind data were subjected to a homogenisation algorithm (PMFT) to identify any significant shifts in the recorded wind speeds and were accordingly corrected to generate homogenised sets of data. Three extreme value analysis methods were used to estimate the extreme wind with a return period of 50 years. The results showed a considerable variation in the extreme winds predicted within the quite small selected area, whereas AS/NZS1170.2 provides a single values of regional wind speeds for large areas of the country. Thus a more accurate and extensive investigation of the New Zealand’s historical wind data, particularly those recorded after the 1990s, is required in order to modify or confirm the current extreme wind speeds given in AS/NZS1170.2 for New Zealand.

Acknowledgments

The authors are grateful to Dr. Richard Turner (NIWA) and Mr. Paul Carpenter (Opus) for their comments and help in providing historical wind data.

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