A survey of current knowledge regarding climate change impacts on extreme wind gusts in Aotearoa New Zealand and implications for AS/NZS1170.2:2021

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ABSTRACT

The Aotearoa New Zealand (NZ) government has recently passed legislation making climate-related disclosures mandatory for many organisations and many are now undertaking assessment exercises to quantify projected climate change risks to their organisation. These assessments often include profiling their exposure of assets or operations to extreme wind gusts under climate change.

Results from a climate model downscaling analysis on extreme wind Annual Exceedance Probabilities (AEPs) for a local power distribution company in the Canterbury region are described. The assessment indicates possible increases in 99% wind speeds and, for inland locations of Canterbury, potentially large changes in design speeds of up to 10% later in the century for the worst-case Representative Concentration Pathways (RCPs). This later outcome could be the result of changes in lee-slope windstorm intensity.

1. Introduction

Recent legislative changes in Aotearoa New Zealand (NZ) have made climate-related disclosures mandatory for many organizations and many are now undertaking assessment exercises to quantify their exposure to risks in a changing climate. Such assessments include profiling asset or operational exposure to wind hazards, including extreme wind gusts.

Here, results from a recently completed regional climate model downscaling analysis on extreme wind AEPs over the Canterbury region of NZ are presented. Although coastal locations in Canterbury do experience the impacts of strong winds from downslope events, it is the inland areas near the foothills of the Southern Alps that are most frequently and severely impacted. One such event in August 1975 led to NZ$66M in insurance costs[1] alone. This fact has long been recognized in building and transmission line design wind codes such as AS/NZS 1170.2 (Standards Australia, 2021). where special "lee-zones" have been designated downwind of mountain ranges. In these lee-zones the design of a structure must account for much higher speeds off the mountains and this does represent a stringent, and likely conservative, design criteria. It is interesting to note while Christchurch experiences downslope wind events it is outside of the Southern Alps lee-zone because (i) the lee-effect is less

[1] https://www.icnz.org.nz/industry/cost-of-natural-disasters/

there, and (ii) the gust records from Christchurch Aero have a strong influence on the A7 Regional Speed's and the NW directional multiplier.

With buildings and other infrastructure often requiring design lifetimes extending to 50 years or more, design wind standards that are appropriate for the period 2070-2080 should be considered. In 2021 a climate change multiplier, M_c, was introduced into AS/NZS1170.2:2021 (Standards Australia, 2021) for Regions B2, C and D over Australia due to the possibility of an increase in Tropical Cyclone (TC) Category 4 and 5 storm activity. For NZ, there has been little work on climate change impacts on design speeds and, by association, lee zones. Historically, the impacts are uncertain, and the trends derived from current observations are for small or decreasing speeds (Pirooz et al. (2019) and Turner et al. (2019)). Thus, a value of 1.0 is currently applied for M_c in New Zealand.

We present results from modelling work that suggest otherwise, i.e., that downslope wind events may increase in frequency and strength under future climate change.

2. Methods and Models

Outage data from a Canterbury power distribution company was analysed to establish thresholds above which regional 3-sec gust speeds caused an outage. Then the ability of the regionally downscaled global climate models used in the study to represent the current climate was assessed and any systematic biases established. This allowed scaled thresholds for down-scaled wind gusts to be set for the frequency analysis that matched observations.

The power outage records (from 2008 to 2018) were quantitatively related to observed wind (maximum daily gust speed and direction) or gridded weather model wind analyses. Each outage in the supplied dataset had the cause noted, with many being due to "adverse weather", "gale winds +60km/h", and "snow" if that was thought to be the main cause of the outage. For each outage event attributed to high winds, the daily peak gust was found for each of a selection of weather stations across the Canterbury region. To give equal weighting to each observing site the peak gusts recorded at the various stations were normalized via scaling by the ratio between the annual mean 3-second gust speed at the relevant station and at Christchurch Aero. This was done to avoid discounting relatively strong wind events at stations with potential sheltering/exposure issues such as Rangiora (see Pirooz and Turner, 2021) and over-counting highly exposed sites with large speed-ups due to topography, such as Sugar Loaf which has a sensor 120 m agl on Banks Peninsula. Overall, 343 unique hours with wind related outage events were found and Figure 1 shows the distribution of gust speeds associated with these events. It is interesting to note the sharp rise in frequency of events from 70 km/h to 80 km/h and to note that 80% of the events had gusts exceeding 50 km/h, while 50% had gusts exceeding 70 km/h.

The future risk assessment was based on analysis of simulations by six Global Coupled Models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) under the four main RCPs, which were downscaled using a New Zealand regional (30 km grid-spaced) climate model. The six CMIP5 models used were BCC-CSM1.1 (BCC, Wu *et al.*, 2014), CESM1-CAM5 (CES, Meehl *et al.*, 2013), GFDL-CM3 (GFD, Griffies *et al.*, 2011), GISS-E2-R (GIS, Schmidt *et al.*, 2014), HadGEM2 (HAD, Jones *et al.*, 2011) and NorESM1-M (NOR, Bentsen *et al.*, 2013). These six GCMs were selected from all the CMPI5 models (there are over 40) based on historical performance in the southwest Pacific, model independence and data availability. They span a range of the CMIP5 warming response to future increases in CO_2, as measured by equilibrium climate sensitivity. The four RCPs used represent greenhouse gas concentrations that result in radiative forcings of 2.6, 4.5, 6.0 and 8.5 W/m^2 by 2100. These RCPs cover a range of possible scenarios with the 2.6 and 8.5 being the likely lower and upper bound in respect of emission pathways.

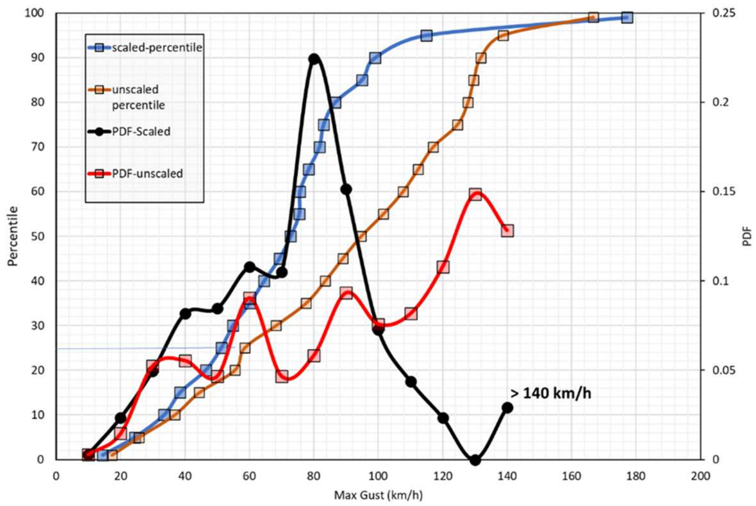

Figure 1. Percentile distribution (blue line) and probability density function (PDF, black line) of scaled maximum gusts for all days for max gust (across all 10 stations) where power outages occurred in between 2008 and 2018 due to strong winds. The orange line shows the percentile distribution with un-scaled gust and the red line the un-scaled PDF.

The annual cycle of observed mean wind speeds and temperatures for the 30-year climate period (1981 to 2010) were extracted from NIWA's Climate Database (https://cliflo.niwa.co.nz) to compare against recent climate simulations from the GCMs. Pressure records were also used as the wind conditions correlate well with the large-scale Trenberth pressure indices (Trenberth, 1976). These measure the difference in pressure between pairs of locations. For example, if the Auckland-Christchurch and Auckland-Invercargill gradients are positive this implies a generally westerly flow over Canterbury. If the Hokitika-Chatham Islands gradient is positive this implies generally southerly flow over Canterbury. Strong lee-slope wind events over the Canterbury Plains are indicated when the Hokitika-Christchurch gradient is highly positive (Turner *et al.*, 2012).

3. Changes in high wind speeds

In this section projections of future wind speed changes for the period 2031-2070 are presented for the Canterbury region.

Figure 2 shows, over all six GCMs used in this study, the average change in the number of hours per month with 3-sec gust speeds exceeding 50 km/h for a typical inland Canterbury point (left panel). The right panel shows the average change in hours of the Hokitika-Christchurch pressure difference exceeding 10 hPa. Together with the relationship between maximum daily wind gust and the Hokitika-Christchurch pressure gradient demonstrated by Figure 3, the changed response is attributable to increased westerly or north-westerly winds across Canterbury, with an associated increase in lee-slope winds. The association with a lee-slope response is also seemingly supported by some interesting contrasts between coastal and inland model locations (not shown).

AEPs for 1-, 50-, and 500-years, calculated using an assumed Gumbel Type I distribution on annual maximum (2031-2070) wind speeds, for a CMIP5 grid point in inland Canterbury are shown in Figure 4 (left panel). Increases, compared to the 1985-2005 baseline, of 4 - 8% in 50- and 500-year AEP speeds are seen for RCP's 4.5, 6.0, and 8.5. Coastal points (not shown), however, show no increase or even a slight decrease. With respect to 1-year AEPs most models show slight increases of 1 - 2% across all RCPs. The increases in average design speeds for 50-year (typical serviceability limit) and 500-year AEPs for inland points are potentially significant, and warrant further research, since the design loads increase as a square of the wind speed, e.g., a +8% increase in wind speed translates to a +17% increase in load.

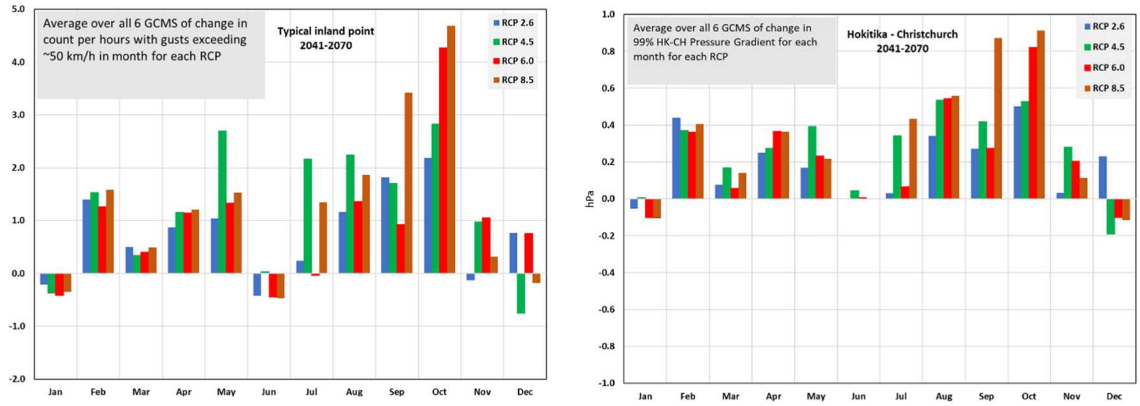

Figure 2. The average change, over all six GCMs of this study, in 99th percentile maximum gust wind speeds for each month for each RCP for a typical inland point (left panel) and 99th percentile value of the Hokitika-Christchurch pressure difference (right panel) for each RCP for the period 2041 to 2070.

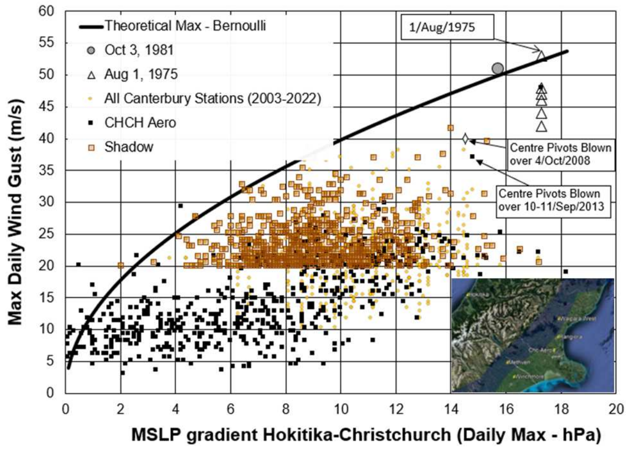

Figure 3. Plot of observed daily maximum wind 3-sec gusts (10 m agl) for several Canterbury region observing stations against the mean sea level pressure (MSLP) difference between Hokitika and Christchurch for the period 2003-2022. The thick black curve is the maximum wind gust based on the pressure difference and application of Bernoulli's equation. Significant historic/damaging wind events are also noted. The inset shows the location of the stations as well as the AS/NZS 1170.2 NW shadow lee-zone (blue shaded area).

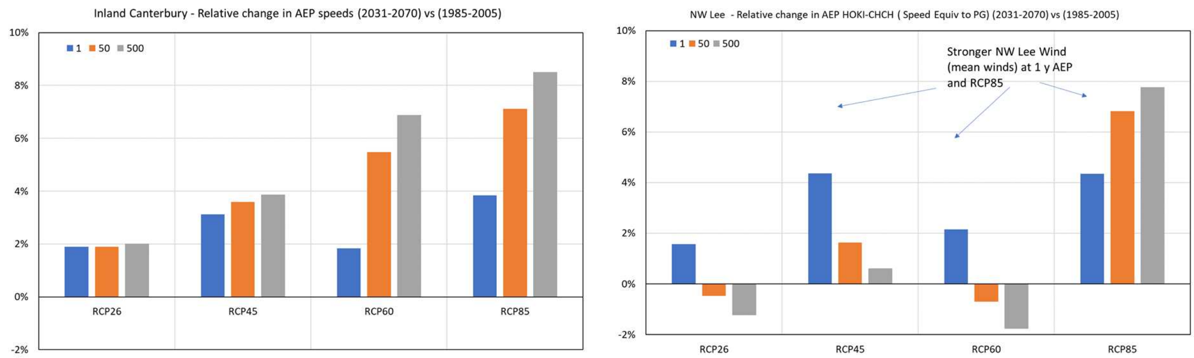

Figure 4. The relative change in AEP wind speed between the period 2031-2070 and 1985-2005 (blue = 1 year, orange = 50 years, grey = 500 years) for an inland Canterbury point (left panel). Right panel shows the relative change in AEP Hokitika-Christchurch pressure gradient between the period 2031-2070 and 1985-2005 (blue = 1 year, orange = 50 years, grey = 500 years) for each of the RCPs.

It is then helpful to compare against changes in the 50- and 500-year AEPs for various pressure indices to see if the lee-slope signal is plausible. This is because downslope windstorms do occur when there is a strong pressure gradient across the Southern Alps, i.e., when the Hokitika-Christchurch pressure difference is > 10 hPa, and these situations also occur in general westerly flow across the South Island. Figure 4 (right panel) shows that there is no definitively similar pattern in changes in the Hokitika-Christchurch pressure gradient between an inland point out of the lee zone (left panel) and one in it (right panel) for the various RCPs and AEPs, except for RCP8.5.

For the future period, the Auckland-Invercargill pressure gradient index (Figure 5) indicates for a generally stronger westerly flow over Canterbury under the RCP6.0 and RCP8.5 scenarios for all AEPs. This could explain part of the trend for increased downslope wind activity, but if so, it is not clear why this would also not also be reflected in the trends of the coastal AEP speeds.

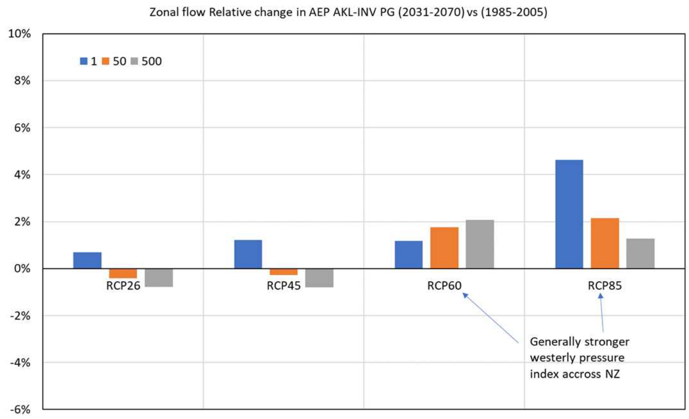

Figure 5. The relative change in AEP Auckland-Invercargill pressure gradient between the period 2031-2070 and 1985-2005 (blue = 1 year, orange = 50 years, grey = 500 years) for each of the RCPs.

The larger average changes in hours with wind gusts exceeding 50 km/h in the winter/autumn months (Figure 2) is corroborated by similarly larger changes in the Auckland-Invercargill pressure gradient index for the same months (not shown). These months overlap with the period of historically worst north-westerly downslope events over Canterbury. Similar analysis of the Auckland-Christchurch pressure gradient index shows no corresponding increase, strengthening the case that the increased westerly gradient is mainly due to increases in the Christchurch-Invercargill pressure gradients.

4. Discussion and Conclusions

Extreme wind gusts in New Zealand are classified as being either synoptic or non-synoptic in origin and a comprehensive analysis of climate change impacts on wind gusts would need to account for the impacts on each gust source phenomenon separately. Furthermore, observed analyses of long-term trends in gusts for Christchurch (Pirooz *et al.*, 2019) show little or slightly negative trends. Unfortunately, good long-term records from inland sites within the lee zone itself don't exist and these are needed to establish a baseline, let alone confirm the emergence of a trend.

Due to the km-scale resolution needed to adequately simulate tropical cyclones, severe convection, squalls, and many downslope windstorms, it is not possible to directly model the likely impacts of climate change on gusts from these phenomena using Global Climate Model's (GCM's) due to their coarse resolutions. However, large scale lee-wave events are primarily hydrostatic and could be represented by the regional model, so the downscaling workflow here should capture some of the impacts on lee slope events.

This work indicates possible increases in 99% wind speeds and, for inland Canterbury locations, potentially large changes in design speeds of up to 10% later in the century for the worst-case RCPs, likely due to changes in lee-slope windstorm intensity.

It is important to note the most dramatic increases in GCM-based design winds occur with RCP8.5 – a worst case emissions scenario and would impact most strongly later in the century. The "Climate Change Projections for New Zealand" (Ministry for the Environment, 2018) report shows the strongest signal in 99% wind speeds in the 2090's and also over the interior of the South Island.

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