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EVALUATING TOPOGRAPHIC INFLUENCES ON THE NEAR-SURFACE WIND FIELD OF TROPICAL CYCLONE ITA (2014) USING WRF-ARW

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ABSTRACT

Tropical Cyclone (TC) Ita (2014) was a major storm that affected coastal areas of Northeast Queensland. Topographic features along the coastline are known to modify the structure and intensity of such events. This study utilises the Advanced Research version of the Weather Research and Forecasting (WRF-ARW) model to investigate topographic influences during the landfall phase of TC Ita. While the removal of topography over the whole domain steers the modelled TC far away from the landfall point, removing topography from only a smaller area allowed an investigation of the topographic influence on near-surface wind conditions in that area. Flow over the region of removed topography exhibit smaller inland velocity gradients for winds flowing onshore and a sharper acceleration of winds as they moved offshore.

INTRODUCTION

Tropical Cylone (TC) Ita (2014) was a major storm that made landfall in Queensland, Australia near Cooktown. In early April it originated over the Salomon Sea (Figure 1) as a low pressure system. Ita gradually intensified and drifted westward over the next few days before strengthening to a Category 1 cyclone on 5 April (BOM, 2014). Three days later, Ita strengthened to Category 3 status and brought heavy rainfall to parts of southeast Papua New Guinea. Through rapid intensification on 10 April, Ita turned into a Category 5 storm and weakened immediately before making landfall as a Category 4 cyclone on midday 11 April. Here, a maximum wind gust of about 44 m/s was recorded at the Cape Flattery automatic weather station (AWS), near to the landfall position.

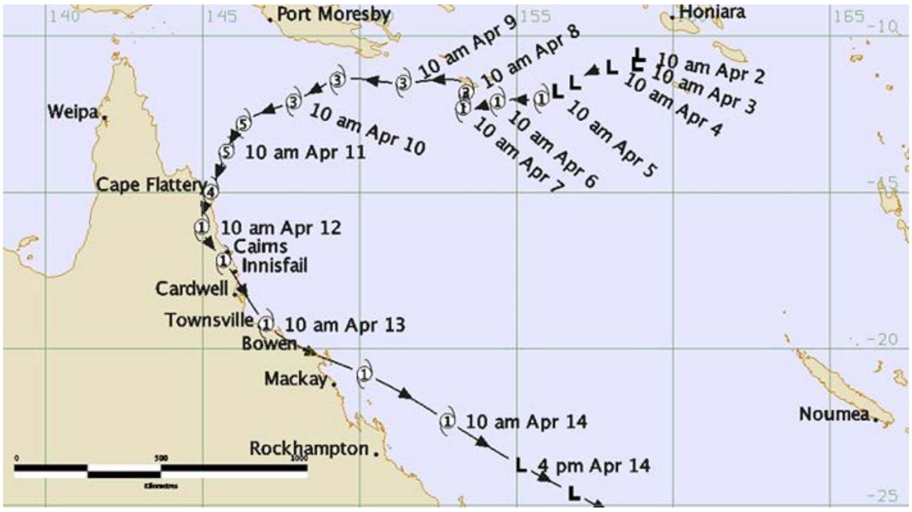

FIGURE 1. BUREAU OF METEOROLOGY TRACK OF TC ITA (BOM, 2014).

Ita continued to weaken over land and turned into a Category 2 cyclone as it followed a southerly track passing approximately 20 km to the west of Cooktown. Before midday on 12 April, Ita became a Category 1 storm and moved further southward along the coast of Queensland before moving offshore between Townsville and Mackay one day later. Overall, approximately 200 structures experienced minor damage and major damage to 16 buildings was reported. Gust wind speeds of 34 m/s were recorded at the Cooktown Airport (BOM, 2014) and 26–28 m/s recorded by SWIRLnet towers (3.2 m elevation) located at a range of sites between the eye of the storm and Cooktown (Mason and Henderson, 2015).

The landfall phase of TC events like Ita is often associated with strong winds, heavy rainfall, and storm surges. Coastal topography can play a major role in reorienting TC path as well as modulating near-surface wind and precipitation fields (e.g. Hsu et al., 2013; Wu et al., 2015). Topography along the northeast Queensland coastline is known to have such an impact, and acts to enhance the destructive potential of landfalling TCs (Ramsay and Leslie, 2008).

This study aims to provide a first insight into topographic influences on near-surface winds during a TC event. To address this, the Advanced Research Weather Research and Forecasting (WRF-ARW) model (Skamarock et al, 2008) is used to simulate the near-surface wind field at 10 m height of TC Ita as it moved through Cooktown.

METHODOLOGY

Model description

The WRF-ARW version 3.7.1 (Skamarock et al, 2008) model was implemented with a moving nest configuration with the vortex-following option turned on for this study. Two domains are set up with grid and time step ratios of 1:3 with 27 vertical height levels. Domain one (d01) includes 230 × 230 grid points with a 10 km horizontal resolution, whereas domain two (d02) has a grid spacing of 3.3 km on a 220 × 220 grid. Model runs used a time step of three hours and the period between 9 April, 12 UTC through 14 April, 12 UTC is simulated. All initial and boundary conditions are sourced from the 1° × 1° NCEP final operational model global tropospheric analyses database (NCEP, 2000). These include air temperature, humidity, hydrostatic and sea level pressure. High-resolution topography data with a horizontal grid spacing of 4 km and 1 km were used for domains d01 and d02, respectively. The highest elevations are found around Cairns with mountains up to 1000 m.

Experimental design

Following Kloetzke et al. (2016), the Kain-Fritsch cumulus scheme, the WRF Single-Moment 3-class microphysics, and the Yonsei University boundary layer parameterisation were used to simulate TC Ita. This combination of physics options yielded the smallest track error with regards to the observed track. To test the influence of topography on the modelled track behaviour, two simulations were run for comparison with the default simulation results discussed in Kloetzke et al. (2016). The first simulation involved all topography throughout the domain being removed (*notop*). For the second, only the topography in the area around Cooktown, ranging from 16S to 14S and 144E to 146E was removed (*notopCT*). Topographic features throughout the remainder of the domain were maintained.

RESULTS

The first simulation used the WRF default physics configuration (Skamarock et al, 2008) with topography turned off for the entire domain (*notop*). As shown in Figure 2, this track matches fairly well with the best track and default (*top*) simulation at the beginning of the track, but quickly begins to diverge after 24 hours. While the WRF default simulation (top, red line) roughly follows the best track, the notop simulation moves fast southward due to a strong steering flow originating near Papua New Guinea. It turns out that by removing all topography throughout the domain has large scale influences, which leads to a blocking ridge to the west and a strong northerly steering flow that forces the storm to move southward in a manner unrepresentative of the actual event.

In an attempt to reproduce the same event track as the default simulation (*top*), but still investigate topographic influences, a smaller area of topography was removed (*notopCT*), as described above. Running this simulation, Figures 2 and 3 show very close replication of event characteristics in terms of track position and central pressure. The track position error (with respect to the best track data) for *notopCT* at landfall is only 11 km, which is in fact an improvement on the default simulation value of 27 km.

Figures 4A and 4B highlight the influence of removing the relatively small area of topography (up to 300 m height) for the broad region around Cooktown in the *notopCT* simulation. The Cooktown area modelled with zero topography values shows slower near-surface winds to the south of the TC core and faster winds to the north, when compared with the *top* case. The *notop* wind field is generally stronger than the flow in the area with topography, as hills and mountains act as blocking ridges that appears to slow winds in this area. Overall, these differences are comparably small due to the little area near Cooktown that was modulated and the non-complexity of terrain; however, the influence of topography cannot be denied.

CONCLUSIONS AND FUTURE WORK

The landfall phase of TC Ita has been investigated to understand the topographic influence on the near-surface wind field. When comparing results for simulations with and without topography in the Cooktown region it is evident that sudden decreases in wind speed occur as flow moves over land, but this slowdown is less pronounced when topographic features are not present. Further research will explore how changing the size of the selected topography removal region will influence results or regions with more complex terrain.

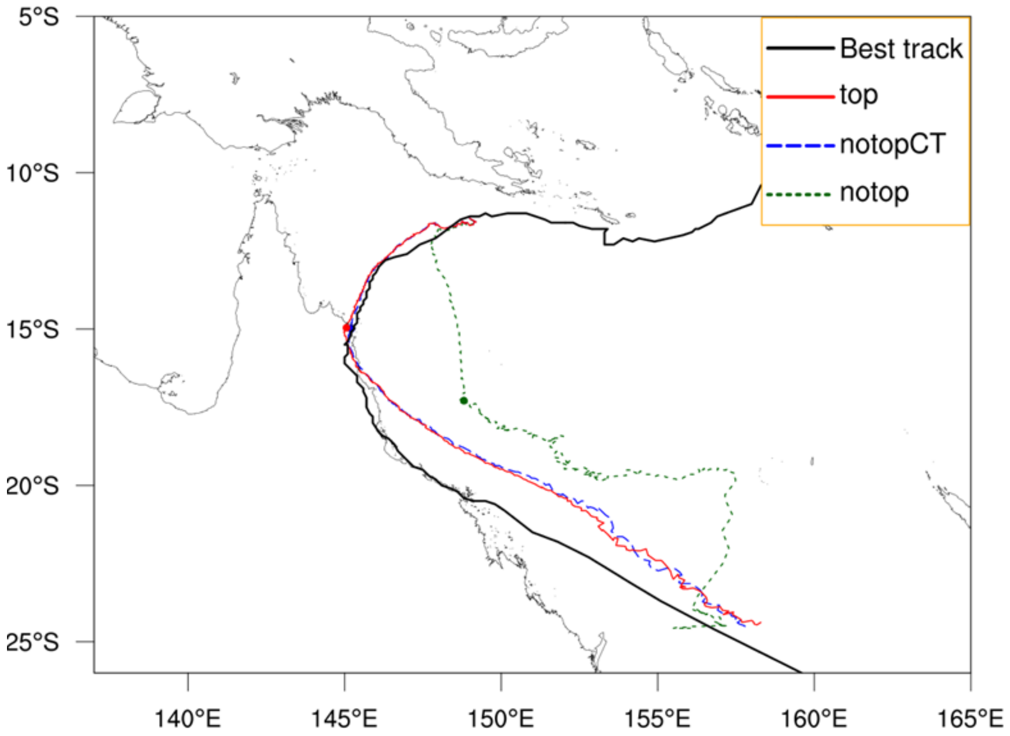

FIGURE 1. WRF MODELLED TRACKS AND BEST TRACK (BLACK) OF TC ITA. WRF DEFAULT PHYSICS MODELLED TRACK (RED), TOPOGRAPHY SET TO ZERO FOR THE ENTIRE DOMAIN (GREEN), AND TOPOGRAPHY TURNED OFF FOR THE COOKTOWN AREA ONLY (BLUE). LANDFALL POINTS ACCORDING TO THE BEST TRACK LANDFALL TIME ARE INDICATED WITH COLOURED DOTS.

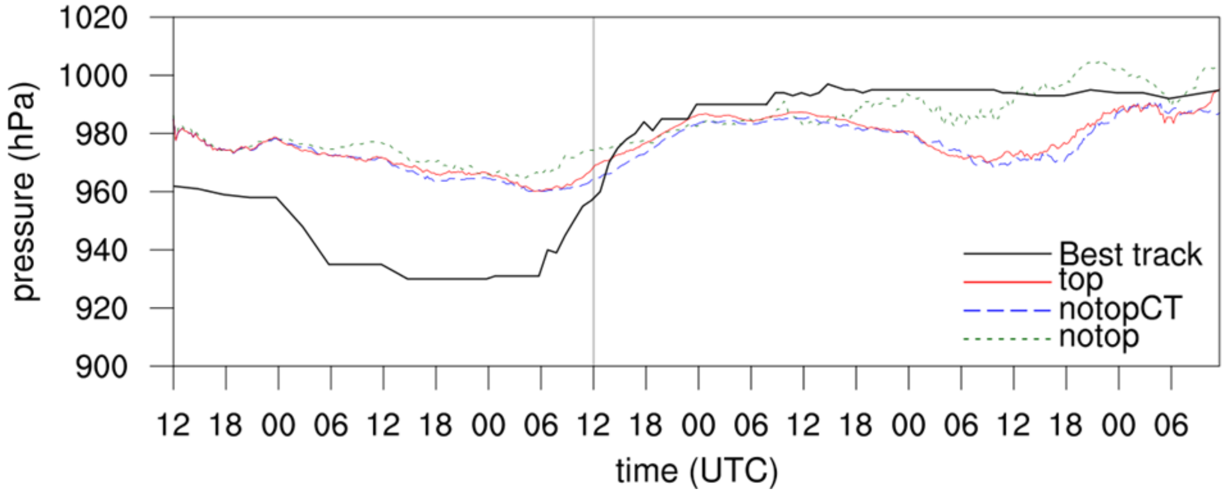

FIGURE 3. PRESSURE SHAPES FOR TRACKS IN FIGURE 2.

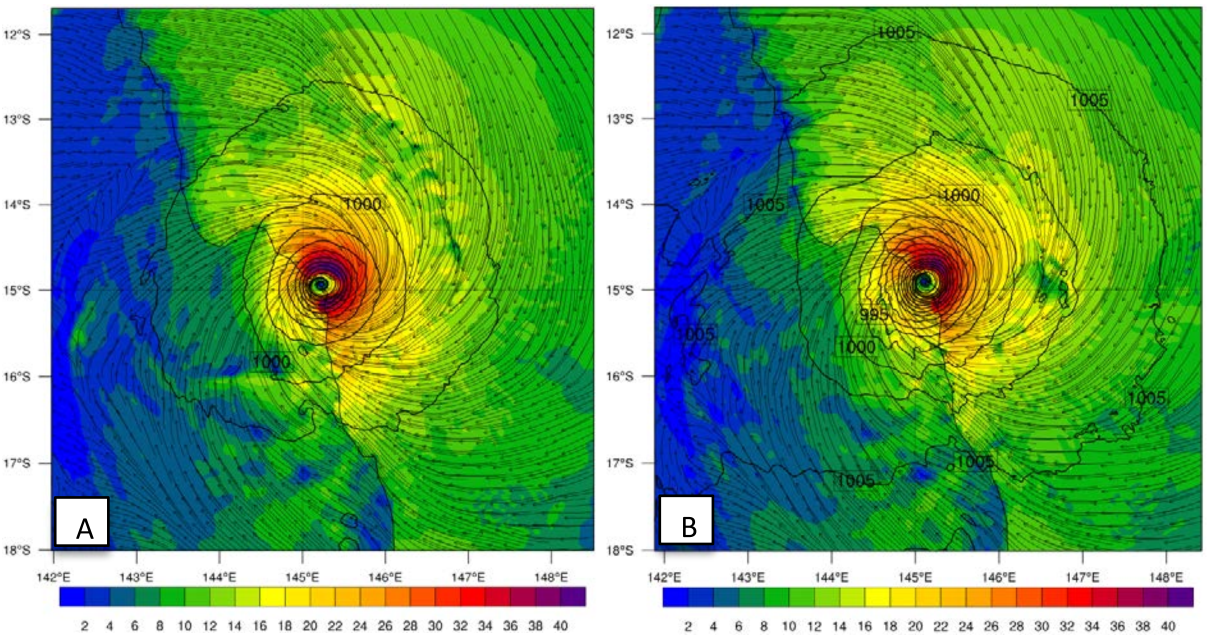

FIGURE 2. WIND SPEED AND PRESSURE FIELDS FOR THE 3.3 KM WRF-ARW RESOLUTION TC ITA AT LANDFALL. COLOURED CONTOURS INDICATE THE 10 M WIND SPEED MAGNITUDE, ISOBARS ARE DISPLAYED WITH SOLID BLACK LINES, AND WIND DIRECTION WITH ARROWS.

Acknowledgments

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