AWESW2022
21st Australasian Wind Engineering Society Workshop
2 – 3 February, 2023

Assessing Severe Wind Risk for an Inland Container Facility

Stuart Moore[1], Amir A.S. Pirooz[1,2], Tristan Meyers[1,2], Richard Turner[1]
[1]*National Institute of Water and Atmospheric Research Ltd, Wellington, NZ.*
[2]*National Institute of Water and Atmospheric Research Ltd, Auckland, NZ.*

ABSTRACT

Following an EF1-strength damaging wind event at a shipping container yard in Auckland, New Zealand in June 2021, a wind climatology study and coupled Numerical Weather Prediction (NWP) and Computational Fluid Dynamics (CFD) study of the event were undertaken. Further, a parametric CFD analysis of the impacts of winds on wind loading on the containers was also completed. It was found that significant speed-up effects at the edge of containers with winds broadside to the container produced the highest wind loads. Significant speed-ups also were modelled in downwash zones at the sides of containers and at flow reattachment points downwind of the container. Speed-ups from channelling effects were also modelled for containers spaced a few metres apart. The coupled NWP-CFD simulation reproduced the tornadic environment at the container yard and indicated that the maximum wind speed exceeded 30 m/s close to the surface.

1. Introduction

On 18 June 2021 a strong tornadic wind event over Auckland, New Zealand, judged to be of EF1 strength, resulted in costly damage to shipping containers in a local storage yard. For this region, EF1 strength winds (38 – 49 m/s) for non-synoptic events have an average recurrence interval of at least 1000 years (Safaei Pirooz et al., 2020). During this wind event, the widespread non-tornadic winds were assessed to have been ~30 m/s, corresponding to a non-synoptic return period of ~50 years.

The tornado caused considerable damage in the suburb of Papatoetoe, Auckland, lifting roofs, shattering windows, toppling trees and downing powerlines (Figure 1 (Stuff, 2021)). More significantly, one worked was killed and two others were injured at the Conlinnx container handling facility at Wiri, Auckland (Radio New Zealand, 2021).

(a) (b)

Figure 1. (a) Aerial image of the tornado damage in Papatoetoe, Auckland (Stuff, 2021). (b) Damaged shipping containers at the ports of Auckland, Wiri (Stuff, 2021).

To investigate the extreme wind conditions, particularly non-synoptic events, in the Auckland region and to replicate the 18 June 2021 tornado event, a comprehensive site wind analysis of the container facility was undertaken. This included establishing a wind climatology for the site and extreme value analysis for the Auckland region, as well as performing coupled Numerical Weather Prediction (NWP) and Computational Fluid Dynamics (CFD) simulations of the event to scales where the wind loading impacts on containers can be assessed and ultimately guidance provided on the optimal container storage layout patterns.

This paper is divided into the following sections. Section 2 provides an overview of the wind event and where it sits in relation to the typical wind climate of Auckland, New Zealand. Section 3 presents results from coupled NWP-CFD modelling of the wind event over the container facility and Section 4 highlights outcomes from the parametric CFD analysis of the impact of winds on container wind loading at this site. Finally, conclusions on the effectiveness of this sort of modelling study are presented.

2. The 18 June 2021 wind event and local wind climatology

2.1 Observed and NWP data

In this section a wind climatology is provided for nearby observing sites with long-term records (Table 1, extracted from (Cliflo, 2018)) as well as for the Conlinnx site as derived from NIWA's[1] very high-resolution numerical model Auckland Model, a convection-permitting regional configuration of the UK Met Office Unified Model (Bush et al., 2022). This model runs with a horizontal grid spacing of 333m on a 300x300 horizontal grid with 140 vertical levels. For more details see (Safaei Pirooz et al., 2021).

Table 1. Description of the meteorological stations and the wind sensors used in the present study.

Site name	Sensor type (Anemometer height)	Data type(s)	Period
Mangere 2 EWS	Vector A101 M (10 m)	10-min mean and 3-s gust wind data at hourly and daily temporal resolutions.	2002 – Apr 2022
Auckland Aero AWS	Vaisala WAA151 (10 m)		1995 – Apr 2022

2.2 Storm Separation and Design Wind Speeds

A homogenisation process, which accounts for anemometer height, terrain roughness and differences in signal processing between anemometers, was conducted using a well-established methodology (Turner et al., 2019). The homogenised wind data were separated into synoptic and non-synoptic (i.e., convective) events using a recently proposed method by Holmes (2019). Safaei Pirooz et al. (2020) demonstrated that at most locations in New Zealand synoptic winds dominate the design wind speeds for most average recurrence intervals (ARI). However, at some locations non-synoptic events resulted in higher design wind speeds at high ARIs or crossed over the synoptic design wind speeds at mid-average recurrence intervals.

Here, the same procedure was applied to the two stations in Table 1, which are close to the Conlinxx site. The extreme value analysis (EVA) was performed separately for synoptic and non-synoptic events. It is evident from Figure 2 that synoptic events dominate design wind speeds in the Auckland region at most average recurrence intervals. The ARI curves (Figure 2) for non-synoptic events and combined synoptic and non-synoptic events indicate that the non-synoptic event on 18 June 2021 with wind speed magnitudes of up to 40 m/s had a return period of around 1,000 and 50 years respectively at Auckland Aero and 800 and 100 years respectively at Mangere

---

[1] The National Institute of Water and Atmospheric Research or NIWA, is a Crown Research Institute of New Zealand. Established in 1992, NIWA conducts commercial and non-commercial research across a broad range of disciplines in the environmental sciences. https://www.niwa.co.nz/.

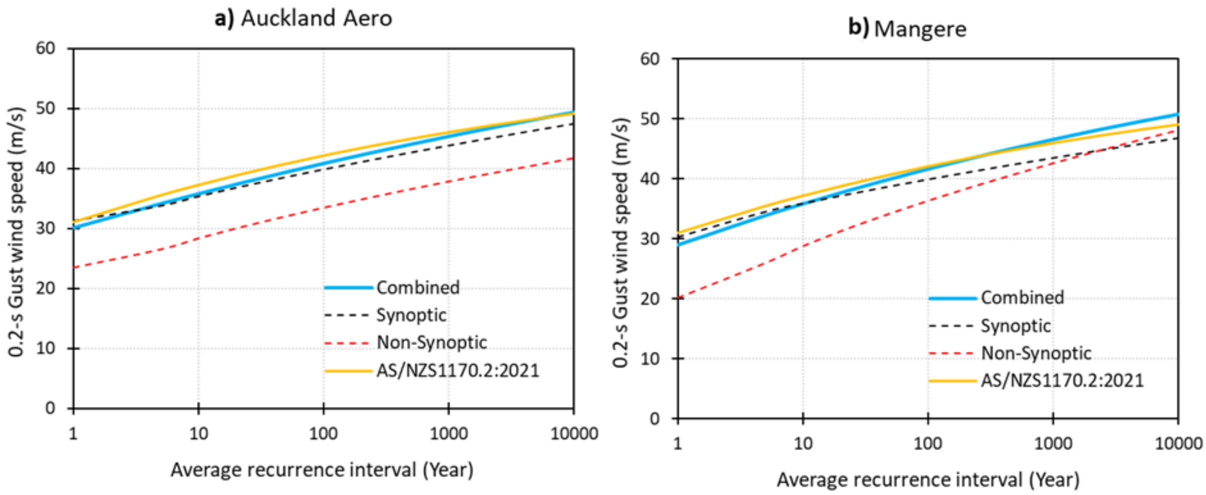

Figure 2. Comparison between design wind speeds provided in (AS/NZS1170.2, 2021) for region NZ1 and calculated 0.2-s design wind speeds separated into synoptic and non-synoptic events for: a) Auckland Aero; b) Mangere.

2.3 Model Climatology

Mean and gust wind data was taken from NIWA's Auckland Model for the period between 18 March 2021 – 14 April 2022 (392 days). The prevailing winds at the Conlinnx site as modelled by the Auckland Model are south-westerly (SW) and north-north-easterly (NNE), with these directions occurring at about 25% of the time. Some key statistics are summarised in Table 2. The maximum modelled wind gust at the site was 39.86 m/s which occurred on 13 February 2022 (Cyclone Dovi). The average 10-minute mean wind speed is 3.00 m/s with a 95th percentile of 6.03 m/s. The maximum recorded 10-minute mean wind speed was 10.97 m/s, occurring in February 2022. It should be noted that even a grid spacing as fine as 333 m, while sufficient to simulate the parent thunderstorms that generate tornadoes, this is still insufficient to resolve tornadic features that often have diameters of order 100 m.

Table 2. Summary of Auckland Model climatology at the Conlinxx site

	Average (m/s)	**95th percentile (m/s)**	**Maximum (m/s)**
Wind speed	3.00	6.03	10.97
Gust	7.78	15.03	39.86
	Most common wind direction (percent of the time %)	**Second most common wind direction (percent of the time %)**	
Direction	SW (14.3%)	NNE (11.5%)	

3. Coupled NWP-CFD Modelling

Outputs from the Auckland Model for the event on 18 June 2021 were coupled to a CFD simulation. The increased resolution possible from such simulations, to 111 m in this study, has demonstrated improvements of wind speed predictions, even for short-lasting gust wind speed events (Safaei Pirooz et al., 2021). The NWP model provided *time-varying* lateral and top boundary conditions for the CFD domain (Figure 3) for the period 18 June 2021 19:20 UTC to 18 June 2021 20:15 UTC. The tornado occurred at around 20:30 UTC (08:30 am on 19th June NZST) but the model forecast the strongest wind feature in the hour prior. The NWP variables used as inputs to CFD are the three components of the wind velocity and air temperature.

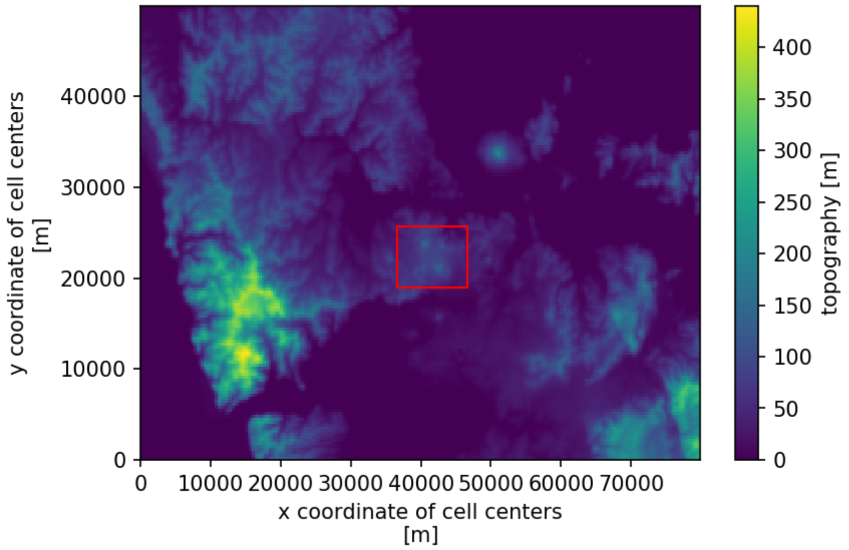

Figure 3. Extent of the CFD domain centred on the Conlinxx site. The red rectangle shows the higher spatial resolution domain with 111 m horizontal grid spacing. Outside the red box, the horizontal resolution is 333-m.

Considering that the tornado event was not orographically driven (i.e., local hills likely had little influence on its development or path) and in order to speed up the CFD simulations, orography was not included in the couple NWP-CFD simulations. Although the horizontal resolution of the Auckland Model and the coarser domain of the CFD are the same, the large eddy simulation (LES) approach used in the CFD simulation is able to simulate large-scale turbulence features, as opposed to the parametrised approach taken in the NWP model. Smaller scale turbulence is modelled in the CFD using a sub-grid scale model, thus providing more information about the wind fluctuations and turbulence generation/dissipation. The nested CFD domain is a two-way nested setup, which allows feedback from the finer resolution 111 m domain to the coarser 333 m domain. An open source parallelised large eddy simulation (LES) model CFD code, PALM (Rodrigues et al., 2015) was used for the CFD simulations. The second-order advection scheme of (Piacsek and Williams, 1970) with central differences is used for the momentum equations and scalar quantities. To ensure the stability of the simulations, adaptive timesteps were used to maintain the Courant number below 0.5 and ensure the Courant-Friedrichs-Levy (CFL) criterion is continually met.

Figure 4 depicts the maximum modelled wind speed over the Auckland region between 19:20 UTC and 20:15 UTC on 18 June 2021, obtained from the coupled NWP-CFD simulation. The red mark in the figure shows the location of Conlinxx site. The model has simulated a high-speed wind event over the Conlinxx site, and surrounding areas to the north, with speeds exceeding 30 m/s. Based on photos available through media reports we assessed the June 18, 2021 tornado to be of EF1 intensity on the Enhanced Fujita Scale. This means that speeds were in the range of 38 to 49 m/s, but it is hard to narrow down further the peak speeds, except to comment that gust wind speeds were likely >40 m/s. The return period for a 40 m/s non-synoptic event was around 1,000 years for the Auckland stations analysed (Figure 2). As mentioned earlier, even with grid spacings as fine as 111 m, while sufficient to simulate the parent thunderstorms that generate tornadoes and widespread strong winds over the area, they are still not fine enough to capture the tornado which will have a diameter on the order of 1 – 10 m, nor the full intensity of the wind speed.

To better understand the wind pattern on 18 June 2021 at the Conlinxx site, Figure 5 shows the vertical profiles of the wind speed and its constituent zonal and meridional components from the NWP and CFD models up to 95 m above the ground. It can be seen that CFD predicted wind speeds of around 30 m/s close to the ground and exceeding 35 m/s at 90 m above the ground. These wind speed values are consistent with an approximate damage threshold of ~37 m/s and higher than those forecast by the NWP model alone.

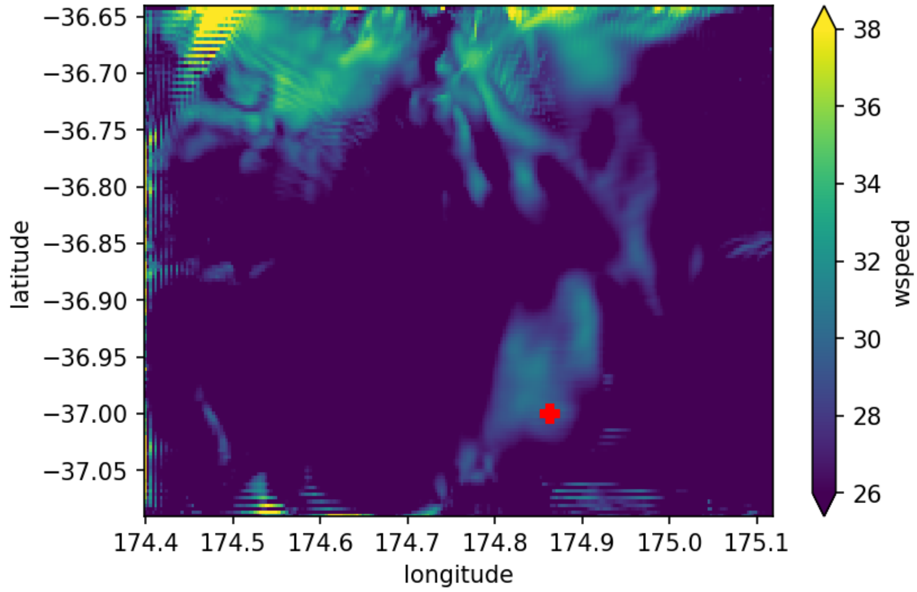

Figure 4. Maximum wind speed (m/s) at 11 m above the ground between 19:20 UTC and 20:15 UTC on 18 June 2021 over the Auckland region from the nested CFD simulations. The red mark shows the Conlinxx site.

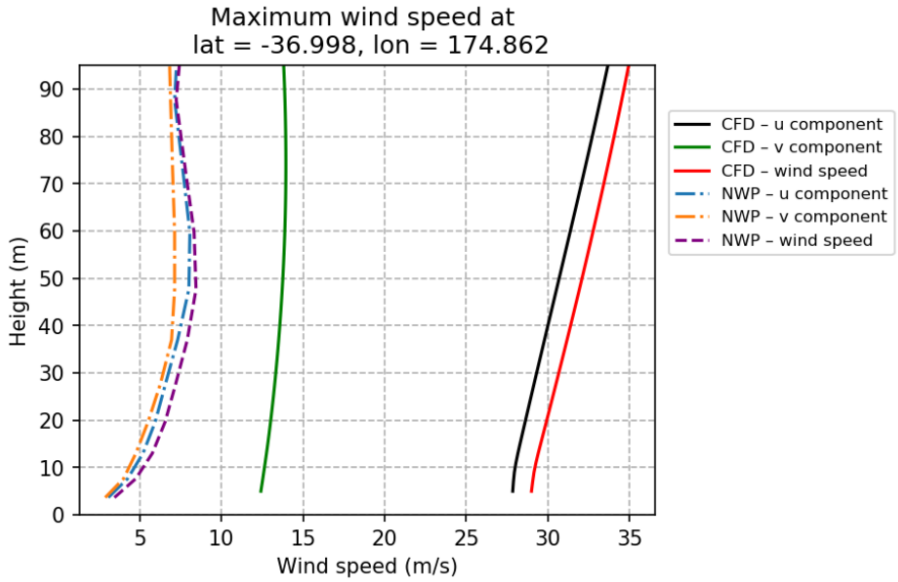

Figure 5. Vertical profiles of the maximum wind speed and its constituent zonal and meridional components between 19:20 UTC and 20:15 UTC on 18 June 2021 at the Conlinxx site location obtained from the NWP and CFD models.

4. Parametric CFD study

A parametric CFD analysis of the impact of winds on wind loads on containers at the site and their effect on localised speed-ups in the wake of containers was also undertaken. Here a 12.2 m (40 ft) long, 2.9 m (9.5 ft) high, and 2.44 m (8 ft) wide cube container was used and the wind load on single containers at different wind angles, channelling and downwash effects and a simplified replication of a stack of containers investigated. A brief summary of the results is presented here.

A three-dimensional steady-state Reynolds-averaged Navier–Stokes (RANS) approach was taken using the open-source CFD package OpenFOAM (2022). For modelling turbulence, the shear-stress transport (SST) (Menter, 1994) model was employed. It has been demonstrated (Safaei Pirooz and Flay, 2018) that the k–ω and SST models provide better predictions of separation and reattachment points, as well as the wake region. For both the advection and turbulence terms of the governing equations, a second order discretisation scheme was used. For this study, a pressure-driven method (Richards and Norris, 2015) was used to generate horizontally homogeneous ABL. The inlet profiles to the CFD domain, which include wind velocity, turbulence kinetic energy (TKE) and turbulence dissipation frequency (Ω), were defined such that they replicate terrain category 3 (e.g. suburban area) with an effective aerodynamic roughness length of 0.2 m as specified in (AS/NZS1170.2, 2021). The velocity at 10 m height above the ground was set to be 20 m/s.

Simulated wind patterns around single and stacked containers for different wind angles and siting arrangements (not shown here) demonstrated significant speed-up effects at the edge of containers and winds broadside to the container produced the highest wind loads. Speed-ups from channelling effects were also modelled for containers spaced from a few centimetres to metres apart. Figure 6 shows the effect of channel width (D) on wind speed around and through the channel as well as its effect on a single container located downstream of the channel. The width of the channel increased from 0.2 m to 1.5 m. For D = 0.2 m (Figure 6a), the airflow is partially blocked, thus, it does not have a significant effect on the wind speed. However, as the width increases, the wind speed between the channel starts increasing drastically (red areas in the channel) with a jet of air forming in the channel (Figure 6b). It should be noted that the size of the jet and strength of the channelling flow affects the flow patterns (e.g., separation/magnitude) around the downstream containers.

When wind encounters a tall solid obstacle/structure, part of flow is diverted towards the ground generating downwash flow on the windward side of the structure, which can significantly increase the velocity on the ground level, and also produce highly turbulent flow. Figure 7 demonstrate the downwash effect on airflow for different number of stacked containers.

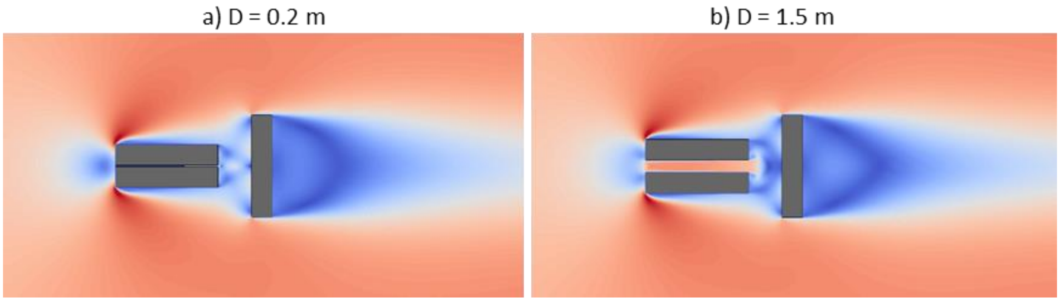

Figure 6. Effects of channel width on wind patterns and force on the 2 containers downstream of the channel. The channel widths are: (a) 0.2 m; (b) 1.5 m.

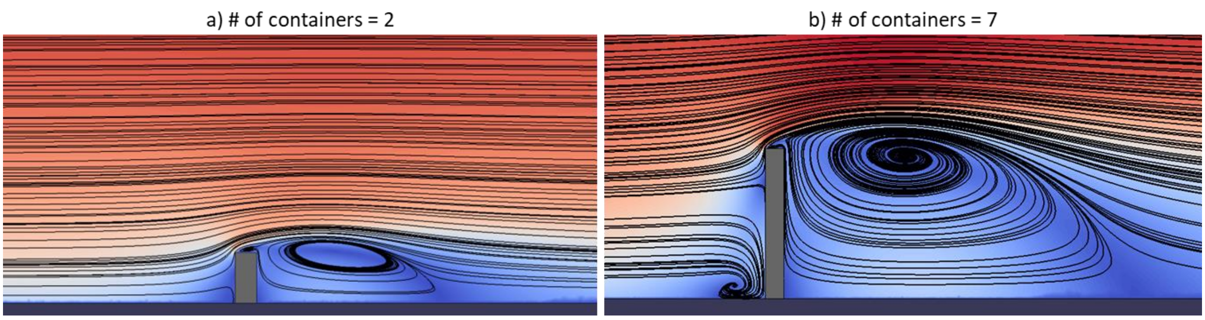

Figure 7. Downwash effect on the wind flow for: (a) 2 containers; (b) 7 containers. The figure shows velocity contours and streamlines on a centre plane passing through the centre of the containers.

4. Conclusions

A brief survey of possible severe wind detection and forecast methods was undertaken. It was found that for non-synoptic events very high-resolution models would likely add significant additional detail around the timing, magnitude, and likelihood (within a set-area) of severe winds. It would also perform well for strong synoptic events, however existing large-scale models also forecast these reasonably well.

Acknowledgements

We thank Anton Tyers of Conlinnx for hosting a site visit and providing a site plan of the container facility. We thank the Resilience to Nature's Challenges programme for providing access to the high-resolution forecast models. We also wish to acknowledge the use of New Zealand eScience Infrastructure (NeSI) high performance computing facilities as part of this research. New Zealand's national facilities are provided by NeSI and funded jointly by NeSI's collaborator institutions and through the Ministry of Business, Innovation & Employment's Research Infrastructure programme (https://www.nesi.org.nz).

References

AS/NZS1170.2, 2021. "Australia/New Zealand Standard, Structural design actions. Part 2: Wind actions". Jointly published by Standards Australia International Ltd and Standards New Zealand.

Bush, M., Boutle, I., Edwards, J., Finnenkoetter, A., Franklin, C., Hanley, K., Jayakumar, A., Lewis, H., Lock, A., Mittermaier, M., Mohandas, S., North, R., Porson, A., Roux, B., Webster, S., Weeks, M., 2022. The second Met Office Unified Model/JULES Regional Atmosphere and Land configuration, RAL2. *Geosci. Model Dev. Discuss.*, 2022, 1-35. DOI: https://doi.org/10.5194/gmd-2022-209.

Cliflo, 2018. web system that provides access to New Zealand's National Climate Database. https://cliflo.niwa.co.nz/. Accessed on Feb 2022.

Holmes, J.D., 2019. Extreme Wind Prediction – The Australian Experience, Lecture Notes in Civil Engineering, pp. 365-375.

Menter, F.R., 1994. Two-equation eddy-viscosity turbulence models for engineering applications. *AIAA Journal*, 32, 1598-1605. DOI: https://doi.org/10.2514/3.12149.

OpenFOAM, 2022. Open Source Field Operation and Manipulation. https://openfoam.org/.

Piacsek, S.A., Williams, G.P., 1970. Conservation properties of convection difference schemes. *J. Comput. Phys.*, 6, 392-405. DOI: https://doi.org/10.1016/0021-9991(70)90038-0.

Radio New Zealand, 2021. Reports tornado hit South Auckland suburb of Papatoetoe. https://www.rnz.co.nz/news/national/445078/reports-tornado-hit-south-auckland-suburb-of-papatoetoe. Accessed on 6 Jan 2023.

Richards, P.J., Norris, S.E., 2015. Appropriate boundary conditions for a pressure driven boundary layer. *J. Wind Eng. Ind. Aero.*, 142, 43-52. DOI: https://doi.org/10.1016/j.jweia.2015.03.003.

Rodrigues, C.V., Palma, J.M.L.M., Rodrigues, Á.H., 2015. Atmospheric Flow over a Mountainous Region by a One-Way Coupled Approach Based on Reynolds-Averaged Turbulence Modelling. *Boundary-Layer Met.*, 159, 407-437. DOI: https://doi.org/10.1007/s10546-015-0116-7.

Safaei Pirooz, A.A., Flay, R.G.J., 2018. Comparison of Speed-Up Over Hills Derived from Wind-Tunnel Experiments, Wind-Loading Standards, and Numerical Modelling. *Boundary-Layer Met.*, 168, 213-246. DOI: https://doi.org/10.1007/s10546-018-0350-x.

Safaei Pirooz, A.A., Flay, R.G.J., Turner, R., 2020. New Zealand design wind speeds, directional and lee-zone multipliers proposed for AS/NZS 1170.2:2021. *J. Wind Eng. Ind. Aero.*, 208. DOI: https://doi.org/10.1016/j.jweia.2020.104412.

Safaei Pirooz, A.A., Moore, S., Turner, R., Flay, R.G.J., 2021. Coupling High-Resolution Numerical Weather Prediction and Computational Fluid Dynamics: Auckland Harbour Case Study. *Appl. Sci.*, 11. DOI: https://doi.org/10.3390/app11093982.

Stuff, 2021. Auckland tornado: The aftermath, in pictures. https://www.stuff.co.nz/national/300338917/auckland-tornado-the-aftermath-in-pictures. Accessed on 6 Jan 2023.

Turner, R., Safaei Pirooz, A.A., Flay, R.G.J., Moore, S., Revell, M., 2019. Use of High-Resolution Numerical Models and Statistical Approaches to Understand New Zealand Historical Wind Speed and Gust Climatologies. *J. Appl. Meteorol. Clim.*, 58, 1195-1218. DOI: https://doi.org/10.1175/JAMC-D-18-0347.1.