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Calculation of Wind Direction Multipliers using Climate Simulated Data.

L.A. Sanabria and R.P. Cechet

Geoscience Australia, Canberra, ACT 2601, Australia

Abstract

A model to assess severe wind hazard using climate-simulated wind speeds has been recently developed at Geoscience Australia. The model can calculate the return period of wind speeds over a given region considering current as well as future climate conditions. The winds extracted from the climate simulations are winds at 10m height over open terrain. In hazard studies it is important, however, to refer the wind speeds to the characteristics of the given location, in order to calculate the actual severe wind hazard at the site. This is achieved by multiplying the generic wind hazard by a number of wind multipliers. One of those multipliers is wind direction.

The wind direction multiplier recognises the prevailing direction of the strongest winds and affects the wind hazard accordingly. Lower wind hazard would correspond to the direction of low wind speeds.

In practical applications engineers calculate the wind load on structures by multiplying the design wind speeds recommended by the Australian/NZ standards for wind loading in structures (AS/NZS 1170.2:2011) by some generic multipliers also given in the standards. The multipliers have been developed considering a number of Bureau of Meteorology (BoM) weather recording stations at particular locations in Australia; this method cannot capture the actual regional characteristics in such a vast country like Australia.

In this paper we propose a new methodology for calculation of wind direction multipliers based on wind speeds and direction extracted from climate simulations. Our method allows a more realistic assessment of the wind direction multiplier at a regional scale.

Introduction

The methodology for calculation of wind direction multipliers used here follows closely the methodology developed by Holmes for the Australian/NZ standards for wind loading in structures (AS/NS1170:2, 2011). Holmes calculates the multipliers by weighting the density of the observed wind direction by the parameters of the extreme value distribution which best fits the data. When using maximum daily wind speed data it is fitted by the 'peaks-over-threshold' approach. In this case the extreme value distribution used is the Generalised Pareto Distribution (GPD) (Holmes and Sanabria 2008).

Climate model simulations

The simulations used in this project were generated by the Climate Futures for Tasmania (CFT) project (Corney at al, 2010). The CFT project dynamically downscaled six general circulation models (GCM) using CSIRO's Conformal-Cubic Atmospheric Model (CCAM). Simulations focusing on Tasmania, for the period 1960 to 2100, were generated within a latitude-longitude grid with resolution of 0.1x0.1 degrees. They also downscaled simulations from 1961 to 2006 driven by the NCEP/NCAR reanalysis data (Kistler at al, 2001). For hazard studies 10-meter height hourly mean wind speeds from each of the climate simulations were extracted. Then the mean hourly speeds extracted in each cell were transformed to maximum daily mean speeds. Finally the mean speeds were transformed to maximum daily gust wind speeds using a Monte Carlo simulation method (Sanabria and Cechet, 2010b).

For calculation of wind direction the 10m maximum daily meridional (v10max) and zonal (u10max) wind components were extracted from the CFT simulations. The wind direction is given by,

$$wdir = \arctan(v10max/u10max) \quad (1)$$

Wind direction is then referred to North = 0 degrees.

To calculate the GPD parameters, total wind speed was calculated as the geometrical sum of the zonal and meridional components. A GPD was then fitted to the total wind speed using an automatic procedure (Sanabria and Cechet, 2007) and wind direction multipliers in each cell of the CFT grid were calculated.

Model validation

In order to assess model accuracy, observed wind speed and direction from the two major BoM weather observing stations in Tasmania (Hobart and Launceston airports) were considered. These airport sites were selected to avoid the problem of the urban environment and/or trees affecting the wind recording instruments. Figure 1 shows the observed wind rose of maximum daily gust speeds at these sites.

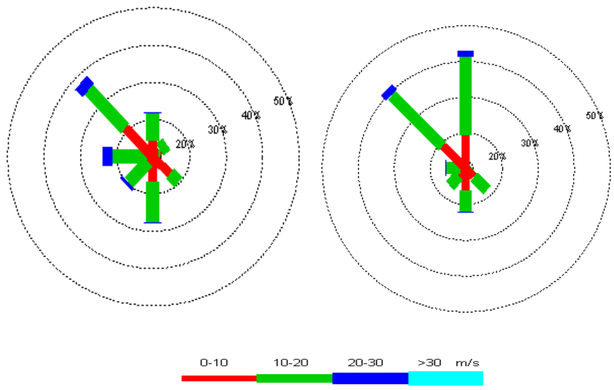

Figure 1. Observed wind rose at Hobart and Launceston.

Figure 2 shows the observed and CCAM-modelled wind direction multipliers at Hobart airport (available range: 1958-2006) and Launceston airport (range: 1941-2006) stations. The CCAM-modelled wind directions were extracted from the NCEP/NCAR-driven simulations from the year range 1961-1990, which is the range defined as 'current climate' in our wind hazard studies (Cechet et al,. 2010).

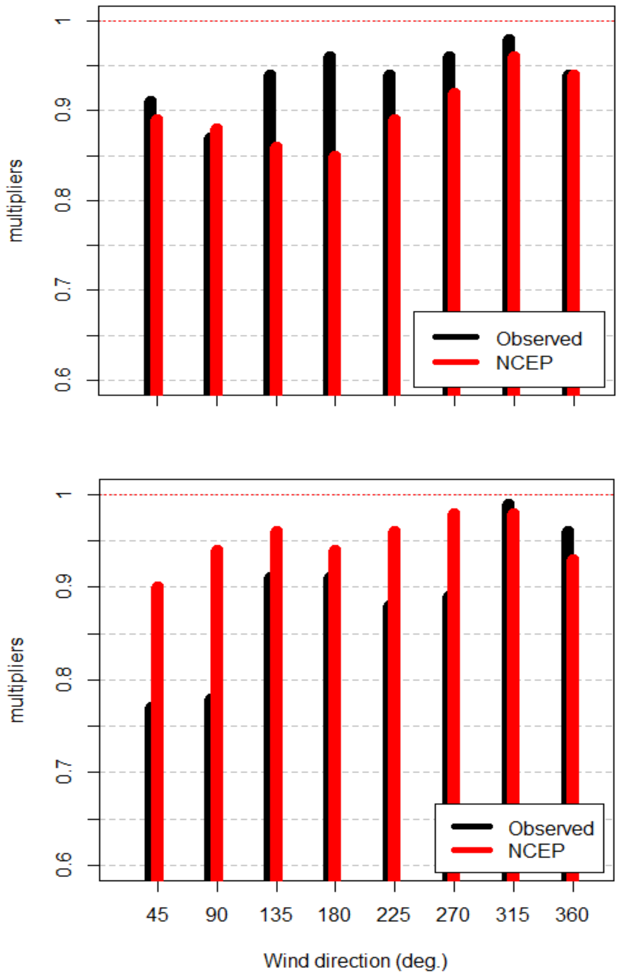

Figure 2. Observed and CCAM(NCEP)-modelled wind direction multipliers at Hobart (top) and Launceston airports.

Figure 2 indicates that the modelled multipliers have similar magnitudes and directional characteristics than the observed ones. The largest magnitude multipliers for Hobart are between 270-360°. The smallest multipliers occur between 45 and 90 degrees. For Launceston the highest multipliers occur between 315 and 360°.

The CCAM-modelled wind direction multipliers closely follow the values of the observed multipliers in the prevailing directions. For the Hobart case values pointing to north and north-east (315 and 360) are very close to the observations. Wind direction multipliers corresponding to south, south-east and south-west, on the other hand, are not as accurate. The largest error is 11.3% obtained for values at 180°.

The same behaviour can be observed for the Launceston case: CCAM-generated wind direction multipliers are close to the observed values in the prevailing directions, 315 and 360°, and not so close in the directions of low activity, 45 and 90°. The biggest error (12%) occurs at 90°.

These results show that it is possible to calculate wind direction multipliers based on climate-simulated data. The maximum errors obtained by this process in the two stations shown are acceptable in normal engineering practice.

Calculation of grided wind direction multipliers

Grided wind direction multipliers for the Tasmanian region were calculated using the methodology outlined in the previous section. Wind speed and direction in each cell of the 2856-cell grid were extracted from the CCAM(NCEP) simulations and the corresponding wind direction multipliers per cell were calculated.

Figure 3a shows the CCAM(NCEP)-modelled wind direction multipliers for the four main cardinal directions N, S, W and E for the period 1961-1990 (current climate). The corresponding wind direction multipliers for NE, SE, SW and NW are shown in Figure 3b. Figures 3a and 3b also show that wind direction multipliers are consistent across the whole of Tasmania. There is little variation particularly in the prevailing directions. This is expected in a climatology dominated by synoptic winds.

For most parts of Australia and New Zealand, as for higher latitudes in most parts of the world, the dominant wind directions are generally from the western half of the cardinal directions (Holmes and Flay, 2011). This is reflected in Figures 2, 3a and 3b: the highest multipliers are in the westerly directions.

There is little knowledge of the spatial distribution of thunderstorm wind hazard. The Tasmanian region experiences very few thunderstorms annually (on average). The frequency varies for 5 to 15 events, with relative maximum areas in the elevated regions along the entire coast and in the northeast. The distribution of thunder-days (days in which thunder is heard) and lightning flash rate have been used to estimate the frequency of thunderstorms across Australia (Kuleshov et al, 2002; 2006). This confirms the synoptic system wind hazard climatology from western stream weather in the Tasmanian region.

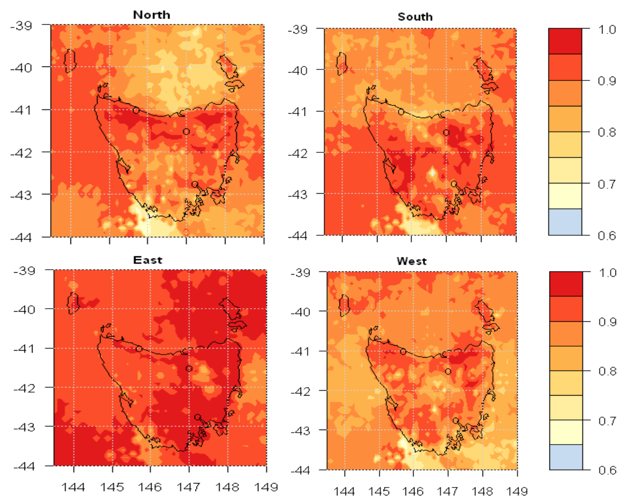

Figure 3a. CCAM(NCEP)-modelled wind direction multipliers for the four main cardinal directions (clockwise: N,S,W and E).

Figure 4 shows the maximum wind direction multipliers for the Tasmanian region. Except for some parts of Southwest Tasmania and King Island, the maximum multipliers are 1.0.

Future climate

Using climate simulations for calculation of wind direction multipliers not only allow wind engineers to look at the regional texture of the multiplier but also allow them to assess possible changes in wind direction multipliers due to climate change. Our wind hazard studies show that it is possible that wind hazard will increase in some regions of Tasmania (Sanabria and Cechet, 2010a). In this Section we examine whether these changes also affect wind direction multipliers.

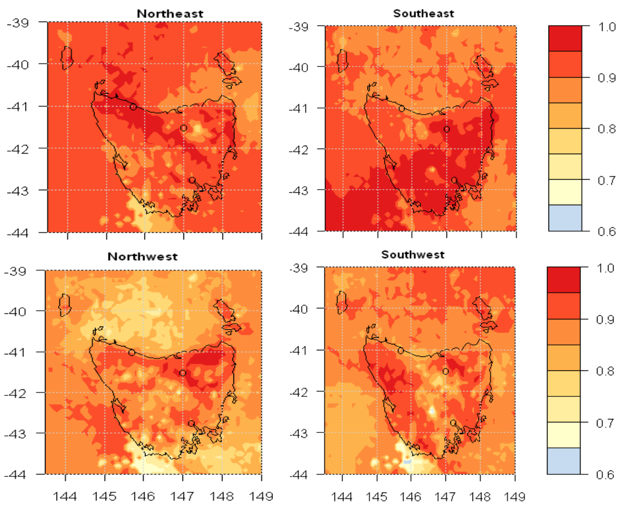

Figure 3b. CCAM(NCEP)-modelled wind direction multipliers for NE, SE, SW and NW (clockwise).

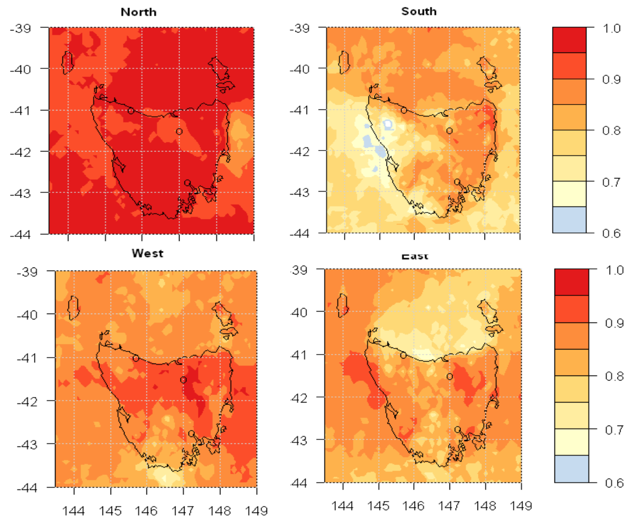

Figure 5. Six-model ensemble average wind direction multipliers for 2081-2100 (A2 scenario).

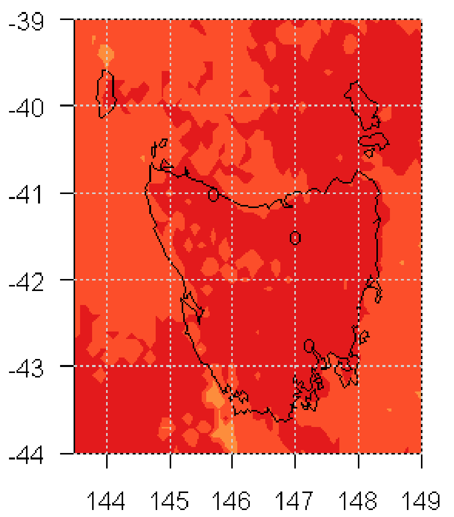

Figure 4. Maximum wind direction multipliers over Tasmania.

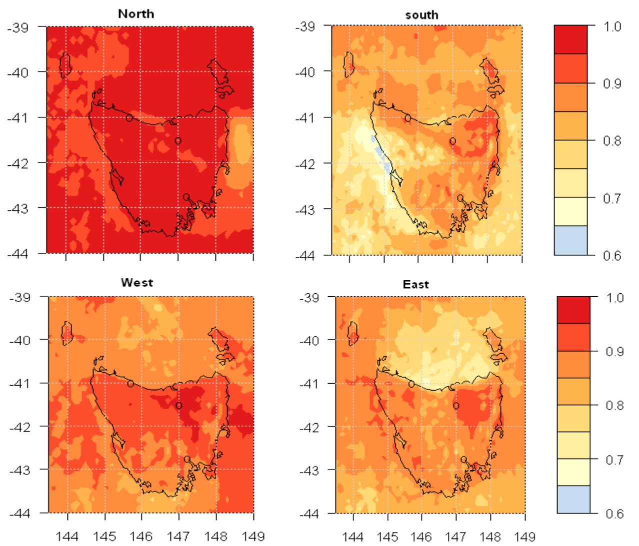

Figure 6. Six-model ensemble average wind direction multipliers for current climate.

To assess the impact of climate change on the direction multipliers, wind direction multipliers using the CCAM simulations driven by the six GCM as explained above were calculated in a time window of 20 years starting at 2081. The IPCC A2 scenario, a high greenhouse gas emissions scenario (IPCC 2000), is used here to demonstrate the influence on the directional multiplier. In order to minimise model variation, the average of the six downscaled models utilised (ensemble average) was used to calculate the wind direction multipliers. Figure 5 shows the six-model ensemble average wind direction multipliers for 2081-2100 in the four main cardinal directions.

For a proper comparison Figure 6 shows the corresponding six-model ensemble average multipliers for current climate (1961-1990).

Small variations can be observed only in the E and W directions. Note the decrease in the easterly direction particularly in the northern part of the State while in the westerly direction there is a small increase in the multipliers. The results show that wind direction multipliers are likely to remain constant throughout this century, i.e. the predominant wind direction does not seem to change with climate change.

Comparison with AS/NZS 1170.2

The wind direction multipliers calculated in this project were compared against the wind direction multipliers for region A3 (Tasmania) provided by the AS/NZS 1170:2 (2011). Figure 7 shows the observed, CCAM(NCEP)-modelled, CCAM-six-model average (current climate) and the AS/NZS 1170.2 multipliers for Hobart airport (top) and Launceston airport stations.

Figure 7 shows that the AS/NZS 1170.2 multipliers match the observations only in the prevailing direction (NW) in which the multipliers are 1.0. In the second prevailing direction in Launceston (360°) they come in a distant forth place while the CCAM six-model average gives the best results slightly better than CCAM(NCEP). Note that for the direction with low activity (NE and E) CCAM-modelled multipliers give better results than AS/NZS 1170.2 multipliers in Hobart but for Launceston the AS/NZS are more accurate.

The results of this study show that CCAM-modelled wind direction multipliers provide more accurate multipliers in the direction of the maximum wind gust direction than the AS/NZS

1170.2. In addition, the CCAM-modelled wind direction multipliers also provide a much greater understanding of the regional nature of the directional wind multipliers than was previously available.

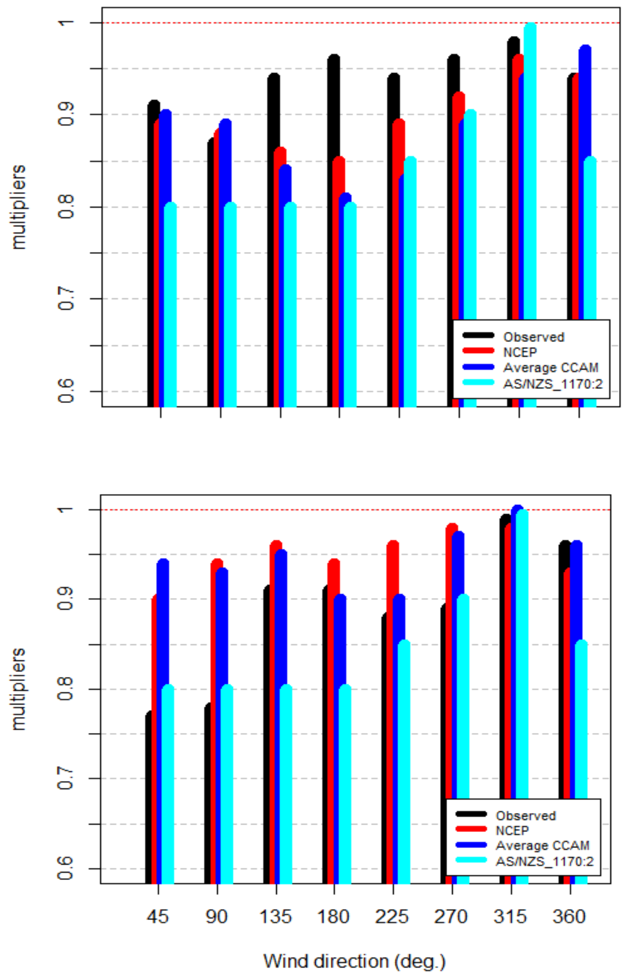

Figure 7. Observed, AS/NZS 1170.2 provided and CCAM-modelled wind direction multipliers at Hobart (top) and Launceston airports.

Conclusions

A new methodology to calculate wind direction multipliers at the regional level has been presented in this paper. The methodology utilises wind speed and direction extracted from a high resolution climate simulation model. This methodology has the added advantage of giving wind analysts the possibility of assessing changes in wind direction multipliers under climate changing conditions. However the results presented in this paper show that climate change has little impact on wind direction multipliers.

Acknowledgments

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