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Bias correction of wind forecasts using high-resolution NWP modelling

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SUMMARY:
The study aims to generate gridded bias correction factors to improve wind speed forecasts of NIWA's[1] operational Numerical Weather Prediction (NWP) models, particularly over complex terrain and high elevation regions. Due to the required smoothing of the underlying orography and parameterisation of unresolved orography in NWP models, wind speed is often under-predicted in areas of complex terrain and also the speed-up in these regions is not modelled. Here, we have developed a national-scale NWP model with a horizontal grid spacing of 750 m to physically model the smaller-scale orography and provide bias correction factors to coarser resolution operational NWP models. The bias correction factors were derived by running the high-resolution NWP model, NZ High-Resolution (NZHR) for more than 60 case studies, chosen to represent the dominant 12 synoptic weather regimes experienced over NZ.

Keywords: Wind forecast bias, NWP downscaling, Complex terrain

1. INTRODUCTION

Many orographic features in a Numerical Weather Prediction (NWP) model domain are not well resolved due to the model's defined spatial resolution and need to maintain numerical stability (Howard and Clark, 2007). Instead, the effects of these unresolved features are represented via parameterisation schemes which, for example, account for the orographic drag produced by surface friction (i.e. effective roughness) and pressure forces. However, applying the parameterisation can potentially cause two issues (Howard and Clark, 2007): 1) a reduction in predicted near-surface wind speed by artificially increasing the surface stress; 2) not being able to model the wind speed-up over the unresolved peaks. Using the linear theory of natural boundary layer flow, Howard and Clark (2007) developed a computationally cheap method to bias correct low-level wind forecasts in coarse resolution NWP models. Although their method improved the outputs of the operational Met Office Unified Model (Bush et al, 2022), it cannot capture the complexities of the boundary layer and wind speed-ups and also is not expected to perform well where flow separation dominates, or in strongly stable/unstable conditions. There have also been more recent attempts combining machine learning and post-processing techniques to improve wind

[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/.

forecasts, e.g. (Tsai et al, 2021; Shin et al, 2022). Although these approaches can potentially improve wind forecasts compared with raw NWP outputs, they do not resolve flow behaviour over complex terrain and have limited capability to include information of the relevant physical processes in the forecasts. An alternative method is to dynamically downscale NWP models to add smaller-scale information and combine these with a correction technique.

In this study, we describe a bias correction workflow, where high resolution dynamically downscaled NWP output over New Zealand (NZ), taken from a collection of case studies chosen to sample the principle synoptic weather regimes that are experienced over NZ, is used to improve the mean and gust wind speeds in coarser resolution operational NWP workflows.

2. NWP DOWNSCALING

The NWP downscaling workflow used in this study follows the setup of NIWA's Auckland Model (Safaei Pirooz et al, 2021) and the NZ Re-Analysis (Safaei Pirooz et al, 2022) workflow. The science configuration used in the NZ High Resolution (NZHR) model is the midlatitude version of Met Office Unified Model (UM) Second Regional Atmosphere and Land configuration (RAL2–M) (Bush et al, 2022). NZHR has a horizontal grid spacing of 750 m and 70 vertical levels extending from near the surface to 40 km above sea level. NZHR (domain shown in Figure 1) is driven by initial and lateral boundary conditions derived from 4.4 km resolution NZ Limited-Area Model (NZLAM). The orography for NZHR is generated from the Shuttle Radar Topography Mission (SRTM) dataset (Farr et al, 2007) and land cover data are based on the Climate Change Initiative (CCI) (Hartley et al, 2017).

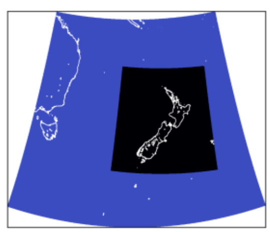

Figure 1. NZLAM 4-km NWP domain (blue) and downscaled 750-m NZHR (black) domains.

3. SYNOPTIC WEATHER REGIMES

Synoptic weather regimes are used to simplify and categorise regional climatology and weather (Williams and Renwick, 2021). They can be used to establish a relationship between near-surface weather conditions and the more general large-scale synoptic state of the atmosphere. There are various techniques to generate synoptic weather clusters, the more common approaches using self-organising maps (Jiang et al, 2013) or k-means clustering (Williams and Renwick, 2021).

3.1. New Zealand's synoptic clusters

There are several synoptic weather regimes classifications over NZ (Williams and Renwick, 2021), the most well-known and applied being the 12 Kidson types (Kidson, 2000). Here, we employed the methodology described by Williams and Renwick (2021), using k-means clustering of principal components of 1000 hPa geopotential height data. The data used are from the ERA5 reanalysis (Hersbach et al, 2020) for the period 1990 to 2021 inclusive at 0000 and 1200 UTC. The domain extends between latitudes 24°S – 52°S and longitudes 150°E – 183°W. The resulting

12 clusters are shown in Figure 2.

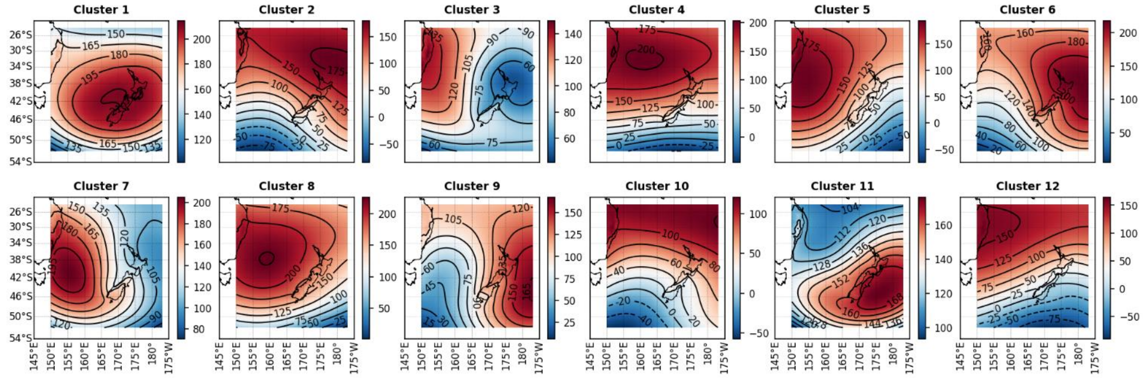

Figure 2. The 12-geopotential height derived clusters representing NZ's dominant synoptic weather regimes.

3.2. Assigning an NWP forecast to a synoptic regime

To reduce the number of computationally expensive case study simulations using NZHR, for each synoptic regime 5 case studies were performed to ensure a good sample size. Then, for each model that a bias correction is sought, the model forecast at 00 UTC and 12 UTC is assigned to a particular synoptic regime by calculating the Euclidean distance, *d*, between the operational model forecast and each of the 12 clusters following (Williams and Renwick, 2021). The minimum of these 12 values determines the cluster matching to the current operational forecast (Figure 3) from which the appropriate set of bias correction factors are taken.

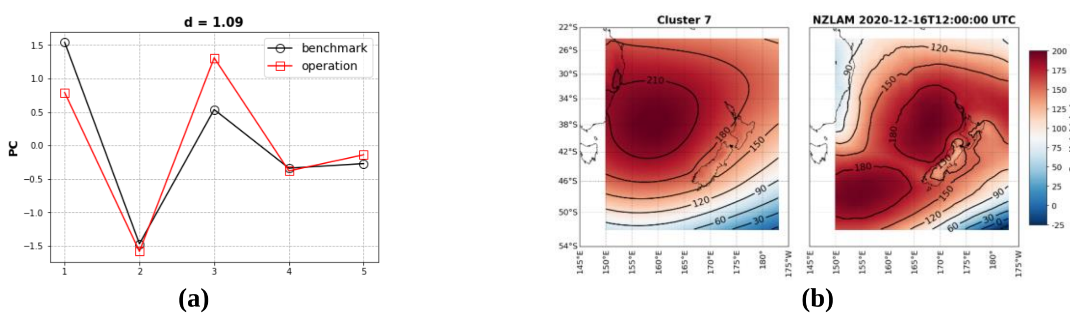

Figure 3. (a) illustration of minimum Euclidean distance between NZLAM and geopotential height cluster 7 for the first five leading principial components (or empirical orthogonal functions); (b) corresponding geopotential height contours to minimum *d*, determining the synoptic regime of NZLAM forecast at 2020-12-16T12:00 UTC.

4. BIAS CORRECTION PRELIMINARY RESULTS

Figure 4 illustrates a preliminary result of averaged gust (left) and mean wind (right) speed bias correction factors computed for NIWA's NZ Convective Scale Model (NZCSM) for a single 6-hour forecast period 2020-12-16 21:00 UTC to 2020-12-17 03:00 UTC, initialised at 2020-12-16 18:00 UTC. The bias correction factors are calculated by dividing the NZHR forecast values by those from the NZCSM. The preliminary results for this single forecast indicate a negative bias of up to 20-30% and 50-60% in NZCSM gust and mean forecasts, respectively, mostly over the complex terrain of the South Island of NZ. This procedure is applied to over 60 case studies, spanning all 12 synoptic regimes, to compute the final regime-based bias correction factors for the operational NWP models.

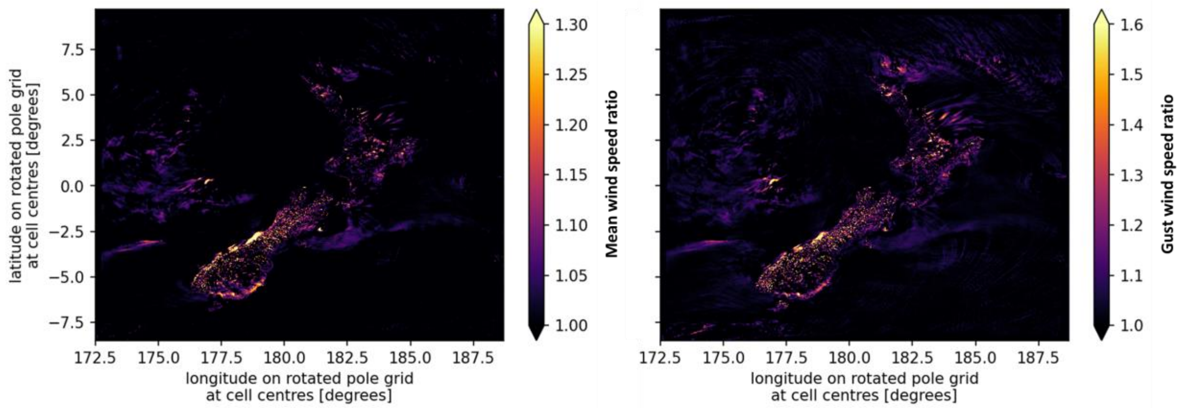

Figure 4. Example result of gust (left) and mean (right) wind speeds for a single NWP cycle.

7. CONCLUSIONS

In this study a high-resolution NWP model with a horizontal grid spacing of 750 m was developed to construct bias correction factors of the mean and gust wind speed forecasts of coarser resolution operational NWP models over NZ's complex terrain. Bias corrections have been generated for a set of 12 large-scale synoptic weather regimes over NZ and are selected for use by matching the synoptic regime present in an operational NWP forecast with one of the 12 pre-determined regimes. Early results indicate correction factors of up to 20% are likely to raw model output.

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