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The value of Convective Scale Numerical Model tools in analysing extreme wind fields during storm events and for climatological purposes.

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Abstract

Continuing advances in computer power and capacity have allowed many weather forecast centres to conduct routine weather analyses and forecasts over large areas on computational grids on the order of 1 km. This horizontal grid spacing allows for the explicit representation of convective processes and thunderstorms, and improved modelling of mountain waves that cause downslope windstorms. This allows the production of “realistic” looking event maps of extreme wind gusts (diagnosed from model wind fields and turbulent intensities inferred from bulk boundary-layer properties) from these models for the phenomena causing the majority of New Zealand’s recorded extreme winds.

We present a preliminary evaluation of a numerical 1.5 km grid spaced weather model’s (NZCSM New Zealand Convective Scale Model) performance in simulating ten-minute time-series of wind gusts (bias and short-range skill) as well as its ability to reproduce daily and annual maximum gusts that occurred in New Zealand in 2014 and 2015. Maps of annual extreme gusts for 2014 and 2015 as simulated by NZCSM are also presented. Maps of this type and at this scale have not previously been produced. Finally we detail plans to create a regional climatology (based on a 30 year NZCSM re-analysis) at this scale.

Introduction

Since 2014 NIWA has produced on a 4 times a day cycle (Initial times of 0300, 0900, 1500, and 2100 UTC) NZCSM 36 hour forecasts (42 hour since November 2015) which include maximum 3-sec gust estimates for each 30 minute period in the forecast. The gusts are diagnosed based on estimates of σ_u, the standard deviation of the horizontal wind from the mean 10 metre speed. The diagnostic method is described in Lock et al 2015 with the key features being that the estimates depend on stability (Panofsky et al 1977) and universal turbulence spectra (Beljaars, 1987). Note, it has also been our experience that the 133 m model level mean speeds are often quite close to these gust estimates over relatively flat terrain, and thus mean speeds at this model level are often a crude proxy for the 10 m surface gust.

The production of these realistic forecast high-resolution gust maps provides not only value for weather forecasters, but also for establishing model climatologies (once properly calibrated) and the calculation of return period statistics for regions characterized by “mixed-wind” climates (Kruger et al 2011). The mixed-wind climate disaggregation when calculating extreme statistics has not been performed for New Zealand as previously it has been too impractical to identify the weather phenomena producing extreme gusts. The existence of the 2 year archive will allow a practical classification of phenomena when examining station records.

This abstract is set out as follows, in the next section the NZCSM model is briefly described, following that a brief summary of wind speed and gust validation efforts to date, then some initial results from the first two years of NZCSM are presented and key features discussed. Finally, plans for a 30 year reanalysis are briefly outlined.

NZCSM Model

The New Zealand Convective-Scale Model (NZCSM is a Numerical Weather Prediction (NWP) model and a local configuration of the UK Met Office Unified Model (MetUM), featuring a non-hydrostatic dynamical core (called New Dynamics), semi-implicit time-stepping and semi-Lagrangian advection and terrain-following vertical levels. The New Dynamics core is described in Davies et al. (2005).

The underlying orography used by NZCSM is created at the model resolution of 1.5 km from the GLOBE source dataset with a horizontal resolution of 1 km (GLOBE Task Team, 1999). The model orography is lower than in reality, because it requires smoothing to prevent numerical instabilities from arising due to overproduction of two grid length features during the course of the forecast. Various verification efforts have been ongoing since 2014 and key settings used with NZCSM for the majority of this period are given in Table 1

Item	Notes
Domain size	$1200 \times 1350 \times 70$
Computational grid	Rotated latitude / longitude
Levels below 2km	23 (model top 40 km)
Dynamics time step	50 s
Radiation time step	600 s / 10 min
Data Assimilation	Pseudo-analysis (merge NZLAM-12 background)
Incremental Analysis (IAU) Period	2 hours (T-1 to T+1)
Observation types used	Surface, Aircraft, Satellite (via NZLAM-12 background)
Forecast period	36 h prior Nov 2015, 42 h since
Forecast frequency	4 times per day at 03, 09, 15 and 21 UTC (Analysis Time)
Lateral Boundary Conditions (LBC)	Derived from NZLAM-12 run at 12km horizontal resolution
LBC Update frequency	30 mins
Output frequency	Prognostic fields: 30 mins ; Accumulations: Hourly, 3, 6, 12 hours, 24 hours

Table 1. Key NZCSM settings during 2014 and 2015.

Validation efforts for a selection of complex terrain sites have indicated normalized RMSE errors of 0.27-0.30 for forecast ranges of 06-12 hours with only a slight degradation out to 36-42 hours (approx 0.34-0.38). Biases of around -2 to -3 m/s (approx 10%) in gust speeds were typical and explained variances have typically ranged from 60% to 70%. Wind rose (direction) climatologies have generally been well reproduced for well exposed sites and the forecast model wind generally beat persistence after 2-3 hours for many sites. However, it also seems to be the case that peak observed gust speeds during high wind events are underestimated. Much of the under-prediction can be attributed to the fact that with a 1.5 km grid spacing many slopes are still not steep enough. More details are provided in Moore and Turner (2016) and they show that improvement of extreme gusts was gained when a NZCSM grid-spacing of 100 m was used and thus steeper model orography was being represented. This means that bias of the modelled NZCSM gusts seen for many stations sited on ridges (or in complex terrain) are likely due to sub-grid hill-shape speed-ups and thus will be largely correctable for most straight-line wind events where the direction is known. Therefore, we concluded that the generally good performance of NZCSM suggests it was worthwhile to attempt to produce gust "climatologies" from NZCSM forecast archives.

Initial results 2014 and 2015

From the archive of NZCSM forecasts; maximum gusts, time of maximum gust, direction of maximum gust, and a count of hours for which gusts exceeded 25 m/s (90 km/h) were compiled for each day (0300 UTC cycle – so forecast hours 9 to 33 cover the midnight to midnight period for which daily maximum gust statistics are recorded) from April 16, 2014 (the forecast which includes ex-TC Ita) through to April 30, 2016.

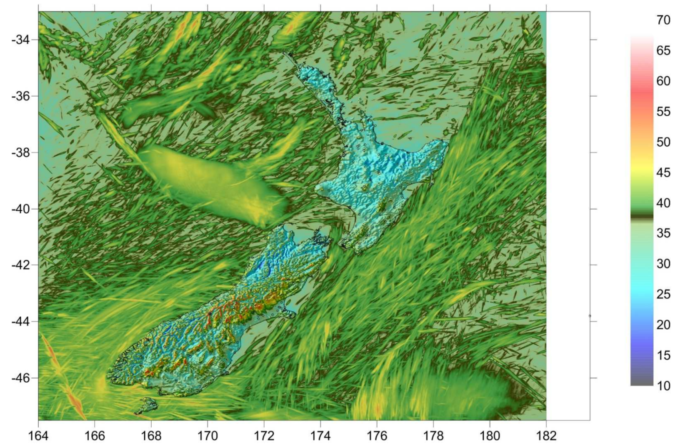

Figure 1. The maximum 10 m 3-sec gust as diagnosed from 0300 analysis time NZCSM forecasts for the period Apr 16 through Dec 31, 2014.

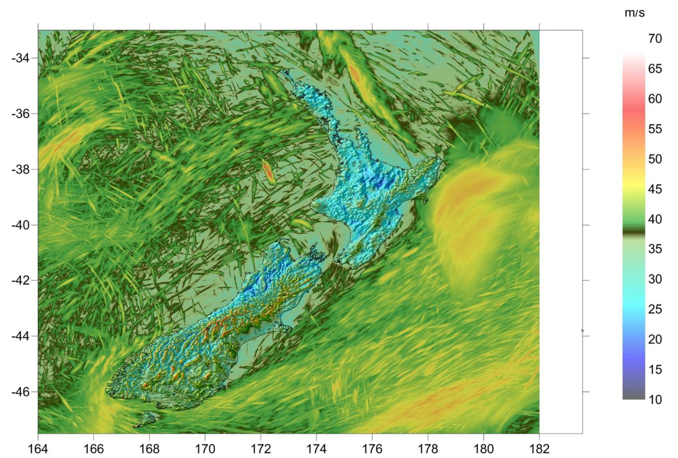

Figure 2. The maximum 10 m 3-sec gust as diagnosed from 0300 analysis time NZCSM forecasts for the period Jan 1 through Dec 31, 2015.

Figures 1 and 2 show the NZCSM estimate of the maximum "annual" gusts for 2014 (8.5 months only) and 2015. Features that stand out in 2014 are ex TC Ita (yellow area to the west of Farewell Spit in Figure 1) and in 2015 ex TC Pam the yellow-red area east of Gisborne in Figure 2). The dark band near 37 m/s in the figures is close to the threshold at which damaging winds often occur. Other aspects to note from these plots are; the prevalence of S-SW gales over the ocean, the general sheltering effect of the lower South Island on much of the country, the high values over the mountains, and the streaky nature of the convective gust footprints. These streaks are most apparent over the sea, but if the mean average daily-maximum gust surfaces (see Figures 3 and 4) are removed, the streaks, and lee wave effects become much more apparent over land (Figures 5, 6, and 7). Reduced gust speeds over land due to friction (increase surface roughness) effects are also obvious. Note, the surface roughness over the sea is modelled to increase with wind speed due to wave state (Lock et al 2015), but this is done in a fairly simple manner as we do not yet run a coupled wave model with NZCSM (although NZCSM outputs are used to drive wave models).

It is interesting to note that the Cook Strait region has a high average gust and high annual maximum gusts and gets its own region "W" in the AS/NZS standard. Similarly Foveaux Strait and SW Fiordland, and Steward Island seems to be similarly exposed and yet are aggregated into region A7 (the rest of New Zealand, except for Northland and Auckland). It was also interesting to note, the overlap of many regions of high average daily maximum gusts with the map (not shown) of duration of 10 m agl model gusts exceeding 90 km/h. This kind of information could be a useful indicator of environments prone to fatigue effects.

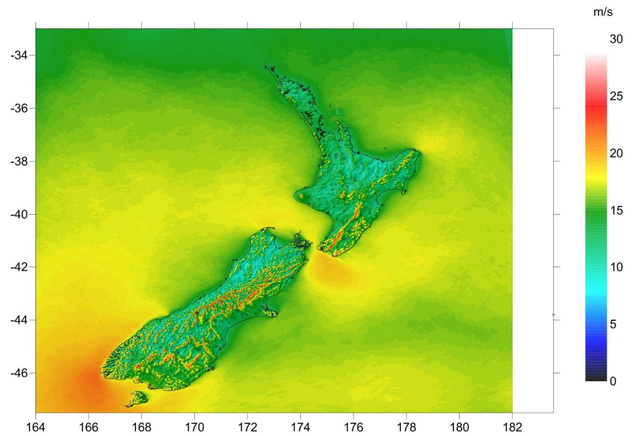

Figure 3 The average daily maimum 10 m 3-sec gust as diagnosed from 0300 analysis time NZCSM forecasts for the period May through Dec 2014.

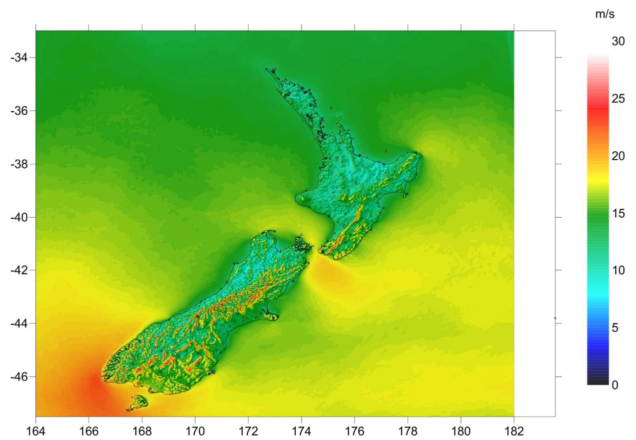

Figure 4 The average daily maimum 10 m 3-sec gust as diagnosed from 0300 analysis time NZCSM forecasts for the period Jan through Dec 2015

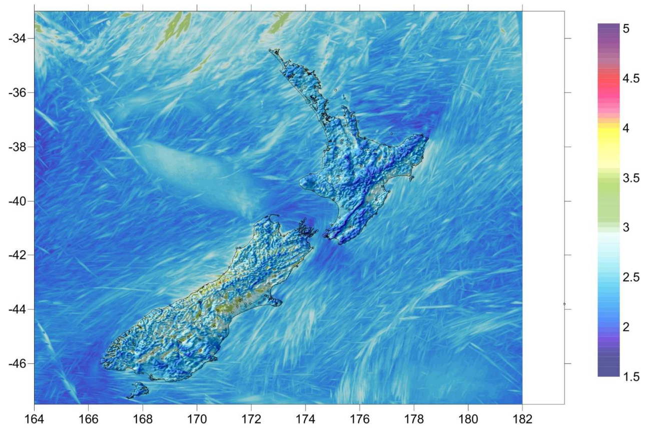

Figure 5 The ratio of NZCSM max gust in the period April 16 to Dec 31, 2014 to the average daily maximum gust for the same period.

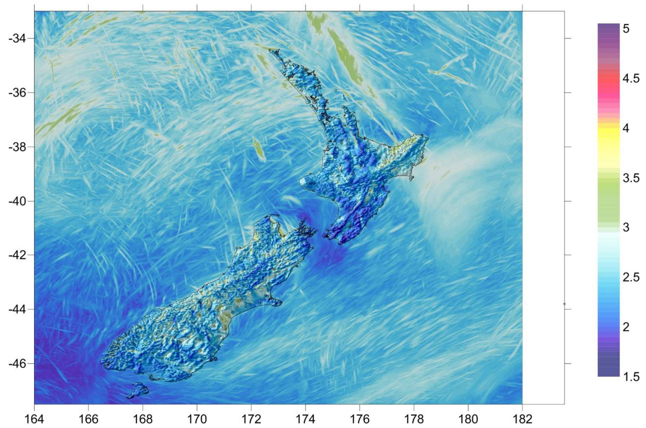

Figure 6 The ratio of NZCSM max gust in the period April 16 to Dec 31, 2014 to the average daily maximum gust for the same period. This plot is like an anomaly plot and highlights the "unusual" events for an area.

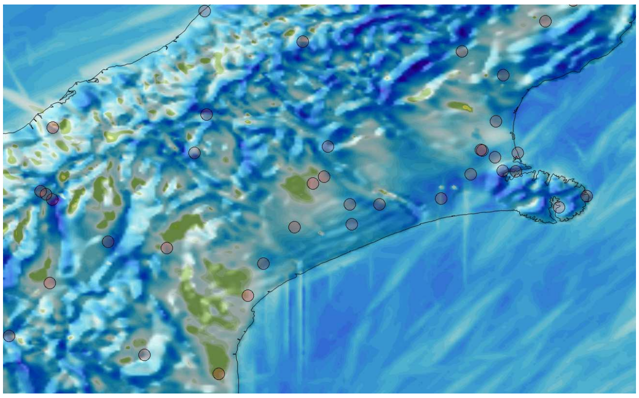

Figure 7 Zoomed in area of Figure 6 over Canterbury showing how altitude effects are largely removed when normalizing (i.e. dividing by average max daily gust) and how lee (downslope) gusts are highlighted. The red circles denote recording stations.

Other interesting maps which can highlight which regions experience "extreme" events in similar synoptic situations can be got by calculation correlations between all the grid points. Figure 8 shows the correlation in Monthly average daily maximum gust events for a point in Cook Strait and reassuringly the highest areas do coincide well with region W of AS/NZS 1170.2. Figure 9 shows the correlations with a point in Foveaux strait and show that extreme events there (more westerly) will often coincide with lee events in east Otago, North Canterbury and the Taraura and Ruahine ranges of the North Island

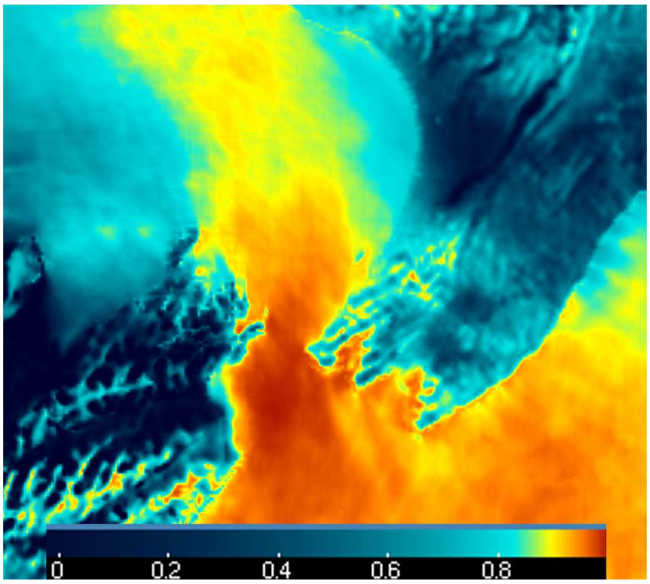

Figure 8 Correlation (Red areas exceed 0.9) of NZCSM average maximum gusts for a grid point in Cook Strait with all other grid points in the area.

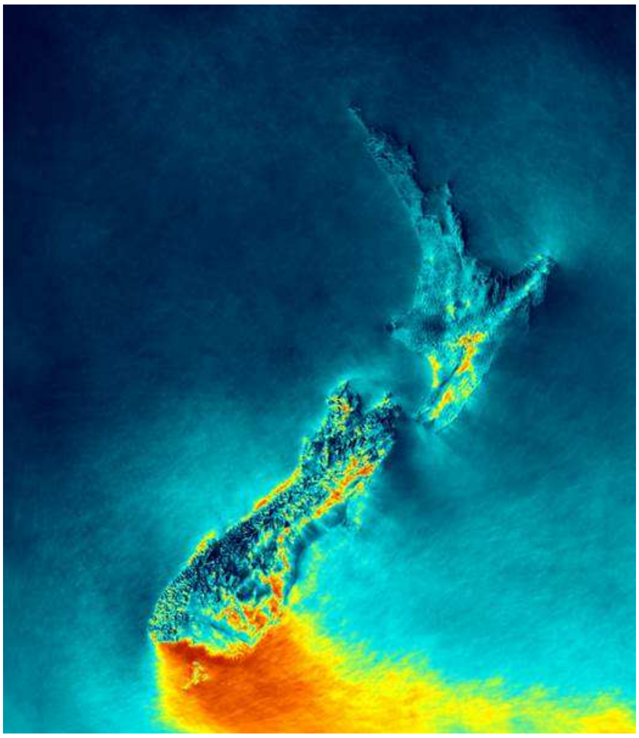

Figure 9 Correlation (Red areas exceed 0.9) of NZCSM average maximum gusts for a grid point in Foveaux Strait with all NZCSM other grid points. Note, the colour scale is the same as for Figure 8.

A preliminary comparison with raw observations from 181 stations which record daily maximum gust speeds (Figure 10) showed reasonable agreement for many stations. However, discrepancies with many stations were apparent. This was for several reasons, one of which is the differences between model terrain and reality and no attempt has yet been made to match the exposure and altitude of model points to actual. To illustrate the issue, Figure 11 shows the location of 3 stations near Mt Cook overlaid on the NZCSM orography. Here Mueller EWS is in the lee (NW) of the ridge, in reality it is on a ridge just to the east of the main divide (Figure 12). To make a fairer comparison model winds from the point indicated by the white arrow need to be used. When this is done annual maximum speeds for 2015 of 54 m/s are obtained (as opposed to the 25 m/s value for the red circle in Fig

11) and compare much better to the observed value of 58 m/s. This exercise needs to be repeated for all the stations where necessary. For many sites, additional adjustments for sensor heights not being 10 m need to be made as well as possibly for directional local hill-shape and terrain category effects.

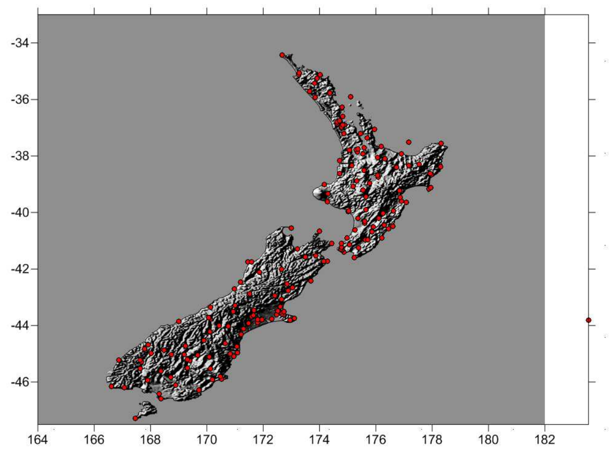

Figure 10 Location (red dots) of stations used to comppare observed and NZCSM daily maximum gust speeds for 2014 and 2015

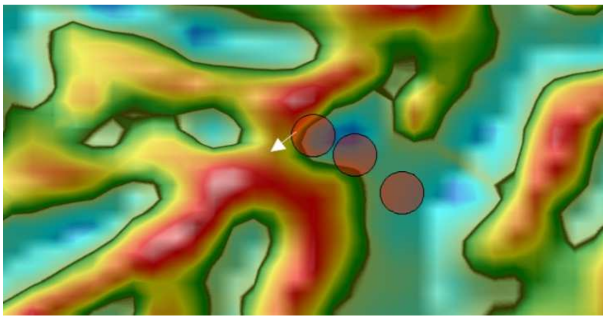

Figure 11 NZCSM orography near Mt Cook and the location of 3 wind recording sttaions in the area.

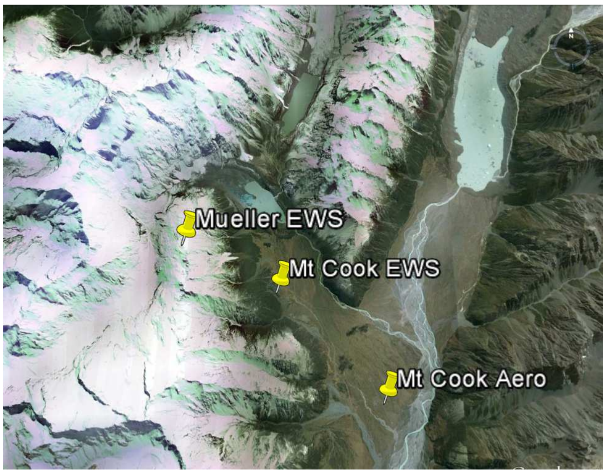

Figure 12 Aerial image (Google) of mountains near Mt Cook and location of wind recording stations in the area.

Reanalysis Project

The capability of NZCSM forecasts in reproducing realistic looking aspects of gust fields (and with other meteorological parameters not described here) has prompted plans to undertake a 30 year (model output every hour) convective-scale (1.5 km) model weather reanalysis (1981-2010) for New Zealand and surrounding oceans. The processing and data storage requirements to undertake such a project are dependent on a planned upgrade to NIWA's HPCF (High Performance Computing Facility) but are eminently feasible.

Having a reanalysis time-series of annual maximum gusts and all the associated meteorological analyses for each extreme event, will allow for station records of gusts to be disaggregated by the cause of the gust (i.e., ex-Tropical Cyclone, mid-latitude cyclone, downslope windstorm, squall line, or isolated thunderstorm (convective storm)) and other synoptic classification systems used such as the Kidson Type (Renwick 2011) and thus provide a foundation for a mixed-wind climate return period analyses for New Zealand and a basis for which climate change results can be interpreted.

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