Nested UM Forecasts of a downburst during TC Pam

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1. Abstract

Tropical Cyclone Pam (March 2015) was a Category 5 Cyclone that was the costliest in Vanuatu's history, with large impacts (16 fatalities and over US$500M in damage) particularly in the southern half of Vanuatu. In a recent effort, one-way nested very high-resolution Unified Model (UM) forecasts (initiated at 6 hourly intervals) were produced over the period that TC Pam was near Vanuatu. We thus gained estimates of mean wind speeds and gusts to assist in return period analyses for parts of Vanuatu. In the highest resolution (100m grid spacing) simulations an interesting, and unexpected, finding was that in strong, moist, sheared and unstable S-SW flow around 200 km east of the eye, where winds and impacts were much less, a downburst event was modelled to occur near the town of Luganville on the island of Espiritu Santo. We demonstrate key characteristics of the synoptic environment and downburst evolution and compared them with those from idealised numerical simulations and the extremely limited reported hindcasts (forensic forecasts) of downburst events in the scientific literature (e.g. Parodi et al., 2019). There are important questions around this, since 100 m resolution NWP capabilities are close to being in scope for many operational forecast centres. There is much active research into this urban or city-scale NWP, notably with international efforts such as the Paris 2024 Research Development Project (https://www.umr-cnrm.fr/RDP_Paris2024/) developing a city-scale model for the 2024 Olympic host cities of Paris and Marseille, and it is not yet established if these models have a bias towards over-forecasting the occurrence of such phenomena.

2. Method

The model set-up followed NIWA's nested Auckland Model (Safaei Pirooz et al., 2021), which is based on a nested configuration of the United Kingdom Met Office Unified Model's (Davies et al., 2005) Model, and runs down to either 333 m and 100 m horizontal resolutions.

It used the Regional Atmosphere-Land 2 – Tropical (RA2T) convective-scale physics configuration. This configuration is convection-permitting and tuned for tropical environments. The model domains are shown in Figure 1.

The finest configuration is able to capture the topographic features around Luganville and provide insights into horizontal and vertical wind patterns and properties, including regional and local orographic effects on airflow at high resolutions during the selected cyclone and extreme wind events.

In this project the model output was also used as an input to downstream modelling activities, such as coastal inundation. It should be noted that, due to the computational cost and project time limits, these high-resolution models were only done for select cases.

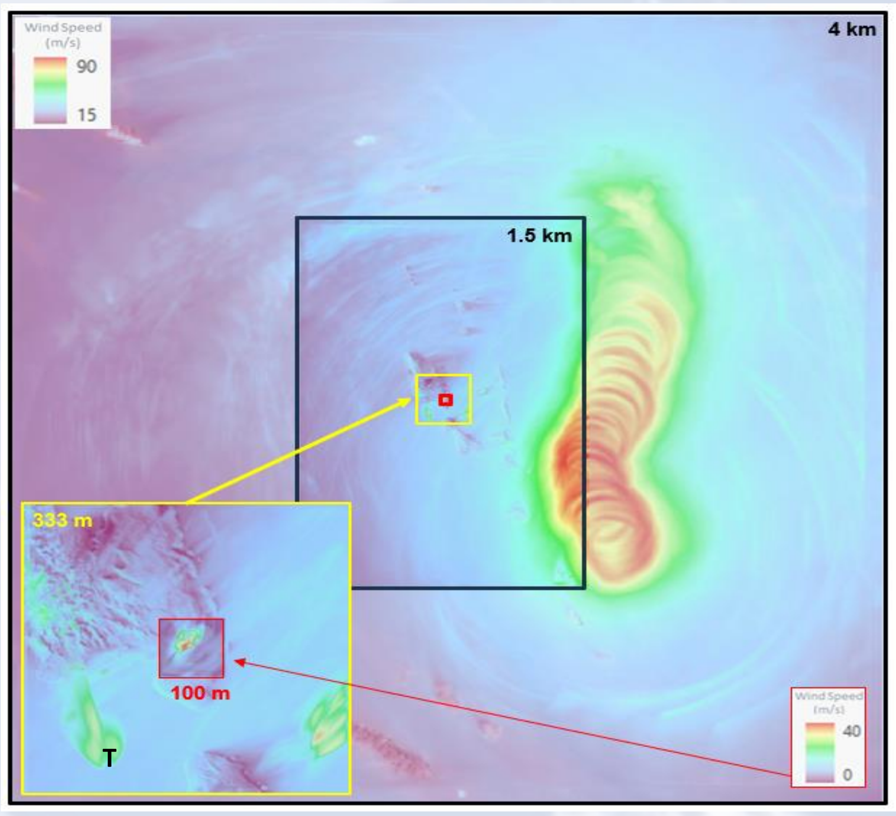


Figure 1: Nested domains used for simulating recent significant cyclones near Luganville. Grid spacings are 4 km, 1.5 km,333 m (inset - yellow border), and 100 m (inset, red border). The colour contours are maximum forecast 3-second wind speeds (gusts) within the 36-hour period from 00 UTC 12 March to 12 UTC 13 Mar 2015 as Cyclone Pam passed to the east of Vanuatu. Sampling of maximum speeds occurred at 15-minute intervals. Note the different colour scale (bottom right) for the 100 m grid.

3. Results

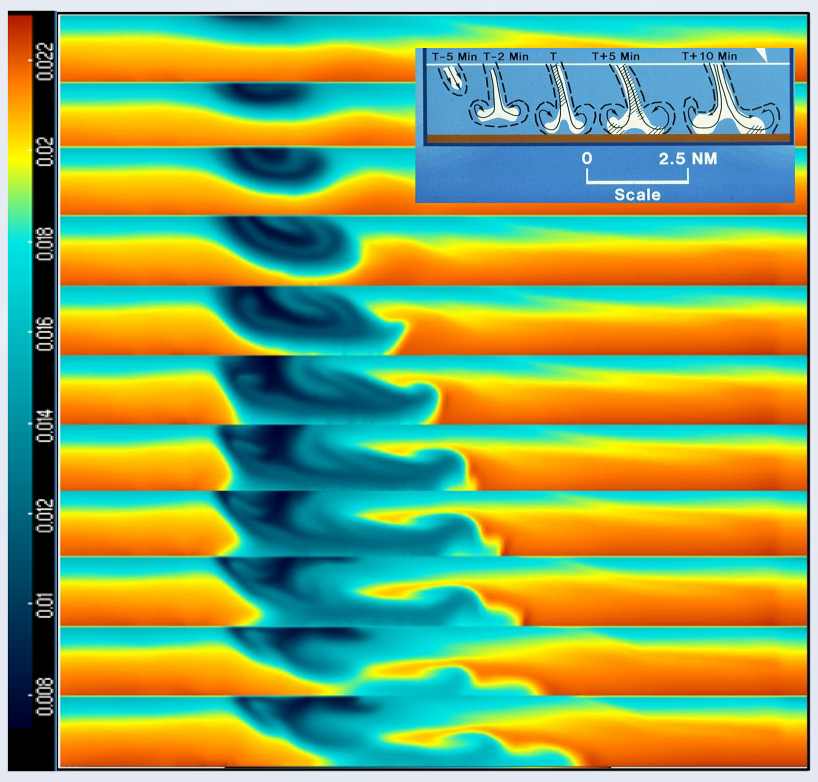


Figure 2: Sequence of vertical profiles of specific humidity (kg/kg) (colour bar shown at left) through latitude -15.563°N (shown by a dashed line in Figure 4) as simulated within the 100 m grid-spaced Unified Model domain between the surface and 1600 m altitude. Images are spaced one minute apart, from 23:55 UTC 12 March 2015 through 00:05 UTC 13 March 2015. This shows rapid downward moving of cold air impacting the surface and then radiating horizontally. The horizontal extent of the cross-section is 20 km. The propagation of the front (lateral to the background flow is approx. 13 m/s. The inset (from UCAR) is an idealised schematic with little background flow. Mason et al. (2009) simulated a propagation speed with no background flow of around 12 m/s.

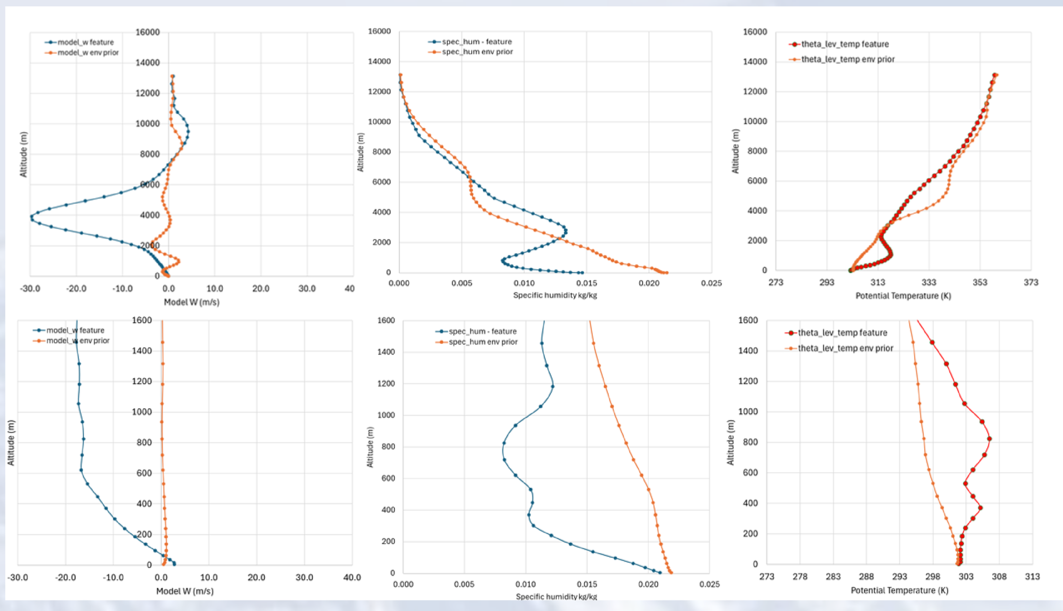


Figure 3: Profiles of vertical velocity (left column), specific humidity (middle column) and potential temperature (right column) for "within feature" (blue and red) and "in environment" (orange) prior to the downburst. Top row from 333 m model near the "T" in Figure 1. Bottom row from 100 m model near point "2" in Figure 4.

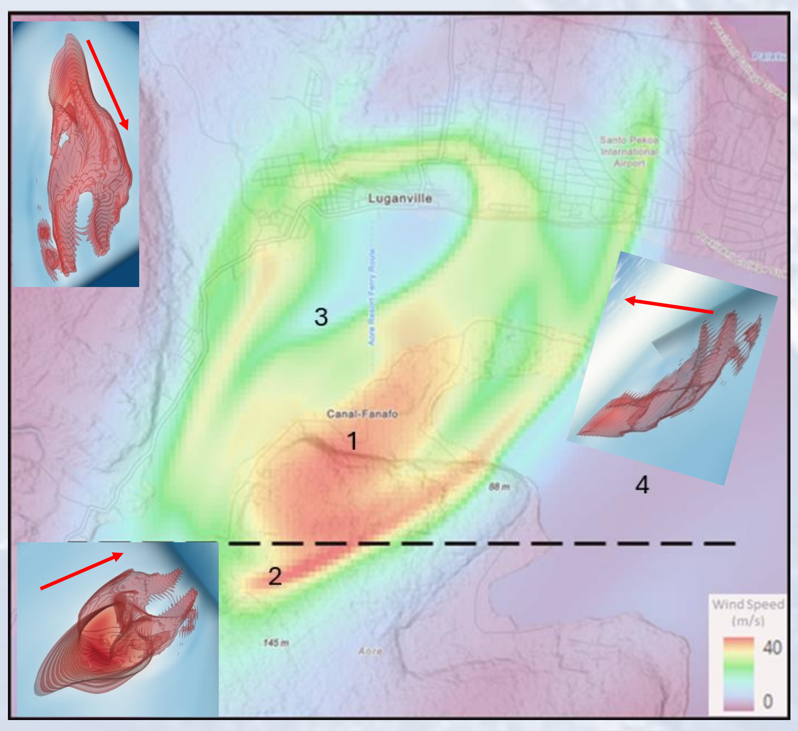


Figure 4: Plot of 10 m above ground level storm-relative horizontal wind speed (m/s) associated with the simulated microburst at 00 UTC 13 March 2015. The general background flow was around 20 m/s from the southwest. The black dashed line shows the location for which the vertical profiles of specific humidity are shown in Figure 3. The three thumbnail images are 3-D renderings of isosurfaces of 43 m/s speeds.

4. How realistic?

The vertical profile of downburst winds are important for structural engineers designing tall buildings and towers, the departure from the typical log-profile (commonly seen, e.g., pt4 yellow curve) for downbursts is clear in Figure 5. The log-profile is often assumed in many design standards and so for areas where the most extreme winds are due to downburst phenomena, describing these profiles accurately is important.

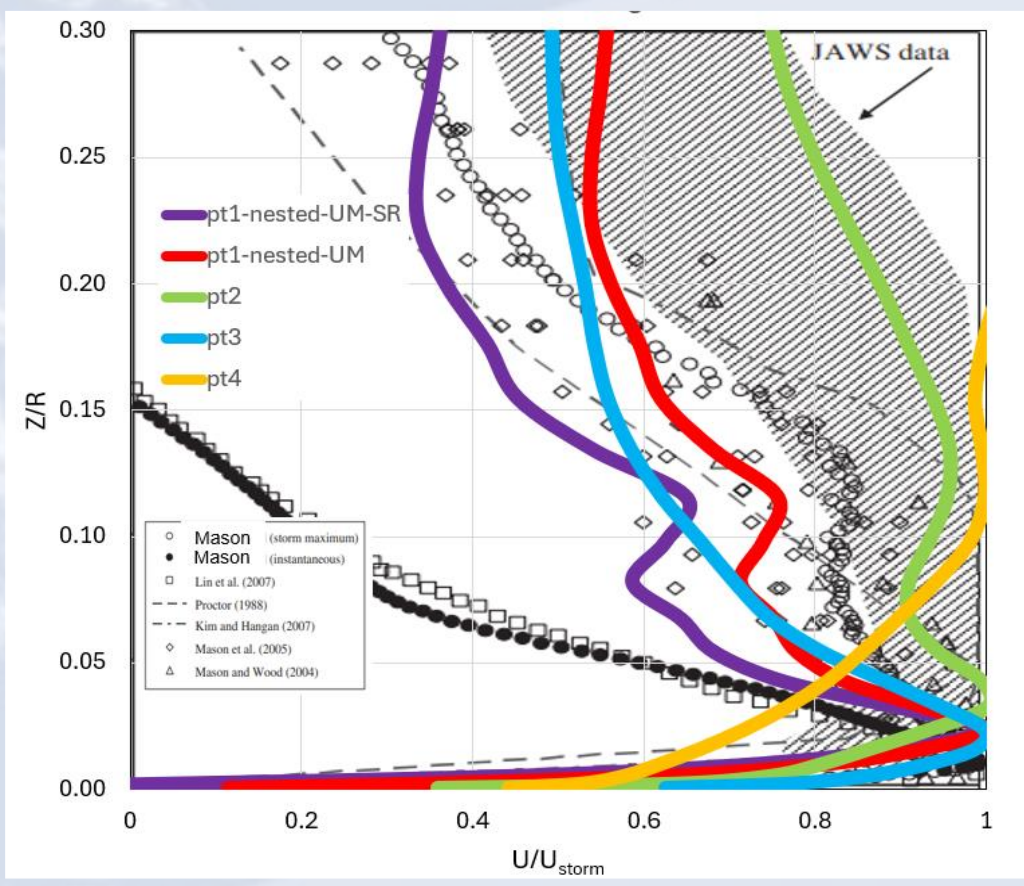


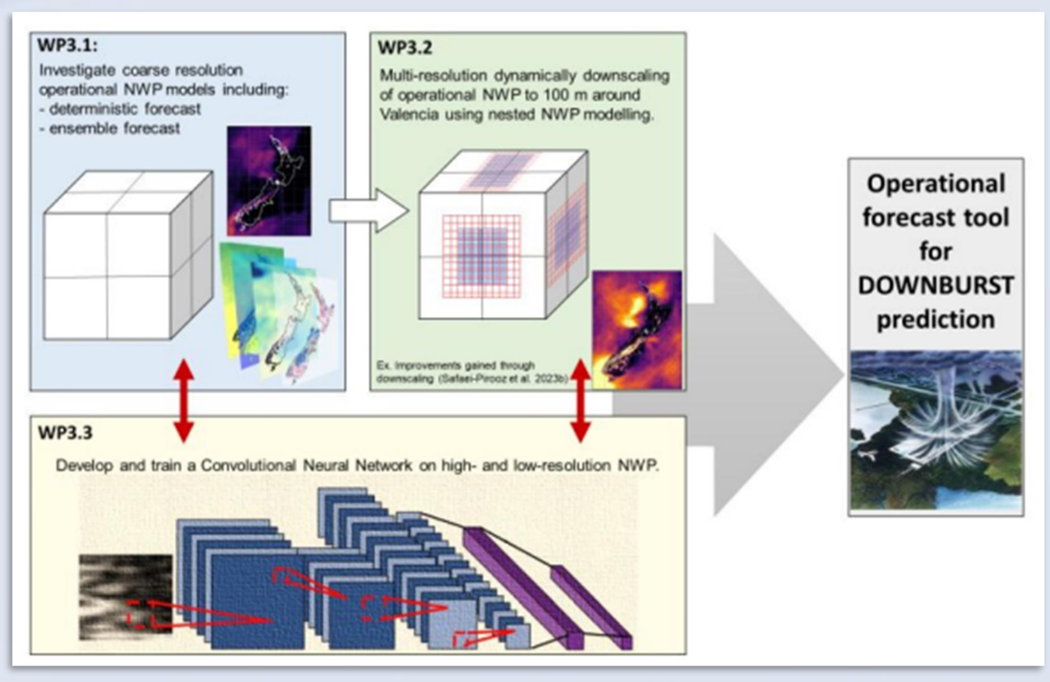
Figure 5: Scale velocity profiles for various points within the downburst area (see numbers in Figure 4) compared against past modelling and observational studies (JAWS). (This figure adapted from the original Figure 5 of Mason et al. (2009))

5. Future work

There appears to be some influence from the orography on the evolution of the wind fields, and undertaking a sensitivity study in regard to the underlying terrain would be useful.

We should also investigate further the atmospheric environments in the parent (333 m and 1500 m) simulations. Since the background flow is quite strong, identifying key development processes at coarser resolution, more representative of operational model set ups, is important. An investigation into the effect of domain size for the 100 m model should also be conducted to better accommodate the winds speeds experienced during this event.

Recently we have been part of a successful proposal funded by the Valencian (Spain) regional government, called "Potential effects of anthropogenic climate warming on windstorm hazards: detection, attribution and prediction of downbursts". Here, we aim to investigate the potential for AI tools to forecast downbursts. A conceptual component of the work plan we involved is shown in the schematic below.



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