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Issues with and performance of very-high resolution (DX=100m) nested configurations of the Unified Model over steep and complex terrain in New Zealand and with Tropical Cyclone Winston

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Abstract

In this paper, we report on the performance of very high resolution one-way-nested configurations of the Unified Model, a Numerical Weather Prediction model, for two high wind cases. The cases are (i) a high wind event over steep and complex terrain in New Zealand, and (ii) the passage of the eye of TC Winston over Vanuabalavu, Fiji, during which a potential South Pacific Basin record wind gust of 85ms^{-1} was recorded. Aside from assessing forecast accuracy for both cases, we investigate for (i) whether a 100m resolution model adds information beyond that which could be achieved by sub-grid-scale corrections of coarser grid forecasts using Model Output Statistics (MOS) (statistical post-processing using observations) or downscaling with “simple” models. The answer at this stage, looks to be yes with respect to MOS. In the case of the Vanuabalavu record, the model is seen to reproduce extreme wind gusts close to the observed values during TC Winton’s passage over Fiji and the evolution of the modelled wind and pressure field is found to be largely consistent with the evolution of the observed wind and pressures.

Introduction

Numerical Weather Prediction (NWP) models have to date typically struggled to be run at resolutions fine enough to begin to resolve the wind flow interactions around buildings and over complex terrain, with Computational Fluid Dynamics (CFD) models and wind tunnels typically used to fill the gap. Now, however, supercomputing resources are such that fine-scale NWP on scales O(100m) for research purposes is very possible and we can begin, for example, to use these models to confidently simulate wind flow over a wind farm in complex terrain and obtain forecasts for individual turbines or better simulate the processes, lifecycles and impacts of Tropical Cyclones.

At NIWA, NWP research and operational forecasting is undertaken using the Unified Model (MetUM) (Webster et al, 2003; Davies et al, 2005), a NWP model developed by the UK Met Office and now widely used around the world by national weather centres and university research departments. Uniquely, the MetUM is designed such that the same dynamical core can be used across all spatial and temporal timescales, from coarse resolution long duration climate scenario forecasting through to very high resolution limited area models forecasting up to a couple of days ahead. NIWA’s operational forecasting is carried out using a 12km resolution mesoscale and a 1.5km convective-scale configuration of the MetUM.

While NWP forecasts at these resolutions are great at capturing the large-scale weather systems and are beginning to resolve some of the more intense convective storms that bring the most severe weather to New Zealand (Yang et al, 2016), they are still limited in their representation of the underlying topography which greatly impacts the simulated wind field via its interaction with hills and valleys and near surface frictional effects via the land surface and vegetation types represented in the model. Therefore, NWP research at NIWA, and around the world, is focussed on the use of very high resolution model configurations, down to scales O(100m). At this resolution, very high resolution elevation datasets, such as the Shuttle Radar Topography Mission (SRTM) (USGS, 2004), can be used to provide a more accurate representation of the complex topography that makes up New Zealand’s landscape.

Running NWP models at resolutions that better represent complex topography opens up their potential application to forecasting for wind energy generation, not just at the coarse wind farm scale but for individual wind turbines. In this paper we look in detail at the performance of a 100m resolution configuration of the MetUM at forecasting the wind field at select wind turbines of a North Island wind farm

Another benefit of running at high resolution is that the NWP model can begin to explicitly resolve some of the atmospheric processes, such as convection, that would otherwise require a parameterisation scheme that uses a gross statistical representation of previously acquired field observations. While strong convective events bring severe weather to New Zealand, convection is also extremely important in the Tropics. Tropical Cyclones are a regular threat to the Pacific Islands and the coasts of northern Australia, so being able to confidently forecast the track, lifetime and wind field of a tropical cyclone is important for mitigating against potential societal and infrastructure damage. This paper details initial experiments with a high resolution implementation of the MetUM at simulating the track and wind field of TC Winston as it impacted Fiji in February 2016.

Finally, we discuss the general potential for very high resolution NWP models to contribute to the field of wind engineering, where traditionally CFD and wind tunnel models have been the go-to tools.

Very High Resolution NWP in Complex Terrain

NIWA’s highest resolution operational NWP model is the New Zealand Convective Scale Model (NZCSM), a 1.5km horizontal resolution configuration of the MetUM with 70 vertical levels (6 of these below 133m AGL). The current observational network for wind in New Zealand is too sparse to properly evaluate the realistic looking finer spatial details forecast by NZCSM and truly reflect the complex and varying terrain that so greatly impacts on the near surface wind field.

Thus, in the context of renewable energy forecasting, i.e., for hub heights in terrain representative of wind farms, the performance of the mean wind speed, mean wind direction and gust speed forecasts made by the NZCSM have been evaluated against observations at turbine hub heights, provided in confidence, for a New Zealand wind farm for a number of specific cases. Additionally, for these cases, the MetUM has been configured to run at even higher horizontal resolutions, down to 100m, to investigate how the terrain representation in the model affects the wind forecast. From NZCSM, 10m surface winds are output and then post-processed using Model Output Statistics (Glahn and Lowry, 1972) to create a corrected wind speed (and direction) forecast comparable to the observed winds. Additionally, wind speeds forecast at the model vertical levels closest to the hub-height are interpolated to generate a raw model wind speed time-series for comparison.

Over the period 22-26 November 2014, a series of high wind speed events, with abrupt speed changes, were observed over a wind farm. For a particular turbine, the observed, MOS corrected 10m NZCSM model wind speeds and NZCSM interpolated model level winds adjusted to hub height are shown in Figure 1.

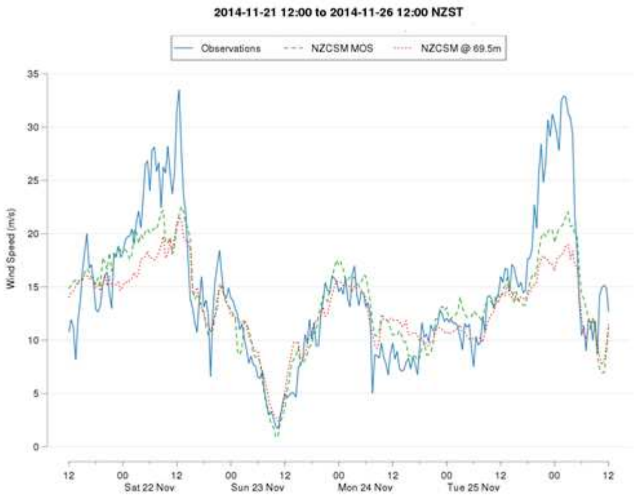

Figure 1. Time series of 10 minute observed, MOS corrected 10m wind speeds and raw NZCSM wind speeds interpolated to hub height from nearest model levels for a wind turbine for the period 22-26 November 2014.

It is clear that neither of the post-processed NZCSM wind speeds were capable of forecasting the maximum wind speeds observed, but the NZCSM did forecast well the timings of the ramp events and sudden drops in wind speed. From a wind forecasting and turbine operation point of view, these results suggest that, if relying on these forecasts only and depending on the operational wind speed envelope of the turbine, the NZCSM forecast might have indicated safe operation of the turbines was possible when in reality the turbine should have been locked down. In the non-extreme periods of this time-series, the potential for reasonable output wind power forecasting is good as the NZCSM wind speeds, both MOS-corrected and interpolated, follow closely the observed wind speeds.

Two possible reasons for this are, i) NZCSM did not adequately capture the synoptic situation (including cloud and rain processes) at the time, or its driving model, a 12km resolution configuration of the MetUM, did not capture the synoptic situation adequately enough to provide good driving Lateral Boundary Conditions (LBCs), or ii) with only a 1.5km horizontal resolution it is unlikely that the model topography will closely match the true terrain of the wind farm, especially where deep steep-sided ridges and valleys are present and thus not capture the speed-up/down effects of the terrain on the local wind field. Figure 2 shows a south-north cross-section along the wind farm used in this study comparing the model orography as used by NZCSM and that of the very high 100m resolution SRTM dataset.

The terrain profile seen by NZCSM is much smoother than that of the SRTM dataset. For this particular wind farm, this means that many of the often steep and deep valleys are not at all captured potentially causing the NZCSM to miss any terrain speed up effects that will influence the local wind flow around the

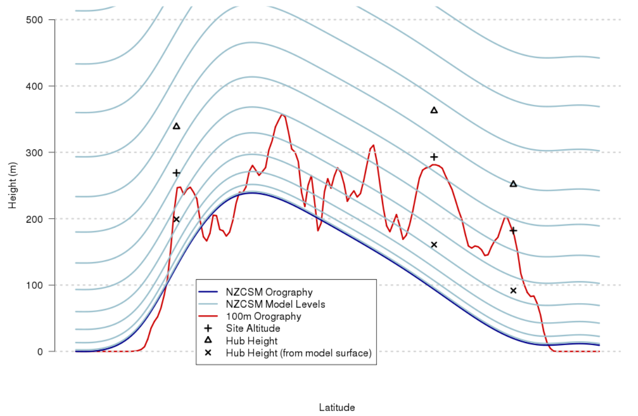

Figure 2. Along-wind (prevailing) cross-section of the wind farm used in this study comparing the orography as used by NZCSM (dark blue line) and from the 100m resolution SRTM dataset (red line). The NZCSM models levels (light blue lines) and markers for model and actual turbine hub heights (ASL) are also shown.

turbine(s). Another point to note is that the model terrain is very much lower than the actual altitude of the wind farm and turbine hub heights, in some places by almost 200m.

To see the effect that the terrain does have on the local wind field for this time period, a more recent version of the MetUM, designed around an improved dynamical core (see http://www.metoffice.gov.uk/media/pdf/s/h/ENDGameGOVSci_v2.0.pdf for a general description) was configured to run in a one-way nested set up from a 17km resolution Global model down to a final horizontal resolution of 100m.

For the same wind turbine as shown in Figure 1, Figure 3 shows a time-series of observed and modelled wind speeds for the high wind event on the 25th November 2014.

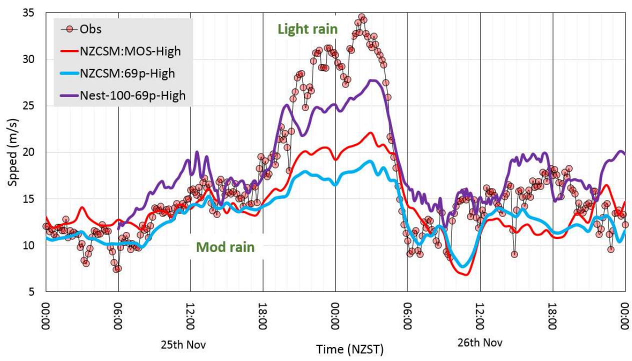

Figure 3. Time-series of 10 minute observed and modelled wind speeds comparing hub height observations against MOS-corrected and interpolated NZCSM wind speeds and interpolated wind speeds from the 100m resolution MetUM configuration (purple line).

While the 100m model featured a newer dynamical core than that used in NZCSM, the atmospheric process parameterisation schemes used in both models are the same. While the newer core may have contributed somewhat to the improved wind speed forecast seen in Figure 3, it is most likely the ability of the 100m resolution model to use the full resolution SRTM dataset to derive its orography field that has had the greatest impact. The observed maximum wind speeds are still underestimated by the 100m model but we see that the raw model wind speeds simply interpolated to hub height are outperforming the MOS-corrected wind speeds for the time period shown.

These results show that the underlying orography used by an NWP model can have a significant controlling impact on the wind forecast. While technically straightforward to implement and conduct very high resolution NWP case studies, the real issue comes when putting models with these resolutions into operational use. On NIWA's current High Performance Computing Facility (HPCF), an IBM P575, a 43 hour NZCSM forecast covering the New Zealand land mass using a 1200 × 1350 × 70 grid takes 2.5 hours of wallclock time. By contrast, the 100m model used in this case study, covering only a 600 × 600 × 70 domain centred on the wind farm location took around 8 hours to complete a 24 hour forecast. This makes running models with such high resolutions impractical, currently, for operational use in weather forecasting or bespoke wind energy forecasting. There are further issues around the availability of very high resolution datasets of vegetation and soil types that would also improve near surface forecasts but these were not considered in this study.

Forecasting Tropical Cyclone Winston

On the 20th February 2016 the Category 5 severe tropical storm TC Winston made landfall in Fiji causing substantial damage to buildings and local infrastructure. 44 people were killed and over 50,000 people evacuated (see Fijian Government NDMO TC Winston Situation Reports at http://www.ndmo.gov.fj).

As with TC Yasi (Northern Queensland) in 2011, NIWA assisted with a damage survey in the weeks after TC Winston to understand how the local infrastructure fared in such extreme winds. Early observations from the Fiji climate network indicated many stations experienced sustained (10 minute means) winds in excess of $50ms^{-1}$ and 3-second gusts exceeding $70ms^{-1}$ consistent with a return period in excess of 500 years. To support the work of the damage survey, NIWA used the MetUM to simulate TC Winston to see if a high resolution NWP model was capable of forecasting the track, central pressure and wind speeds associated with the storm. Being able to do so with a model at a resolution that can be run on a current HPCF in reasonable time would greatly assist with planning damage surveys during future events. The modelled wind speeds, along with local wind observations, are also to be used as input to the development of wind vulnerability models tying in with the findings of the damage survey.

For this work, an ENDGame version of the MetUM was used with a horizontal resolution of 1.5km on a 600 × 600 × 70 grid driven using a one-way nesting with LBCs from a 17km Global model version of the MetUM. In contrast to the wind farm work described above, this model used a "tropical" rather than a "mid-latitude" science configuration. The key changes pertain to the radiation, cloud and precipitation microphysics schemes to better reflect the differences between tropical and mid-latitude weather systems.

The first key technical issue encountered in this study was that there was no land mask data for Fiji (and the Pacific Island in general) in the IGBP (IGBP, 1990) source dataset used by the MetUM to create a land/sea mask. This meant that it was not straightforward to use any orography in the model runs. It was decided to run without orography in the first instance (note that there are no Fiji land points in the driving Global model forecast either) and future work will look at manually creating a Fiji land/sea mask and using SRTM orography.

Figure 4 compares the 1.5km forecast of 10m maximum wind gust speeds valid at 0500 UTC on 20th February 2016 against imagery from the Himawari 8 satellite for the same time. Figure 4 also highlights how well the MetUM was able t ast the central eye position and storm size.

For three observation sites, Table 1 compares the ed and modelled central pressures and maximum 10m d gust wind speeds. Vanua Balavu is far to the east Fijian mainland with Levuka a small island off Fiji's eas ast and Ba is a town in

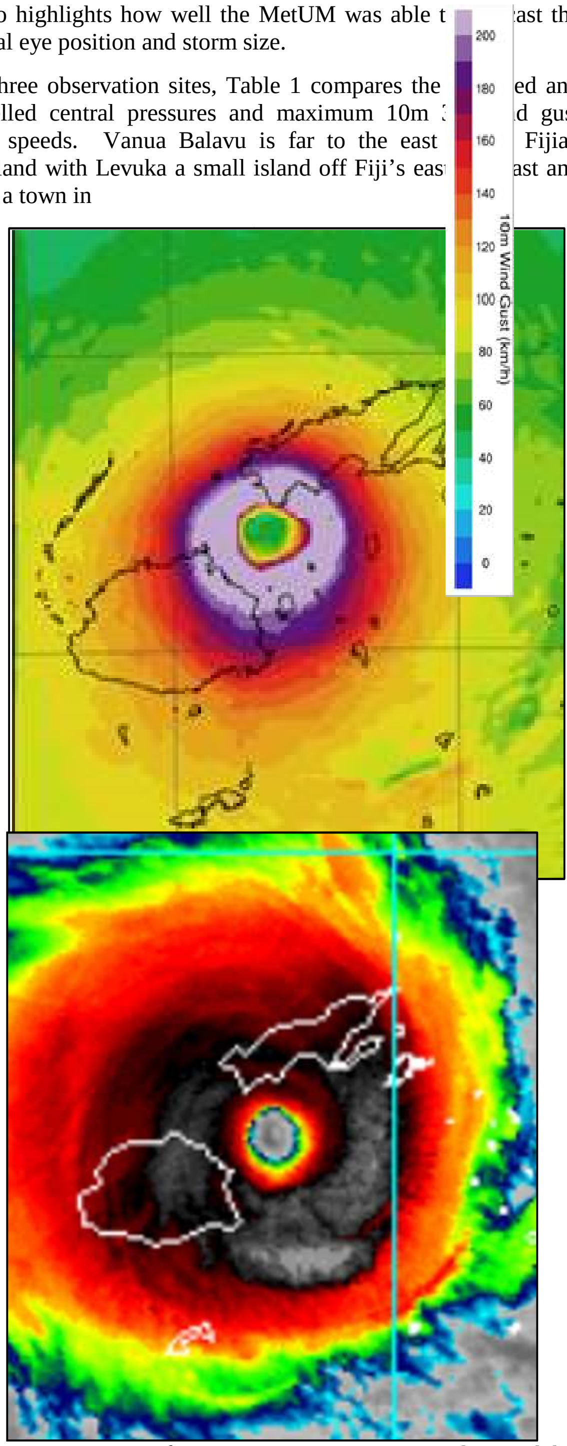

Figure 4. Comparison of TC Winston eye positioning and size valid at 0500 UTC on 20th February 2016. Top panel is the simulated 10m maximum wind gust speed from the 1.5km MetUM and the bottom panel is Himawari 8 cloud top temperature imagery.

	Observed		Modelled	
Site	Min sfc pressure (hPa)	Max 10m 3s gust (ms^{-1})	Min sfc pressure (hPa)	Max 10m 3s gust (ms^{-1})
Vanua Balavu	929.5	85.0	936	74
Levuka	954.9	67.0	960	64
Ba	956.7	52.7	940	70

Table 1. Comparison of observed and modelled minimum surface pressures and 10m 3-second gusts at Vanua Balavu, Levuka, and Ba on 20th February 2016. To account for forecast timing and track errors, the modelled estimates are for forecast hours within 2 hours of minimum central pressure being recorded at each site and for grid-cells located in a similar position relative to the eye.

the northwest of Fiji, north east of Nadi and west of where TC Winston made landfall.

It is highly encouraging that the forecast storm track and intensity over the sea (not shown) are reasonably accurate, but it is clear that the local orography and the land-friction effects that result should be included to better model the wind speeds at sites such as Ba that are more influenced by these factors than the Vanua Balavu and Levuka locations.

Furthermore, while the overall performance of the 1.5km model at forecasting TC Winston, is good, it is only adequate for broad-scale application to an extended photo assessment of damage to buildings and infrastructure on Vanua Balavu, Koro Island and other eastern islands where orographic and land friction effects are likely to be less dominant. The absence of orography in these initial forecasts means usable estimates of wind speeds for developing vulnerability models in locations such a Ba, that are going to be dominated by orographic and land friction effects, will be too uncertain to be usable.

Adding orography to the model set up will form the basis of the next stage of this work with the 1.5km model re-run and its output used to drive much higher resolution model configurations down to 100m horizontal resolution where the full resolution SRTM orography dataset can be utilised. Results from this additional work will then be used to bolster the results of the post event damage survey and inform the development of the vulnerability models needed to better inform building and infrastructure planning and hazard mitigation in Fiji and other Pacific Islands.

Conclusions

In this paper, we have presented results from two case studies that used high resolution NWP models run at resolutions as high as 100m to simulate wind fields in regions of complex terrain and at a coarser 1.5km resolution to simulate the wind field associated with the passage of TC Winston over Fiji in February 2016.

In the first case study it has been shown that a very high resolution NWP model with a realistic orography can forecast well the near-surface and hub-height wind speeds that in the past would typically have only been possible using CFD or wind tunnel scale models. While running such NWP models are still computationally prohibitive for operational real-time forecasting for wind power generation, this will become less of an issue over time as HPC resources continue to advance.

In the second case study, a 1.5km resolution NWP model was used to simulate the passage of TC Winston over Fiji in late February 2016. Despite a lack of any land/sea mask and orography in the model because none existed in the source datasets, the model was able to well simulate the storm track and forecast surface pressures and wind gust speeds compared to observations, particularly at sites where orographic and land-friction effects are less dominant. Future work will see the introduction of a land/sea mask and orography for the larger Fijian islands and the simulations rerun. Output from these reruns, including simulations at resolutions as high as 100m, will then be used to reliably inform the development of vulnerability models for better planning and mitigation against storms of this type.

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References

Davies T, Cullen MJP, Malcolm A, Mawson MH, Staniforth A, White AA and Wood N, (2005) A new dynamical core for the Met Office’s global and regional modelling of the atmosphere, Q. J. R. Meteorol. Soc. 131:1759-1782

Glahn HR and Lowry DA (1972) The use of Model Output Statistics (MOS) in Objective Weather Forecasting., J. Appl. Meteor., 11:1203-1211

IGBP (1990) The International Geosphere–Biosphere Programme: a study of global change— the initial core project. IGBP Global Change Report no. 12, International Geosphere–Biosphere Programme, Stockholm, Sweden

USGS (2004) Shuttle Radar Topography Mission, 1 Arc Second scene SRTM_u03_n008e004, Unfilled Unfinished 2.0, Global Land Cover Facility, University of Maryland, College Park, Maryland, February 2000

Webster S, Brown AR, Cameron DR and Jones CP (2003) Improvements to the representation of orography in the Met Office Unified Model, Q. J. R. Meteorol. Soc., 129:1989-2010

Yang Y, Uddstrom M, Revell M, Moore S and Turner R (2016) Damaging southerly winds in the Cook Strait and Wellington region: barrier jets enhanced by downslope winds, Submitted to Monthly Weather Review May 2016