**Application of very high resolution Numerical Weather Prediction to assessing wind damage during TC Winston**

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**Abstract**

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 and an estimated US$1.0 billion of damage was done [3]. With events such as these, accurate forecasting of the storm strength, storm track, timing and lifespan is vital to aide preparedness and to mitigate against possible damage and loss.

Part of the solution to achieving this is being able to run Numerical Weather Prediction (NWP) models in a timely manner at horizontal resolutions that not only properly resolve the processes most important to cyclone development and propagation, but also make use, where possible, of high resolution ancillary data such as terrain data.

Today’s supercomputers are now capable of doing just this and in this presentation we describe work that looks at how well a modern NWP model running with horizontal resolutions of 1.5 km down to 100 m can forecast an event such as TC Winston, focussing on the key storm features such as wind speed (mean and gusts), landfall timing and location and storm track.

In addition, we investigate how NWP model output, namely the surface and lower level winds, can be used to estimate the likely wind damage to be expected by a storm and the possible economic and infrastructure damage via application of the RiskScape natural hazard impact and loss evaluation tool, jointly developed by NIWA and GNS Science in New Zealand.

**Introduction**

Only in recent years, with ever-improving supercomputer resources, have Numerical Weather Prediction (NWP) models begun to be run at resolutions that explicitly resolve the wind flow interactions over complex terrain. Now, supercomputing resources are such that fine-scale NWP on scales O(100 m) is very possible and we can begin, for example, to use these models to confidently simulate the processes, lifecycles and impacts of tropical cyclones.

TC Winston is considered the most costly cyclone in South Pacific history with a central low pressure minimum of just 915 hPa and 10-minute sustained winds of 230 kph (~63 m/s) (see <https://en.wikipedia.org/wiki/Cyclone_Winston> and references therein). The passage of the eye of TC Winston over Vanua Balavu, Fiji, during which a potential South Pacific Basin record wind gust of 85m/s (approx. 305 kph) was recorded, provides a recent case where such fine-scale NWP can be tested.

Using the UK Met Office Unified Model (hereafter UM, see description in [8] and [1]) as the chosen NWP model, we will present the results of work that investigates how well modern NWP models, when run at horizontal resolutions approaching 1 km and higher, can simulate an event such as TC Winston, the effects that ancillary data such as high resolution terrain data can have on the simulations and attempt to apply the modelled wind fields to the RiskScape [6] natural hazard impact and loss tool to assess the likely built infrastructure and economic losses TC Winston would have caused. Comparison against observed meteorological observations and actual loss figures will be made too.

**The NWP Model**

The UM is a state-of-the-art NWP model now widely used by many national meteorological centres around the world, and collaboratively developed under the guidance of the Unified Model Partnership. NIWA is a member of this Partnership and uses the UM as the primary tool in its EcoConnect hazard forecasting system with output from the UM used to drive many downstream models covering hydrology, storm surge, and wave forecasting applications, and is run in two configurations; a 12 km resolution New Zealand Limited Area Model (NZLAM) set up that covers the New Zealand and wider Tasman area including the eastern Australia coastal region, and the 1.5 km resolution convection-permitting New Zealand Convection-Scale Model (NZCSM).

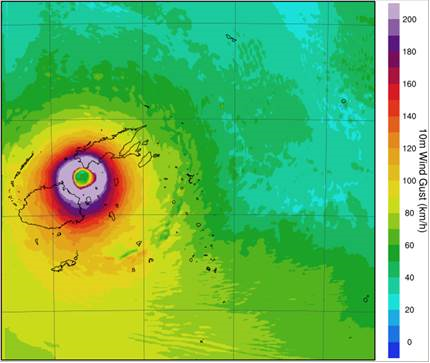
In this work, a one-way nested configuration of the UM is used whereby a Global configuration of the UM with ~23 km horizontal resolution at tropical latitudes is used to generate lateral boundary conditions for a 1.5 km configuration of the UM centred on Fiji using a 600 × 600 × 70 domain. This model is run for 48 hours and in turn is configured to generate initial and lateral boundary conditions for higher resolution configurations of the UM, down to ~100 m. From each UM forecast, meteorological fields are output to enable qualitative comparison against available satellite imagery and quantitative verification against available ground-based observations.

Where available, land use and terrain data is sourced from the IGBP [5] and CCI [2] and GLOBE [4] and Shuttle Radar Topography Mission [7] projects respectively.

**Simulating TC Winston**

Being able to forecast the track, central pressure, and associated wind speeds of a Tropical Cyclone would greatly assist in the preparing for the arrival of the storm, and, after the event, assist in planning of damage surveys and in better understanding how the built infrastructure was affected.

From a forecast started at midnight UTC on the 19th February 2016, Figure 1 shows the forecast size, location and associated wind speeds of TC Winston as it approaches the island of Fiji at 0500 UTC on 20th February 2016 from the 1.5 km model. The size and location of the modelled storm can be compared to the Himawari 8 cloud top temperature imagery in the bottom panel.



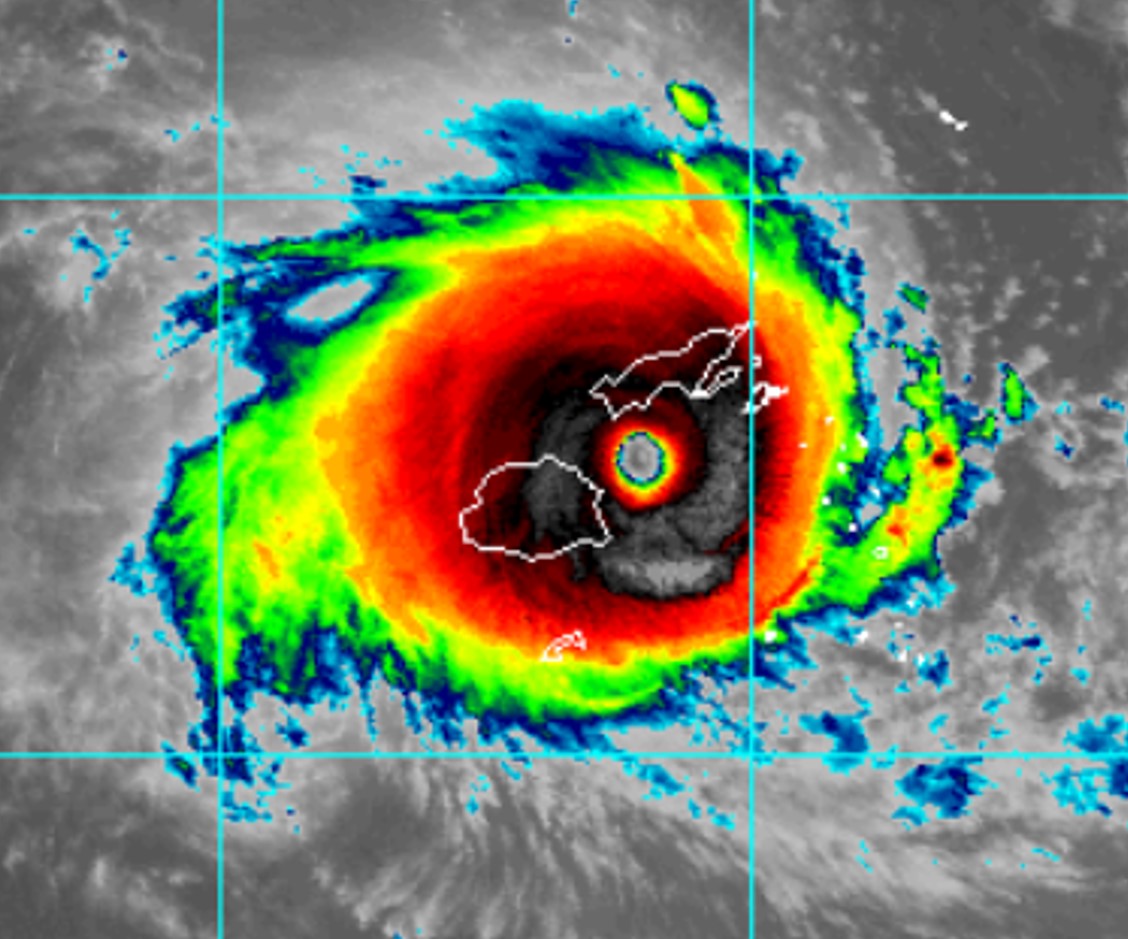


Figure 1. Comparison of TC Winston eye positioning and size valid at 0500 UTC on 20th February 2016. Top panel is the simulated 10m maximum wind gust speed from the 1.5 km UM and the bottom panel is Himawari 8 cloud top temperature imagery.

Qualitatively, the 1.5 km model has done a very good job of forecasting the storm location and size, even 31 hours out from the data validity time. From the same model forecast, modelled wind and pressure values were also compared against ground-based observations. Table 1 compares these for Vanua Balavu, Levuka and Ba.

From Table 1, it is clear the 1.5 km model is quantitatively capable of forecasting some of the key elements of TC Winston, albeit the peak observed gusts are simulated slightly too low and the simulated low pressure centre a too high. Regardless such a forecast is still a useful in corroborating aerial or ground-based photo assessments of storm damage where local observations are not available.

A horizontal resolution of 1.5 km is likely still too coarse to be able to resolve the topographic features of Fiji and its outlying islands which will have played a dominant role determining the near surface wind field. To counter this, additional forecast runs of the UM are made at horizontal

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| --- | --- | --- | --- | --- |
| **Site** | **Observed** | | **Modelled** | |
| 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.

resolutions as high as 100m using underlying topography data at similar resolutions in an attempt to capture the local near surface wind field as well as possible. Forecasts from multiple initial times also, giving a lagged ensemble of forecasts to capture the forecast variability of the storm, are also completed. An ensemble of forecast wind speeds and central pressures enables confidence intervals to be generated that can be used downstream to assess both conservative and best-case damage scenarios. This work is ongoing.

**Hill Shape and Terrain Category Modelling**

A further benefit of running the NWP model to resolutions approaching 100 m, where the local terrain is more accurately resolved, is that estimates of the hill shape effects and terrain category, components regularly used in wind action calculations, can be directly modelled and compared against those calculated from the Standards themselves. When accompanied by the modelled wind fields, in particular the modelled surface wind gust, forecast estimates of point-of-damage wind speeds can be calculated for individual properties that have been surveyed post-event.

Using UM forecast output, these factors are being evaluated per the AS/NZS 1170.2 (2011) Standards on Wind Actions and will inform on both the validity of the Standards in terms of the wind speeds that should be expected over a given terrain or region and in validating the outcomes of loss/damage disaster analysis tools such as RiskScape.

**Evaluating the loss and damage impact of TC Winston**

Vulnerability models are one way of forecasting the likely impact, both on built infrastructure and economic loss, a given event will impart. For natural hazard events, NIWA, in conjunction with GNS Science, has developed the RiskScape impact and loss evaluation tool.

In quiet times, these models can be used to evaluate worst-case scenarios based on hypothetical events, advising on how new infrastructure projects could be developed to minimise against large losses. In post-event use, on-the-ground damage surveys, coupled with event observations and more recently high resolution NWP forecasts of surface winds, can be used as input to the vulnerability models and damage functions for various building types and materials can be more rigorously tested and updated accordingly.

Here, the RiskScape tool’s wind damage module will be run to generate pre- and post-event damage estimates using both UM forecast and observed winds. These simulations will assess the capabilities of the existing damage functions in RiskScape and inform on future developments, where a variety of stakeholders, from regional civil defence authorities, governments and insurance companies will have a vested interest.

**Conclusions**

Initial results from a 1.5km resolution NWP model used to simulate the passage of TC Winston over Fiji in late February 2016 have been shown. The model was able to well simulate the storm track and forecast surface pressures and wind gust speeds compared to observations. Output from these and planned future model simulations, including simulations at resolutions as high as 100 m with appropriately resolved terrain data, will be used in future work to estimate and compare against the terrain category and hill shape effects that inform the design wind estimates used in building design and in testing the accuracy and reliability of natural hazard disaster risk/loss tools such as RiskScape. Used in conjunction with results from post-event damage surveys and observations, we will show how high resolution NWP can aide the continued development of vulnerability models and damage functions for different types of built infrastructure which are needed for better planning and mitigation against events of this type.

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