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Potential effects of climate change on design wind speed estimates using dynamical downscaling of RCMs

Amir A. S. Pirooz [1], Stuart Moore [2], Stephen Stuart[3], Richard Turner [4]

[1]NIWA, Auckland, New Zealand, *Amir.Pirooz@niwa.co.nz*
[2]NIWA, Wellington, New Zealand, *Stuart.Moore@niwa.co.nz*
[3]NIWA, Wellington, New Zealand, *Stephen.Stuart@niwa.co.nz*
[4]NIWA, Wellington, New Zealand, *Richard.Turner@niwa.co.nz*

SUMMARY:
Design wind speed values in wind loading standards are based on historical wind records without accounting for the potential impact of climate change on extreme wind speeds. Recently, Australia/New Zealand wind loading standard (AS/NZS1170.2:2021) introduced a climate change multiplier, whose value for New Zealand (NZ) is 1.0 due to the lack of a significant observed upward trend in historical gust wind speeds. However, some preliminary investigations of regional climate model (RCM) projection outputs show signatures of increased wind speeds towards the end of the current century. Therefore, a robust analysis of future extreme wind speeds is required to ensure the safety and resilience of structures currently being designed/built with a life expectancy of >50 years. This study aims to: 1) analyse the wind speed outputs of NIWA's[1] 2.2-km RCM for 2081-2100; 2) identify extreme winds and their signature in RCM outputs, and 3) dynamically downscale selected RCM cases with a 12-km resolution to sub-kilometre scale over NZ under three Shared Socioeconomic Pathway (SSP) scenarios of 1-2.6, 2-4.5, and 3-7.0. These high-resolution assessments of extreme wind speeds will yield a more accurate estimation of future design wind speeds and inform adaption planning.

Keywords: Climate change, NWP and RCM, Future design wind speeds

1. INTRODUCTION

All structures are designed to withstand maximum wind speeds expected during the lifetime of the structure, as specified in wind loading standards (Holmes, 2015). However, the design wind speeds in standards are obtained by analysing historical wind records without accounting for potential changes due to climate change. Analyses of observed trends (Safaei Pirooz et al, 2019) in New Zealand's (NZ) wind record do not show statistically significant changes in the magnitude and frequency of historical extreme wind speeds, and this is consistent with historical period of CMIP5 GCMs (Global Climate Models) simulations. However, future projections from these CMIP5 GCMs do contain signatures of significantly increased extremes winds (up to 10% which translate to load increases of up to 20%) from around 2060 onwards, particularly for inland areas in the lee of mountain ranges in NZ (Turner and Stuart, 2021). This means that structures being built now with a 50-year life expectancy would be affected by these changes.

[1] The National Institute of Water and Atmospheric Research or NIWA, is a Crown Research Institute of New Zealand. Established in 1992, NIWA conducts commercial and non-commercial research across a broad range of disciplines in the environmental sciences. https://www.niwa.co.nz/.

National climate change projections inform adaption planning and decisions in downstream impact assessments. However, it has been demonstrated (Kendon et al, 2017) that coarse-resolution RCMs, particularly those making use of traditional convection parametrisation, might not be adequate and differ significantly from convection-permitting models. To better understand extremes and their impact, such as severe wind gusts and local storm dynamics, kilometre and sub-kilometre scale convection-permitting models are therefore required for future projection.

Besides the changes in frequency and magnitude of cyclones and tropical cyclones (TC) under future climate change (Emanuel, 2020), some recent studies, such as (Wang and Toumi, 2021), demonstrated poleward migrations of TCs, increasing the risk of these ex-TCs making landfall in NZ beyond the current low risk (Lorrey et al, 2014). However, uncertainties around changes in the location, magnitude, and frequency of (ex-)TCs in the future climate highlight a need for accurate evaluation of climate change effects on extreme winds.

1.1. Project Aims

In this study, we will provide evidence base for better guidance around design wind loads under climate change to improve the resilience of NZ's infrastructure against extreme winds intensified by climate change. This will lead to more accurate estimates of design wind loads and avoid costly over/under design of structures.

2. METHODOLOGY

Global climate models typically have relatively low spatio-temporal resolution. This is because it is too computationally expensive to run the models at resolutions suitable for capturing the extreme events needed to adequately inform structural design for the time spans and over the geographical area they need to cover. To reduce the computational burden of these physics-based models, we identify signatures of extreme winds for a few case studies using other climate variables, e.g. pressure, temperature profiles and foehn effects, in low-resolution climate models and then run high-resolution numerical weather prediction (NWP) models to dynamically downscale a limited number of identified events. This will provide a better scientific understanding of the physical characteristics of wind extremes in the future, which are required for governmental and regional executive decision-making plans.

This analysis will leverage years of investment and dedicated research on NWP and climate model development at NIWA. Model data from NIWA's future climate projections (Table 1) extending to the year 2100 will be initially assessed and compared with current design wind speeds estimated using historical wind records (Safaei Pirooz et al, 2020).

Table 1. NIWA's Regional Climate Models (RCMs) for NZ based on the UK Met Office Unified Model (UM).

#	UM version	Physics config.	Horizontal resn. (km)	Vertical Levels	Driving model(s)	Historical		Future		Output available for further downscaling?
						Period	Experiment	Period	Experiment	
1	4.5	UM4.5	30	19	6 x CMIP5 models	1971-2005	CMIP5 historical	2006-2100	RCPs 2.6, 4.5, 6.0, 8.5	No
2	10.3	Based on GA7.0	12	63	NZESM	1950-2014	CMIP6 historical	2015-2100	SSPs 1-2.6, 2-4.5, 3-7.0	Yes
3	10.6	Based on RA1-M	2.2	70	NZESM	1995-2014	CMIP6 historical	2081-2100	SSP3-7.0	No

Several extreme events across the country will then be downscaled using sophisticated NWP dynamical downscaling techniques. Ensembles of downscaled fields will be generated to investigate three different Shared Socioeconomic Pathway (SSP) scenarios and their effects on characteristics of wind gust climatology in NZ. Extreme value analysis will be performed on the downscaled extremes and will be compared with the current values in (AS/NZS1170.2, 2021).

3.1. Signature of extreme winds

Extreme wind gusts, particularly short-duration events, are often under-predicted or not resolved in RCMs. Therefore, it is essential to identify climate/weather conditions, present in the RCMs, that are likely to generate high-impact wind events before initiating the computationally expensive high-resolution downscaling model simulations. It has been demonstrated that machine-learning assisted windstorm identification algorithms can perform well in classifying the wind climate type (Cui et al, 2021; Spassiani and Mason, 2021). These approaches use mean and gust wind speed, pressure, air temperature, wind direction and precipitation timeseries to identify storm type.

Figure 1, by way of example, illustrates the timeseries of gust and mean wind speeds, mean sea level pressure (PMSL) and 2-m air temperature during non-synoptic (top panel) and synoptic (bottom panel) events at the Auckland Aero meteorological station. In this study, machine learning algorithms, using self-organising maps and random forest methods, will be trained and tested on the historical observation data as well as the outputs of our RCM #2 for the period before 2014 (Table 1). Then, the algorithm will be applied to future outputs of RCM#2 (2015-2100) to identify extreme wind events under three SSPs.

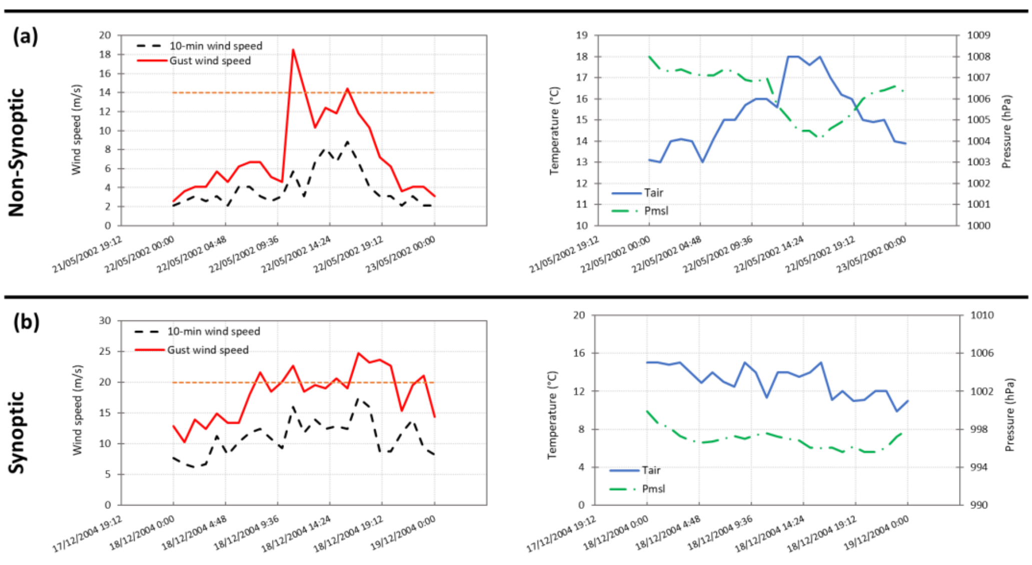

Figure 1. Timeseries of gust and mean wind speed (left), and temperature and mean sea level pressure (Pmsl) at the Auckland Aero station for: (a) non-synoptic; and (b) synoptic events.

3.2. Modelling workflow

Turner and Stuart (2021) analysed the outputs of RCM#1 (Table 1). This study indicated 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 Representative Concentration Pathways (RCPs), likely due to changes in lee-slope windstorm intensity. It was also concluded that km-scale resolution is needed to adequately simulate tropical cyclones, severe convection, squalls and many downslope windstorms. Therefore, in this study, we dynamically downscale the outputs of RCM#2 (Table 1) to sub-km scales for selected cases using a convection-permitting NWP model. Sufficient cases will be run to ensure statistically reliable extreme value analysis can be performed on the NWP outputs to generate regional design wind maps and compare with the NZ design wind speeds (Safaei Pirooz et al, 2020; AS/NZS1170.2, 2021).

The science configuration used in the NWP model to dynamically downscale RCM#2 output is the midlatitude version of second Regional Atmosphere and Land configuration (RAL2–M) of the UM (Bush et al, 2022). It has a horizontal grid spacing of 750 m and 70 vertical levels extending from near the surface to 40 km above sea level.

7. CONCLUSIONS

In this study the potential effects of climate change on design wind speed estimates under three SSPs, i.e. 1-2.6, 2-4.5, 3-7.0, are investigated using dynamical downscaling of regional climate models (RCM). Extreme wind event cases for dynamical downscaling are selected based on the signatures of these events in other climate variables, such as pressure and temperature. Machine learning algorithms are trained on historical events to detect synoptic and non-synoptic events. Extreme value analysis is performed on downscaled cases to estimate design wind speeds and compared against current NZ design wind speeds (AS/NZS1170.2, 2021).

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