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# Effects of site relocation and instrument type on recorded wind data characteristics at Wellington Airport

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## ABSTRACT

Using surface wind speed observations directly without correction for terrain and instrument response characteristics can introduce significant errors in extreme wind speed estimates and other climatological studies. Wind speed measurements collected during 1972 to 2016 at Wellington airport, New Zealand, are the focus of this study. There is a considerable shift in the recorded gust speeds for years after 1993, due to changes in instruments and observing practices, and also the relocation of the mast. In this study, directional gust factors, effective roughnesses, and turbulence intensities at both sites are calculated using the recorded mean and gust data. In addition, by taking into account the response characteristics of the old and new measuring systems, a set of directional correction factors is obtained that can be used to homogenise the historical wind data at this meteorological station. The results show that direct usage of the raw data can lead to wind speed errors of up to about 40%.

## 1. Introduction

Long-term historical mean and gust wind data are used in many meteorological and climatological studies, including evaluation of wind-speed trends over a long periods of time, estimates of extreme wind speeds for design wind loads, and so on. Various systematic errors originating from different sources, like change in instrumentation response characteristics and site location, affect the homogeneity of the historical data. Using the raw data without accounting for these changes and eliminating the artificial breakpoints can lead to significant errors in further analyses. Therefore, in order for a wind field analysis to be useful, all input data should conform to a common standard framework. Powell et al. (1996) analysed the wind data collected during Hurricane Andrew and demonstrated that using non-standardised data might lead to errors of 15%-40%. Later, Masters et al. (2010) assessed the gust and mean wind speeds recorded at 148 stations and computed directional effective roughness ($z_0$), and based on the values of $z_0$ calculated a set of directional correction factors for each station. Their results also show that direct use of surface wind speed data could introduce errors on the order of 40%.

Wind speeds recorded at airports are important to researchers, due to the good quality of instruments at these stations and the usually long duration of available data. However, there are various factors, mentioned above that affect the historical wind data. In addition, the assumption that airport terrain can be adequately described as open exposure will likely introduce errors in subsequent analyses, as shown by Masters et al. (2010). Thus it is crucial to consider all the possible sources of error and to adjust the data in such a way that they conform to a common standard.

In this study, we investigate the wind data recorded at Wellington airport, New Zealand during the period 1972 to 2016 and compute directional gust factors, turbulence intensity and $z_0$ for 16 wind sectors. Several substantial changes took place at this station in 1993, including a change in anemometer type, from a heavy-cup Mark II Munro (MK II) to a light Vaisala WAA151 cup anemometer, change in observing practices, and adoption of the WMO-recommended 3-s moving average for gusts, a change in anemometer height from 11 m to 7 m, and there was also a site relocation. The locations of the anemometers prior to 1993 and after 1993 are shown in Figure 1. A careful analysis of the impact of these factors on the gust record in creating an homogenous record will also aid in interpreting longer term climate trends.


Fig. 1. The locations of anemometers at Wellington airport; (left) after 1993; (Right) before 1993

Figure 2 shows the raw annual maximum gust wind speeds recorded at Wellington airport from 1972 to 2016. As can be seen, there is a breakpoint at 1993, and the gusts measured after this date are lower compared to those recorded by the old system at the previous mast location.

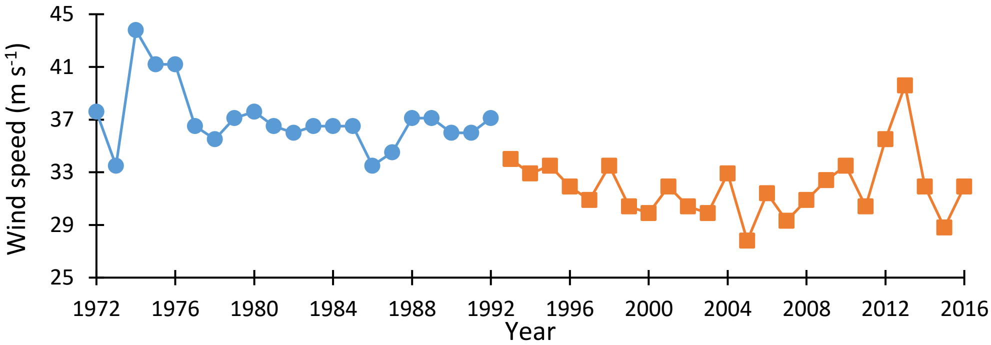



Fig. 2. Raw annual maximum gust for all directions as recorded at Wellington airport from 1972 to 2016 (NIWA, CliFlo)

Having said that, many factors have affected the recorded data at this station resulting in the artificial shift, and now the question is “how much has the actual climate signal changed?”.

Regarding the effects of change in the anemometer type and observing practices, Safaei Pirooz and Flay (2018) carried out an experimental study and proposed a set of correction factors that take into account the effects of both instrument changeover (from MK II to Vaisala WAA151), and adopting the WMO 3-s moving average gust speeds. However the other factors also must be considered.

The anemometer height can be compensated for using the logarithmic velocity profile (Eq. (1))

$$\frac{U}{u_*} = \frac{1}{\kappa}\ln\left(\frac{z}{z_0}\right) \tag{1}$$

where $u_*$ is the friction velocity and $\kappa$ is the Von Karman constant.

A traditional way of determining directional effective roughness ($z_0$) is to use aerial photographs and land cover information, which is inherently subjective and sensitive to the quality and age of the photographs (Masters et al. 2010). However, here we perform a mathematical analysis based on historical recorded wind data to estimate $z_0$ values.

Wieringa (1973) presented gust factors for wind speeds recorded over a lake and at the edge of a town, and proposed a simple non-spectral model for gustiness at high wind speeds in the constant shear-stress layer that relates the gust factor to surface roughness and measuring height. Later Wieringa (1976) demonstrated how the omission of exposure correction might lead to exaggeration of mesoscale horizontal wind gradients. Ashcroft (1994) investigated the relationship between the gust factor and terrain roughness and showed that median gust factors for each wind section successfully correlated with the estimate of terrain roughness. In addition, the dependence of gust factors on the averaging time and gust duration was discussed in detail, and Ashcroft (1994) showed that the 3-s gust factor shows a much wider range of wind-speed dependence from station to station and it was impossible to define a general pattern of change with wind speed. Verkaik (2000) evaluated the accuracy of the gustiness models of Wieringa (1973) and Beljaars (1987) in estimating the local roughness length and exposure correction factors. It was shown that both gustiness models were able to compute the exposure correction within a 5% error, and also it was concluded that the accuracy of calculation of $z_0$ depends strongly on the magnitude of $z_0$ itself.

In this study, the directional effective roughness values at both mast locations are computed using the recorded mean and gust wind speeds. Finally, directional correction factors are obtained that convert all the gust measurements to equivalent standard wind speeds, as recommended by AS/NZS1170.2 (2011) (i.e. $z = 10\ \mathrm{m}, z_0 = 0.02\ \mathrm{m}$) and WMO-recommended 3-s gust duration. The factors include effects of terrain, anemometer height as well as the response characteristics of the anemometers.

## 2. Analysis Procedure

Initially, the gust ($\widehat{U}$) and 10-min mean wind speed ($\overline{U}$) data are quality controlled and reduced. Mean wind speeds with a value of less than 5 m/s are excluded from the analysis to ensure that the atmospheric boundary layer (ABL) is nearly neutral, since in strong wind situations due the quite strong mixing the ABL tends towards the neutral condition. In addition, abrupt gust fronts that result in high gust factors are also eliminated. The remaining data points are divided into 16 wind directions.

Gust factors are calculated for all segments using 10-min means and gusts recorded by the MK II and Vaisala anemometers. The gust factor equation is written in Eq. (2).

$$GF(T, \tau, z, z_0) = \frac{\widehat{U}(\tau, z, z_0)}{\overline{U}(T, z, z_0)} \tag{2}$$

The gust factor (GF) is dependent on the gust duration ($\tau$), averaging duration ($T$), anemometer height ($z$), and the effective roughness ($z_0$). Then GF measurements collected from the same instrument in the same direction are averaged to determine the expected mean GF values.

A theoretical GF model of Davenport (1964) is applied to calculate directional turbulence intensities. The model is defined in Eq. (3)

$$GF = 1 + gI_u \tag{3}$$

where $g$ is a peak factor, and $I_u$ is turbulence intensity. The value of $g$ depends on the instrument type as well as the gust duration. Safaei Pirooz and Flay (2018) discuss the effective gust duration of MK II and Vaisala WAA151 anemometers, and show that the expected average values of $g$ for MK II with a gust duration of about 1s, and for the Vaisala when applying the 3-s moving average are 3.2 and 3.34, respectively. Thus, by having the GF and $g$, $I_u$ can be computed from Equation 3.

To find an estimate of $z_0$ from the turbulence intensity, Equation (4) can be used

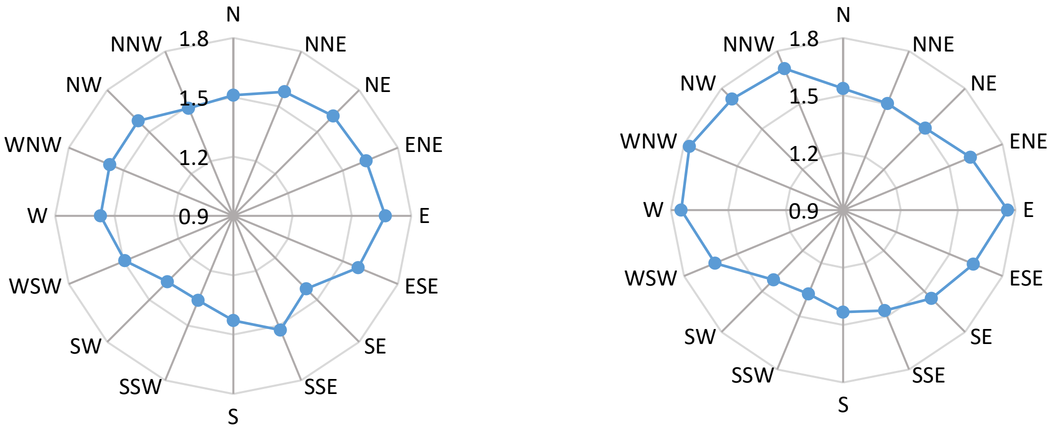
$$I_u(z) = 1/\ln(z/z_0) \tag{4}$$

which is derived from Equation 1 with an assumption that $\sigma_u = 2.5u_*$. Eq. (4) can be recast as Eq. (5).

$$z_0 = z\exp(-1/I_u) \tag{5}$$

## 3. Results and Discussion

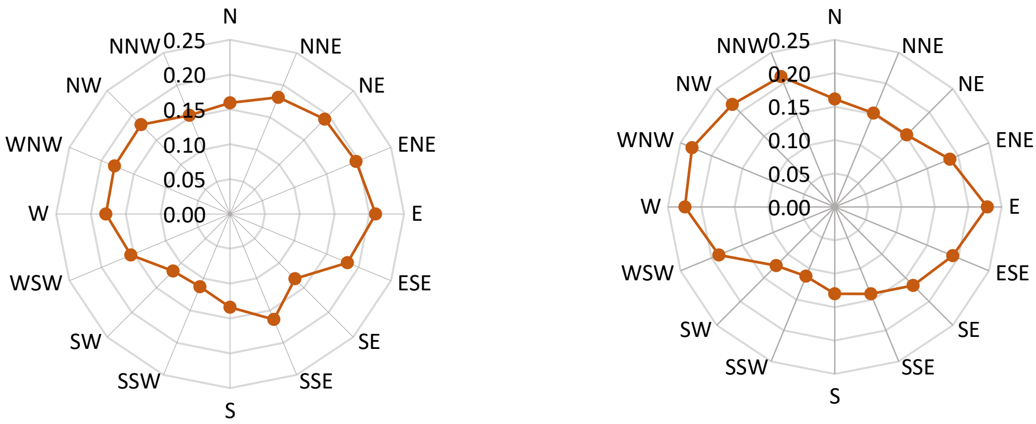
The GFs for periods of 1972-1992 and 1993-2016, during which, as explained above, different anemometers were used, and also the measurement height and mast location were different, are calculated and shown in Figure 3. As can be seen, the gust factors for directions from W to N, also NNE and NE are quite different for the two periods, and also there are some slight differences for other directions as well. The averaged values of GF for years 1972-1992 and 1993-2016 are 1.525 and 1.585, respectively.




(a) (b)

Fig. 3. Gust factors: (a) 1972-1992; (b) 1993-2016

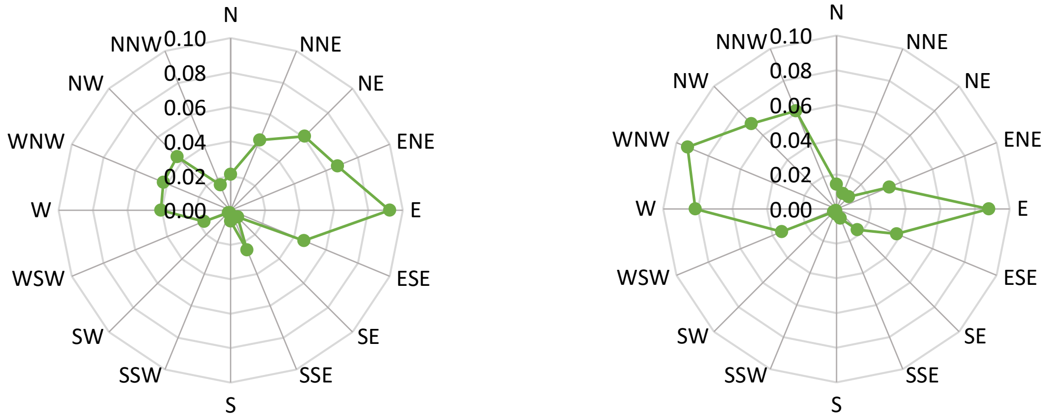
Figure 4 compares the directional turbulence intensities, computed from Equation 4, for both mast locations. The turbulence intensities averaged over all directions for periods 1972-1992 and 1993-2016 are 0.164 and 0.176, respectively. Although the averaged values are nearly equal, similar to the GF trends, values for individual directions differ for the two periods.




(a) (b)

Fig. 4. Turbulence intensity: (a) 1972-1992; (b) 1993-2016

Having calculated the directional GF and turbulence intensities for both periods, $z_0$ can now be calculated using Equation 5. The results are shown in Figure 5. The values of $z_0$ are close to the expectations based on the terrain conditions surrounding the stations. For both periods, the lowest values are obtained for the southerly directions, including SE, SSE, S, SSW, and SW, where the wind flows over open water. Also, when the wind flows along the airport runway, $z_0$ takes on low values. For the years 1972-1992 the runway was on the West side of the mast, so $z_0$ for NNW and N is low, and at the current mast location the runway is at the East side, thus values of $z_0$ for N, NNE, NE are quite small. The only unexpected values are obtained for W and WNW for 1993-2016, which seems a bit high, considering that for these directions wind flows over the seawater that extends for a distance of about 900m to the West.




(a) (b)

Fig. 5. Effective roughness (in metres) (a) 1972-1992; (b) 1993-2016

## 4. Directional Correction Factors

Finally, a set of directional correction factors are computed that account for the terrain roughness, anemometer height, and instrument response characteristics. The correction factors for the period 1972-1992, convert the MK II gust measurements to equivalent 3-s Vaisala gust measurements, as dicussed by Safaei Pirooz and Flay (2018), and they also correct the measurement height from 11 m to 10 m, and convert the calculated $z_0$ to the standard value of 0.02 m. However, the factors for period 1993-2016 include just the effects of terrain roughness and measurement height (from 7 m to 10 m).

Table 1. Directional correction factors to convert the measured data to standard conditions

| Direction | For 1972-1992 | For 1993-2016 |
|---|---|---|
| N | 0.892 | 1.003 |
| NNE | 1.013 | 0.943 |
| NE | 1.076 | 0.947 |
| ENE | 1.097 | 1.160 |
| E | 1.170 | 1.420 |
| ESE | 1.021 | 1.189 |
| SE | 0.738 | 1.032 |
| SSE | 0.918 | 0.876 |
| S | 0.749 | 0.808 |
| SSW | 0.633 | 0.699 |
| SW | 0.648 | 0.774 |
| WSW | 0.862 | 1.168 |
| W | 0.998 | 1.395 |
| WNW | 1.006 | 1.438 |
| NW | 1.013 | 1.348 |
| NNW | 0.855 | 1.311 |

From the above factors, it can be seen that for some directions if the measured data are not corrected, errors of 40% would be introduced to the wind speeds and subsequent analyses. These values are in agreement with findings of Masters et al. (2010) and Powell et al. (1996). The averaged values of these factors are applied to the annual maximum gust speed data recorded at Wellington airport, and homogenous time series is produced, as shown in Figure 6.

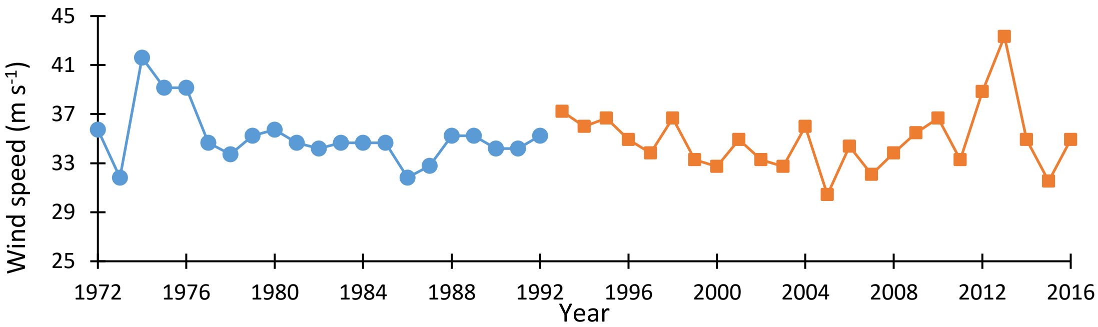



Fig. 6. Corrected annual gust speeds at Wellington airport from 1972 to 2016

## 5. Conclusions

Gust and mean wind speeds recorded at Wellington airport were used to compute directional turbulence intensity and effective roughness for two different periods. First, from 1972 to 1992, when a heavy-cup Mark II Munro anemometer was used and the measurement height was 11 m; second, 1993 to 2016 when the mast was relocated and a new light Vaisala cup anemometer was utilised at a height of 7 m. All these changes that happened in 1993 have significantly affected the historical wind data. In this study, by taking account of the calculated effective roughness, anemometer height and response characteristics of the recording systems, sets of directional correction factors were computed that convert the raw measurements to an equivalent standard wind speed, as defined in AS/NZS1170.2 (2011) (i.e. $z = 10\ \mathrm{m}, z_0 = 0.02\ \mathrm{m}$) and WMO-recommended 3-s gust duration. Results show that failure to implement the adjustment procedure and use of the data without correction could lead to errors of up to 40% for some wind directions.

## Acknowledgements

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