Aotearoa New Zealand Design Wind Speeds: Updates to AS/NZS 1170.2 and High-Resolution Maps using Reanalyses

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ABSTRACT

The paper comprises two parts. The first part summarises our recent work on the homogenisation of the historical wind speed records across New Zealand and the design wind speed estimates using these homogenised time series. Changes in design wind speeds and associated directional and lee-zone multipliers proposed to be incorporated in the next version of the Australian/New Zealand Wind Action Standard (AS/NZS 1170.2) are also presented in the first part. The second part of the paper presents the results of utilising two global reanalysis products, namely ERA-Interim and ERA5, to generate high-spatial resolution design wind maps for New Zealand. Various extreme value analysis (EVA) methods were employed. The gust wind speeds were separated into synoptic and non-synoptic events to determine the main source of extreme winds across New Zealand. The advantages and uncertainties of the use of reanalysis data in the estimation of design wind speeds are also discussed.

1. Introduction

1.1 Historical Wind Speed Records in New Zealand

A comprehensive review on New Zealand gust climatology and historical wind records as well as instrumentation and the associated gust durations are provided by Safaei Pirooz et al. (2020b) and Safaei Pirooz et al. (2020a), respectively. Almost all buildings and structures in New Zealand are designed to resist the effects of the wind speeds specified in the wind-loading standard (AS/NZS 1170.2, 2011). The regional wind speeds in this standard are based on the analyses of gust speeds recorded prior to the 1990s (Holmes et al., 2018). New Zealand's wind records had not been studied for extreme value analysis (EVA) purposes for the past two decades, until recently (e.g. Safaei Pirooz et al., 2020a,b; Turner et al., 2019). Therefore, over the last few years, we have attempted to initially develop a homogenisation algorithm (Turner et al., 2019) to ensure the suitable quality and homogeneity of the historical records, and then to separate storm types and carry out extreme value analysis (EVA) (Safaei Pirooz et al., 2020b) to obtain more accurate design wind speeds estimates and associated multipliers based on homogenised long-term wind records.

One of the major points to consider when homogenising and performing EVA is the difference between the recording systems and signal processing (i.e. gust duration) used during various time periods. The basic maximum gust speed duration in (AS/NZS 1170.2, 2011) is defined as 0.2 s, as opposed to a 3-s duration or average, recommended by the (World Meteorological Organisation, 2014) (WMO). Holmes and Ginger (2012), Miller et al. (2013) and Safaei Pirooz et al. (2020a,b) elaborated the rationale behind the redefinition of the design gust speed, which was the fact that both the low-speed and high-speed versions of the Dines anemometer recorded maximum gust speeds equivalent to a 0.2-s moving average. Since the design wind speeds provided in (AS/NZS 1170.2, 2011) are mainly based on the EVA of maximum gust wind speeds recorded by the Dines anemometer used in Australia, the gust duration was redefined to 0.2-s gusts. However, in New Zealand before the 1990s the heavy Mark II Munro cup anemometer with a chart recorder, referred to as MKII, with a gust duration of about 1-s was used, which was then replaced by automatic weather stations (AWS) with light Vector A101 and Vaisala WAA151 cup anemometers with digital recorders with a 3-s gust duration.

1.2 Reanalysis Data

Although meteorological stations generally provide valuable and reliable data, they are usually located far from one another, resulting in low-quality spatial analyses (Safaei Pirooz et al., Under review). In addition, historical observation data are often not continuous, or are only available for a limited number of years. However, for analyses, such as EVA and trend analysis, long-term datasets are preferable. Reanalyses have the potential to compensate for the lack of in-situ data and fill the gaps in observations time series (Dee et al., 2011; Tetzner et al., 2019). Recently, we (Safaei Pirooz et al., Under review) used gust wind speeds from two global reanalyses products, namely ERA5 and ERA-Interim, which provide high-spatial resolution data (31 km and 80 km, respectively), for a 30-year period, from 1990 to 2019, to initially validate them against observation data and then to generate high-resolution wind maps for New Zealand.

This paper summarises our recent research and methodologies employed to propose changes for the next version of AS/NZS 1170.2, which includes adding a new wind region to New Zealand, refinements of wind zone boundaries, revising all regional wind speeds and directional multipliers, and modifying the lee-zone regions and multipliers. In addition, the results of the analyses of the reanalysis products and the high-resolution wind maps are presented.

2. Methodology

To eliminate artificial, non-climatic trends and breakpoints in historical wind speed time series resulting from changes in anemometers and signal processing (i.e. gust duration), site relocation, surrounding environment and local topography, the recently proposed homogenisation algorithm (Turner et al., 2019) was employed. In order to account for the changes in the response characteristics of anemometer and gust durations utilised during different times, the results of (Safaei Pirooz and Flay, 2018; Safaei Pirooz et al., 2020a) were used. Then, the homogenised wind speeds were separated into synoptic and non-synoptic events using the procedure proposed by (Holmes et al, 2018; Holmes, 2019).

Lee zones, areas affected by the wind speed-up due to the presence of mountains, can significantly influence the design wind loads. To estimate the lee-multipliers, first the locations of lee zones were identified by analysing New Zealand Convective-Scale Model (NZCSM) (Turner and Moore, 2017) wind speeds to determine prevalent locations of strong winds downwind of mountain ranges in New Zealand. Then, EVA was carried out on the records of stations located in or near the lee zones to estimate the magnitude of the lee-multipliers.

For EVA of the historical observational data, three different extreme value distributions were used, namely Type I (using Gumbel, Gringorten and best linear unbiased estimators (BLUE) fitting methods), Type III (using maximum likelihood and probability weighted moments methods), and Peaks-Over-Threshold (POT) approach. For Type I and III approaches, annual maximum gust wind speeds were used, while maximum daily gusts were used for POT. The independency of POT values was studied and elaborated upon in (Safaei Pirooz et al., 2020b). In the case of reanalysis data, four methods, namely Gumbel, Gringorten and BLUE based on annual maxima, and the method of independent storms (MIS) using peaks over a threshold, were used. More detailed explanation and comparisons of these methods can be found in (Safaei Pirooz et al., 2020b; Safaei Pirooz et al., Under review). In this paper only the final results are presented.

The reanalysis data were validated against homogenised wind gust observations from 52 meteorological stations across New Zealand by calculating bias, root mean squared error (RMSE) and correlation. In addition, a post-processing technique was employed that uses the observation data to correct the biases in the reanalyses data. Lastly, EVA was performed on both corrected and uncorrected reanalyses.

3. Results and Discussions

3.1 New Zealand's Updated Design Wind Speeds and Multipliers

Figures 1 and 2 show the updated lee zones and design wind speeds proposed for the next version of AS/NZS1170.2, respectively. The lee zones identified through the analysis of NZCSM data are shown in Figure 1. For the values and directionality of lee multipliers of each zone numbered in Figure 1 see Table D.2 in (Safaei Pirooz et al., 2020b).

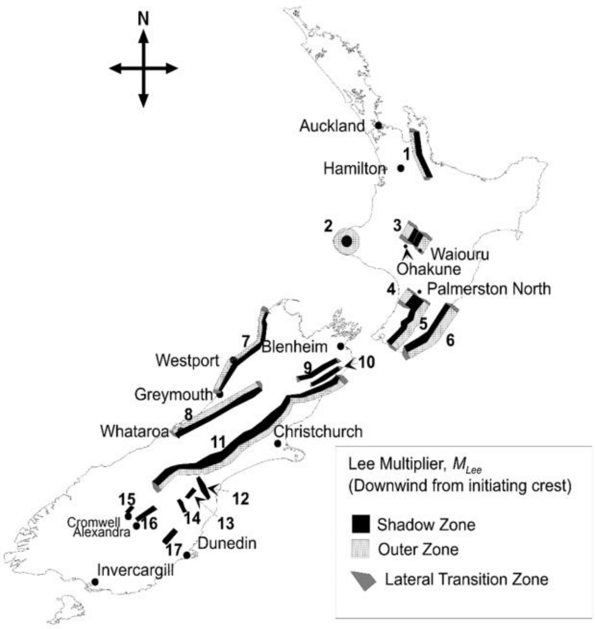

Figure 1. Updated lee zones in New Zealand. Numbers identifying each lee zone correspond to the mountain ranges explained in detail in (Safaei Pirooz et al., 2020b)

Figure 2 compares the proposed design wind speeds and directional multipliers for each wind region with those of provided in the current version of (AS/NZS 1170.2, 2011). First it should be noted that in order to make the nomenclature similar, simple and distinguished from the Australian wind regions, we have proposed renaming the regions NZ1, NZ2 and NZ3, which were previously known as A6, A7 and W, respectively. In addition, as shown in Figure 2g, the analyses demonstrated that the southern region of the South Island (i.e. Foveaux Strait) requires considerably higher regional wind speeds than those provided in (AS/NZS1170.2, 2011). Therefore, adding a new region has been proposed, named region NZ4, to New Zealand's wind regions in the future version of AS/NZS1170.2. The four regions were determined based on the orography and wind climate of each region. For regions NZ1, NZ2 and NZ3, the proposed design wind speeds are higher than current values, particularly for average recurrence intervals (ARI) of less than 500 years. Regarding the directional multipliers, for NZ3 and NZ4 the proposed multipliers are considerably different and less conservative compared with those in (AS/NZS 1170.2, 2011). The proposed values are consistent with the directional multipliers obtained based on the wind data records in these regions. Also, for NZ1 and NZ2, the multipliers have changed slightly, particularly for the north, south and southwest directions. Detailed explanation of how the multipliers were computed and how resulting probabilities defer from the current values in (AS/NZS 1170.2, 2011) is provided in (Safaei Pirooz et al., 2020b).

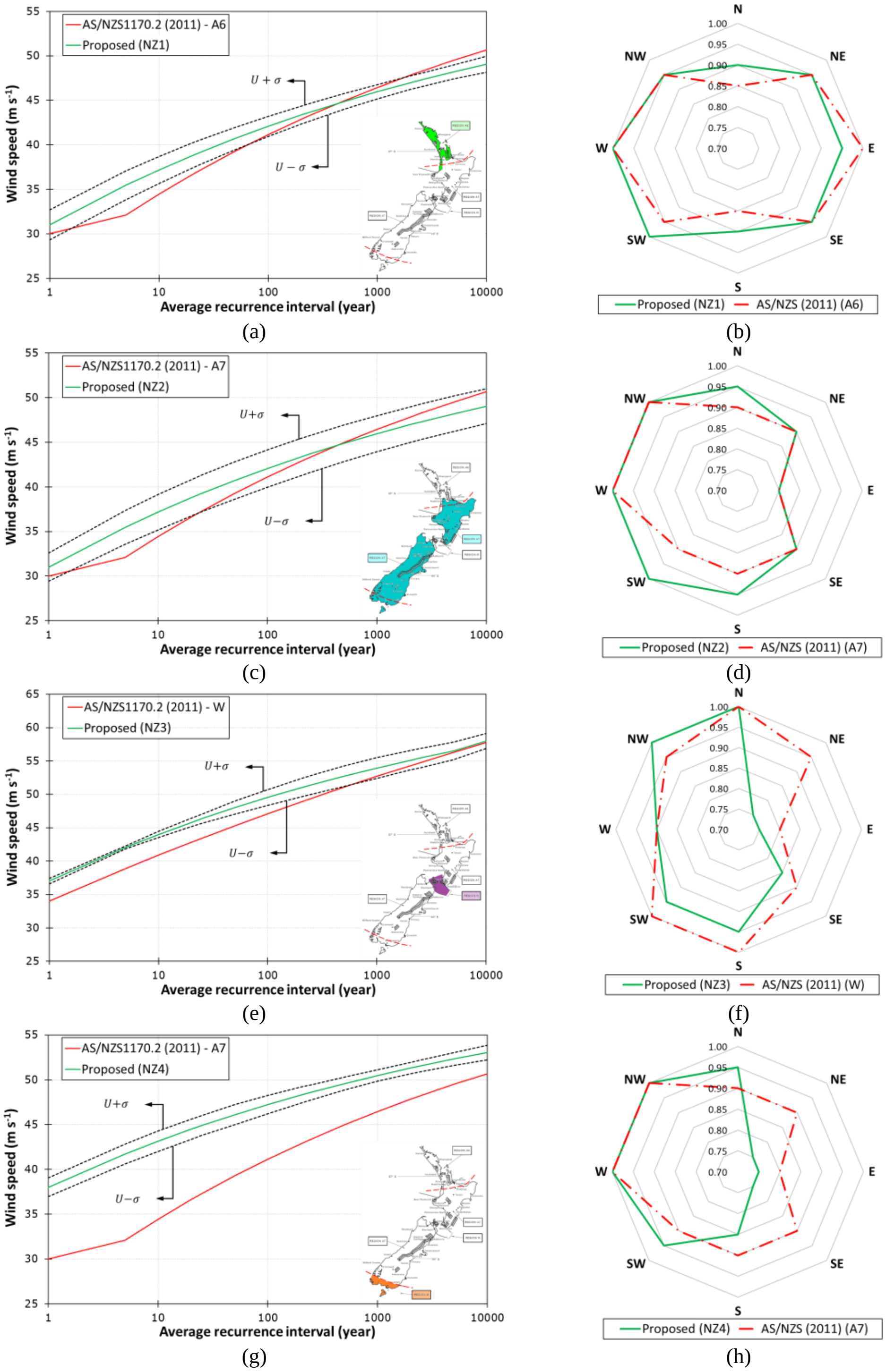

Figure 2. Design wind speeds (left) and associated directional multipliers (right) computed for regions: (a,b) NZ1 (A6); (c,d) NZ2 (A7); (e,f) NZ3 (W); (g,h) NZ4

3.2 High-Spatial Resolution Wind Maps

The validation process illustrated that over relatively flat terrain with no significant orography, e.g. NZ1 and NZ2-North, the reanalyses performed well. However, over complex and mountainous terrain, e.g. NZ2-South, and high-wind regions, e.g. NZ3 and NZ4, the statistical scores were relatively lower. In addition, the validation results revealed the dependency of bias on the wind speed intensity, such that the positive and negative biases increase at low and high wind speeds, respectively.

Table 1. Percentage difference ($100 \times [(U_R)_{Reanalysis} - (U_R)_{Obs}]/(U_R)_{Obs}$) between the design wind speeds calculated using observations, corrected and uncorrected ERA5 (inside parentheses) data.

	BLUE				MIS			
Return Period	**NZ1**	**NZ2**	**NZ3**	**NZ4**	**NZ1**	**NZ2**	**NZ3**	**NZ4**
1	3.49 (1.38)	3.27 (1.53)	-0.35 (-13.03)	-0.06 (-9.16)	2.25 (-1.44)	1.02 (-1.72)	-1.47 (-11.58)	0.11 (-5.54)
10	3.61 (-1.43)	3.93 (-0.29)	4.22 (-11.81)	1.71 (-9.97)	2.23 (-3.07)	1.51 (-3.38)	-0.49 (-14.17)	0.76 (-6.53)
100	3.72 (-3.37)	4.35 (-1.61)	7.64 (-10.82)	2.84 (-10.74)	2.20 (-4.65)	2.01 (-4.98)	0.47 (-16.70)	1.42 (-7.53)
500	3.77 (-4.22)	4.53 (-2.21)	9.24 (-10.34)	2.50 (-11.88)	2.18 (-5.53)	2.30 (-5.86)	1.01 (-18.11)	1.80 (-8.10)
1000	3.79 (-4.52)	4.59 (-2.41)	9.80 (-10.16)	2.30 (-12.36)	2.18 (-5.87)	2.41 (-6.20)	1.21 (-18.65)	1.95 (-8.32)
10000	3.85 (-5.30)	4.75 (-2.97)	11.31 (-9.68)	1.81 (-13.59)	2.16 (-6.84)	2.74 (-7.17)	1.80 (-20.22)	2.39 (-8.98)

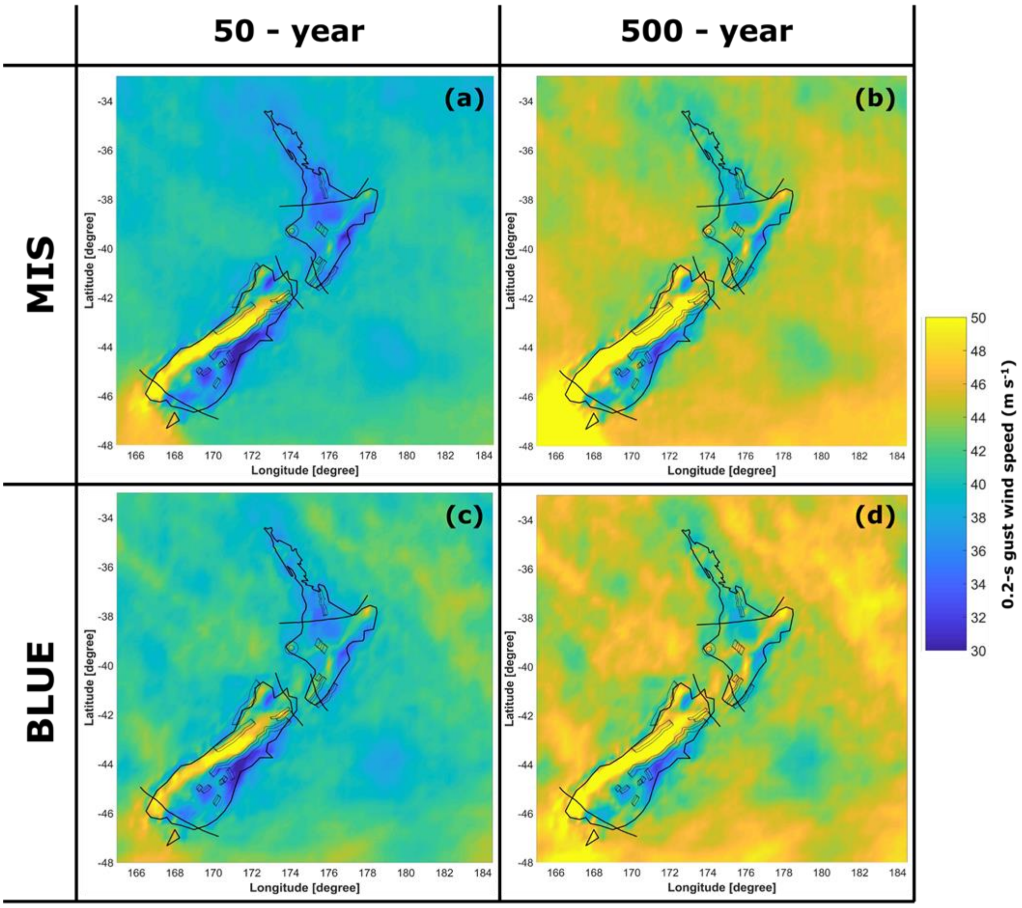

Figure 3. New Zealand design wind speed map along with the locations of lee-zones (within black polygon boundaries) for 50-year and 500-year ARIs obtained from ERA5 data using: (top) MIS; (bottom) BLUE.

Based on the values of the biases for each region as a function of wind speed intensity, a simple bias correction method was used (for details see (Safaei Pirooz et al., Under review)). Applying the correction method to the reanalysis data led to higher statistical scores and design wind speeds that agree with observations considerably better. By way of example, Table 1 shows the percentage difference between the design wind speeds calculated using observations, corrected and uncorrected ERA5 data, by BLUE and MIS methods.

Generally, ERA5 outperformed ERA-Interim in the validation process and more accurately captured wind speed-ups over the mountains and in lee-zones. Among the EVA methods employed for the reanalyses data (Gumbel, Gringorten, BLUE and MIS), the MIS method and then the BLUE method provide the best estimations of the design wind speeds, in terms of the lowest difference compared with the observation-based design wind speeds. Figure 3 shows the final results of the design wind speeds, lee-zone locations and wind speed-ups at 50-year and 500-year ARIs obtained using the ERA5 reanalysis data and the MIS and BLUE methods for the whole New Zealand domain.

4. Conclusions

The paper outlines our recent work on analysing historical wind records across New Zealand, including homogenisation and extreme value analysis, that resulted in determining updated design wind speeds and associated directional and lee multipliers. Substantial changes to New Zealand's wind regions and design wind speeds have been proposed for the next version of the AS/NZS1170.2 based on the results of these studies. The second part of the paper demonstrated the use of reanalysis products in the estimation of design wind speeds and generation of high-spatial resolution wind maps for New Zealand. It was demonstrated that reanalyses can be used as a complementary method to observation data to estimate design wind speeds with a higher-spatial resolution. The MIS approach using the reanalysis data yielded the least errors compared with the observation-based design wind speeds, ranging from – 1.5% to 2.75% and – 4.5% to 1.0% for corrected ERA5 (30 km) and ERA-Interim (80 km), respectively. However, unlike ERA5, ERA-Interim failed to correctly capture wind speed-ups over the mountains and lee-zones.

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