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Wind predictions of ex-Tropical Cyclone Cook making a direct hit on Auckland CBD

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SUMMARY
Ex-Tropical Cyclones are a serious threat to New Zealand, and have been studied by scientists over many years using Numerical Weather Prediction modelling, and more recently some computational fluid dynamics investigations have also been carried out. This paper presents work carried out to develop a framework which couples numerical weather prediction data with computational fluid dynamics modelling to create a high resolution method of investigating the impact of strong winds from an ex-Tropical Cyclone, a serious wind hazard for the northern regions of New Zealand.

Keywords: ex-Tropical Cyclone; ABL; CFD

1. INTRODUCTION

Ex-Tropical Cyclones (ex-TCs) are remnants of Tropical Cyclones (TCs) which form when TCs lose their asymmetric structure from tracking over cooler bodies of water. However, ex-TCs remain a hazard to populated areas due to maintained strong wind speeds. Considering New Zealand, over 85% of the population resides in large cities, with Auckland City being the most densely populated (Cameron, 2018). Due to the country's geographic location between latitudes 34 S and 47 S, it is impacted, on average between one and two times every year, which has raised concerns about the potential impacts if one were to make landfall, particularly near Auckland (Lorrey et al., 2014).

Currently, only a small body of work has been completed in determining the impact of an ex-TC on New Zealand urban environments generally, let alone Auckland. Most of the recent work has been carried out by NIWA via their reanalysis using Numerical Weather Prediction models (NWPs – which are configurations of the UK Met Office's Unified Model) of past storms to determine peak wind speeds and rainfall rates (among other meteorological parameters). Output from NWPs tends to be at a larger scale and a lower resolution compared with computational fluid dynamics (CFD), however, recently, an effort was made to couple the NIWA NWP model with a high-resolution CFD model (Safaei Pirooz et al., 2021). Subsequently, that approach has formed the basis of the work carried out in this study, which is described in Section 2. Overall, this paper outlines the progress of developing a numerical framework which can embed NWP data into a higher resolution CFD model in the pursuit of investigating, in more detail, the impact of ex-TCs wind speeds on parts of New Zealand.

1.1. Modelling Approach

To couple NWP with CFD, data from numerical models used by scientists at NIWA were used to determine the maximum mean wind speed from an ex-TC. In this paper ex-TC Cook, which made landfall near Auckland in April 2017, is used as a case study. The maximum mean wind speed was then interpolated within CFD to produce wind speed changes and behaviour over a section of the Auckland CBD. However, the CFD modelling approach taken follows the practice of computational wind engineers, in which a horizontally homogeneous atmospheric boundary layer (HHABL) is first generated, and then a target geometry is embedded in it.

2. COMPUTATIONAL MODELLING

2.1. HHABL

Recently, (Richards and Norris, 2015) presented a new set of inlet profiles which would produce an HHABL. Importantly, the velocity profile they used resembles the Deaves & Harris (Deaves,1978) velocity profile, which is also used in the AS/NZS 1170.2 Wind Loading standard. Therefore, the (Richards and Norris 2015) methodology was used in this study. A caveat of this choice is that the profiles had to be adapted to ANSYS Fluent as the recommended coefficients were for CFX. Mainly, the aerodynamic roughness was converted to an equivalent sand-grain roughness appropriately for Fluent, as suggested by (Blocken, 2007).

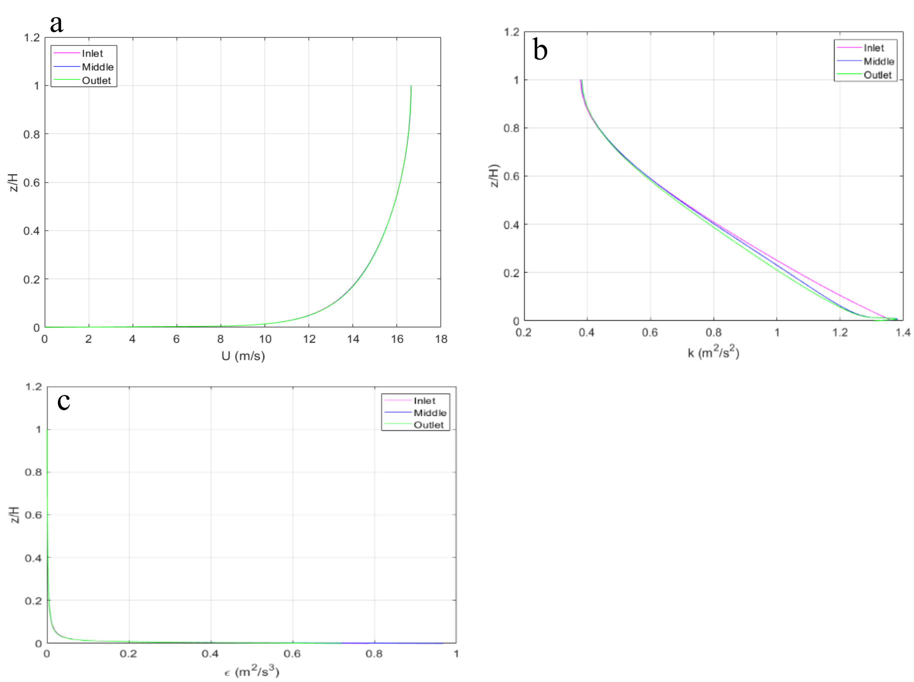

Figure 1. HHABL profiles for (a) velocity, (b) turbulent kinetic energy, (c) turbulent dissipation rate

The HHABL was modelled for a terrain category 2 site which has an aerodynamic roughness length of 0.02. All the other simulation parameters including the domain size were the same as those used by Richards and Norris (2015), for the purpose of replicating their results. From visual inspection of Figure 1 it is evident that the ABL is homogeneous, as the vertical profiles at the inlet, middle and outlet of the domain match perfectly. A mean average percentage error (MAPE) assessment provided quantitative proof that the domain was homogeneous; the results are summarised in Table 1.

Table 1. MAPE results for HHABL

Parameter	Application	Middle (%)	Outlet (%)
Velocity	Fluent	0.06	0.08
	CFX	0.04	0.05
TKE	Fluent	1.49	2.58
	CFX	0.44	0.63
TDR	Fluent	1.70	2.52
	CFX	5.47	6.02

TKE is turbulence kinetic energy, and TDR is turbulent dissipation rate. As shown in Table 1, percentage differences in the flow properties at the inlet and downstream of it are very small, and have the same range of percentage error as (Richards and Norris, 2015).

2.2. Auckland CBD case study: ex-tropical cyclone Cook

Using the HHABL model described in Section 2.1, a section of the Auckland CBD was embedded into a 3000 x 1000 x 1000 m rectangular domain. All simulation parameters were kept the same as in Section 2.1, with the exception of the inlet profiles which were adapted to ex-TC Cook, for which a maximum mean wind speed of 46 m/s at a 10 m reference height was estimated. Wind behaviour over the Auckland CBD location is represented by Figure 2, where wind speeds at four different heights; 1.5 m, 10 m, 50 m, 105 m, are plotted.

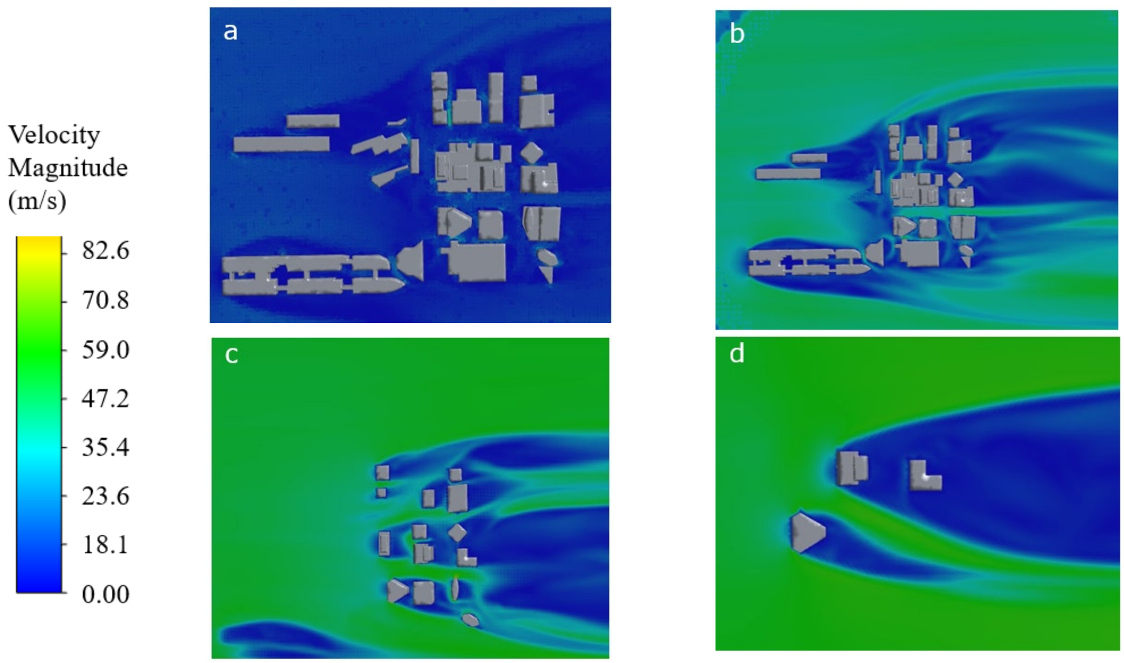

Figure 2. Velocity contour plots at heights of: (a) 1.5 m, (b) 10 m, (c) 50 m, (d) 105 m.

The CFD simulations reveal that channels of wind speeds close to 70 m/s are generated in between buildings even at a low height of 1.5 m which can be considered as pedestrian level. These faster channel flows could create an unsuitable environment for pedestrians with the risk of flying debris. The number of such channels increase with height and so does the severity of the wind. Figure 2 (b-d) show faster wind speed estimations, greater than 70 m/s, in these channels at greater heights where there could be a significant risk of cladding damage. Therefore, it is apparent that ex-TC winds are indeed severe and can be increased further by the blockage and channelling effects of buildings.

The implications of these findings can be better understood when contextualised through comparison with design wind speeds in various wind loading standards. Nonetheless, these results indicate that accelerated wind speeds form in channels between buildings and also increase with height above the ground. Additionally, there is ongoing work to validate these CFD results by a direct comparison with wind-tunnel testing.

3. CONCLUSIONS

This paper outlined a numerical modelling framework in which NWP data is coupled with high resolution CFD to investigate the impact of strong wind speeds from ex-TC Cook. An HHABL was successfully generated in ANSYS Fluent and wind speeds in a section of Auckland CBD was investigated. NWP data on ex-TC Cook were obtained from NIWA, and these data were used to generate strong winds over Auckland. The results from this investigation reveal that wind channels form in the CBD area from the arrangement of the buildings which cause accelerated wind speeds. These wind channels become more prevalent with height and the speed winds also increase.

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