Scoping Requirements for an air quality model for Tasman District Council

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Background

During June and July 2018, the Richmond airshed exceeded the NESAQ PM_{10} standard 12 times. There were also a number of days when there were near-exceedances. Tasman District Council (TDC) staff noted that these incidences occurred when weather conditions were cool and calm - which in New Zealand typically indicated anti-cyclonic conditions - and coincided with days when there were a number of permitted outdoor rural fires typically associated with the burning of horticultural waste in rural Richmond, Motueka and Riwaka. In recent years, TDC has received a number of complaints regarding large outdoor fires in these areas in relation to smoke nuisance, visual amenity effects and concerns regarding human health effects.

Aside from the one permanent monitoring station located in Richmond airshed, TDC does not monitor air quality on a regular basis across the district. Previous air quality modelling has been undertaken which considers emissions from within the wider Richmond and Nelson urban areas only (in conjunction with Nelson City Council) and does not model the effects of rural emissions on the Richmond airshed. To date, there is only anecdotal evidence available regarding the connectivity of the Richmond airshed with the wider Waimea Plains, which due to topographic channelling and the particular complex regional airflow in this region might be spatially variable.

TDC staff are considering the need for new air quality models of PM_{10} dispersion to answer the following questions:

- Is rural burning/emissions of PM_{10} affecting air quality in the Richmond airshed; and
- is the Richmond airshed part of a larger 'air catchment' (or network of interlinked catchments) and if so, what are the boundaries?

Project Brief:

My task here is to scope out and document the requirements for an air quality model of PM_{10} dispersion for Tasman Bay (Richmond (and including Stoke/Tahunanui if appropriate) to Riwaka) including:

- review of resources and information provided including a brief assessment of any existing air models in the area and their applicability
- identification of information and data requirements for an air quality PM10 dispersion model
- Identify options for a methodology/modelling technique based on available information/data requirements, including cost estimates (if possible)
- Recommendation of preferred methodology/modelling technique

- Identification of any potential limitations or assumptions for modelling

This includes understanding the reasons for Particulate Matter (PM) exceedances in the winter of 2018 for the Richmond airshed by cursory analysis of the air monitoring data supplied and review of the literature by Golder associates pertaining to air quality modelling of the Richmond and the surrounding airshed, and the source apportionment research conducted by GNS Science.

The advice will be used to develop an air quality PM_{10} dispersion model which is outside the scope of this project brief.

1. Context

Source apportionment study of the Richmond airshed by GNS Science in 2017 (Davy and Trompetter 2017; from hereafter referred to as GNS2017) indicates five main source types contributing to both $PM_{2.5}$ and PM_{10} concentrations. Sources were determined to be from biomass combustion (burning of wood for home heating), motor vehicles, secondary sulphate, marine aerosol and a copper chromium, arsenic (CCA) source. During the winter, emissions attributed to solid fuel fires for *home heating* were found to be the primary source of both $PM_{2.5}$ and PM_{10} in the Richmond airshed. It is important to note that home heating is the dominant source contributing to exceedances of the PM_{10} National Environmental Standard for Air Quality (NES) of 50 µg m^{-3}, this situation is typical for most urban airsheds in New Zealand as home heating in the evening emits smoke into an atmosphere that has the least capability of flushing the particulate matter away.

Analysis of wind direction and PM concentrations indicated that "katabatic flows under cold and calm anticyclonic synoptic meteorological conditions coupled with domestic fire emissions and poor dispersion were likely responsible for elevated particle concentrations" (GNS2017).

It is worth pointing out that GNS also provides long-term analysis of PM trends for different seasons as emission profiles and meteorological conditions can be vastly different; they report that "*Analysis of temporal and seasonal trends showed that $PM_{2.5}$ and PM_{10} from biomass combustion peaked during the winter and showed no variation between days of the week. The lack of variation between days of the week was not surprising because peak biomass combustion contributions occur under meteorological conditions conducive to the build-up of pollutants (cold, calm, anticyclonic conditions). The biomass combustion source originates from domestic wood combustion for home heating and also includes arsenic and lead in the profile, suggesting that CCA-treated and lead-painted wood is being included as fuel*" (GNS2017; page 37).

The report from GNS is a comprehensive study for the Richmond airshed, its findings are representative for many other urban airsheds in New Zealand. There is no indication that rural burning contributes significantly to PM issues in Richmond. The reports by Golder (from hereafter referred to as Golder 2012 and Golder 2015) complement the GNS report by providing further information on dispersion characteristics of the Nelson, Richmond airsheds using meteorological dispersion models. The model used by Golder is CALPUFF/CALMET (which performs the pollutant dispersion tasks) coupled meteorological fields supplied by MM5 for 2008, which provides the dispersion module with the background wind field (Golder2012; page 1). It is important to understand that this type of methodology is pretty standard in New Zealand when studying air pollution dispersion, but also to realise that strictly speaking, the dispersion characteristics of the atmosphere are only valid for the year the meteorological field was supplied, in this case 2008. If there is significant climactic variation between 2 years, this method will not be instructive.

The dispersion model runs, which are an independent dataset from the *in situ* monitoring data confirm that most of PM_{10} is from home heating (Golder2012; page 1). In addition, because the dispersion model can spatially track the advection of the simulated air pollutants, it was found that modelled PM10 is mostly from Richmond airshed (Golder2012; page 22). Moreover, and probably most relevant for this report, they state that the model run indicates that Richmond can experience 10 exceedances in PM_{10} (Golder2012; page 39).

This report also identifies sharp spatial gradients in averaged fields produced for PM_{10}, as evident from modelled simulations and an attempt is made to link it to the NIWA mobile monitoring platform which measured instantaneous values (Golder 2012; page 48). I don't think it is possible, and neither the report provides, a satisfactory explanation for sharp gradients in concentrations. The role of microtopography and its combined influences with a nocturnal shallow mixing depth is offered as an explanation, but not explored further. This type of analysis requires analysis of hourly simulated concentration fields in close association with the wind field generated by the meteorological component of the model.

A higher resolution dispersion modelling report is also available that uses CALMET/CALPUFF at higher resolution than (Golder 2012) using meteorological fields from 2009, yet using emission estimates for 2014 (Golder 2015; page 3). The dispersion modelling is aimed at determining the geographical suitability of the Richmond airshed (in regards to the extent of the airshed boundaries); it is found that the current airshed boundaries are adequate since receptors placed in the airshed indicate the emission sources of PM_{10} are mostly within the Richmond airshed, although up to 20% of PM_{10} in Richmond East can come from Nelson (Golder 2015; page 16). It is also stated that contributions from southwest are possible, presumably from nocturnal katabatic flows or any other south-westerly wind flow caused by synoptic weather patterns.

2. <u>Analysis of 2018 data</u>

PM_{10} hourly concentrations from Richmond Central were ranked according to hour of day and averaged (Figure 1). PM_{10} concentrations in the early morning typically show a downward trend as emissions from the previous night have ceased and the nocturnal katabatic flow advects pollution away from Richmond. There is a small peak in the morning, between 8-10 AM, presumably from morning traffic and home heating, then concentrations remain low for the rest of the day. Low daytime concentrations are attributed to the greater mixing-depth, as simulated by Golder (2012), and typically faster wind velocities – from the sea-breeze circulation. After/near sunset, as the nocturnal cooling sets in and the surface-based inversion grows, the emission of PM_{10} from home heating causes increased concentrations.

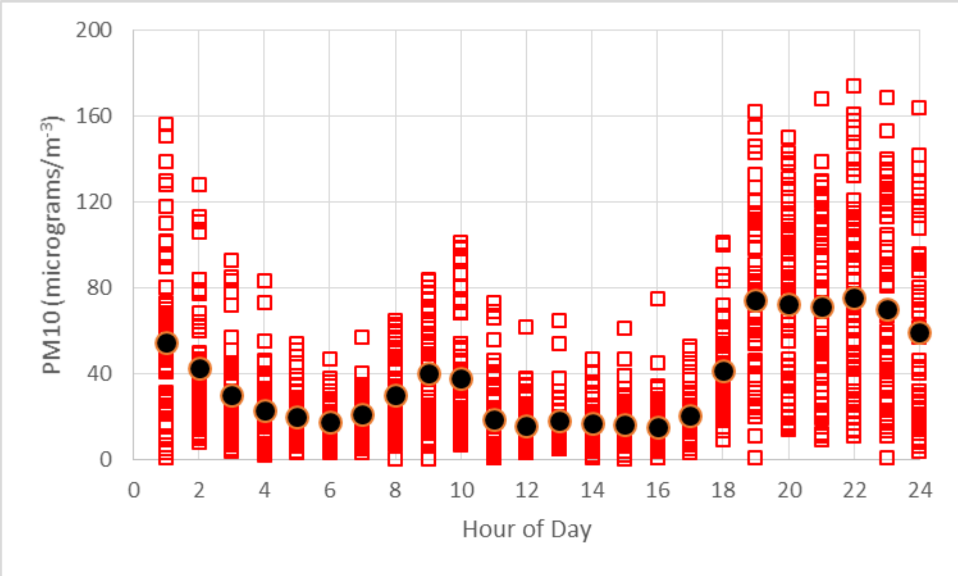

Figure 1 PM_{10} concentrations in Richmond, June, July, 2018. Red squares indicate hourly values while the black circles indicated averages for each hour for the period.

The highest concentration of PM_{10} is associated with the south-southwest quadrant, which is the direction the nocturnal katabatic wind system flows from (see plots in the appendix).

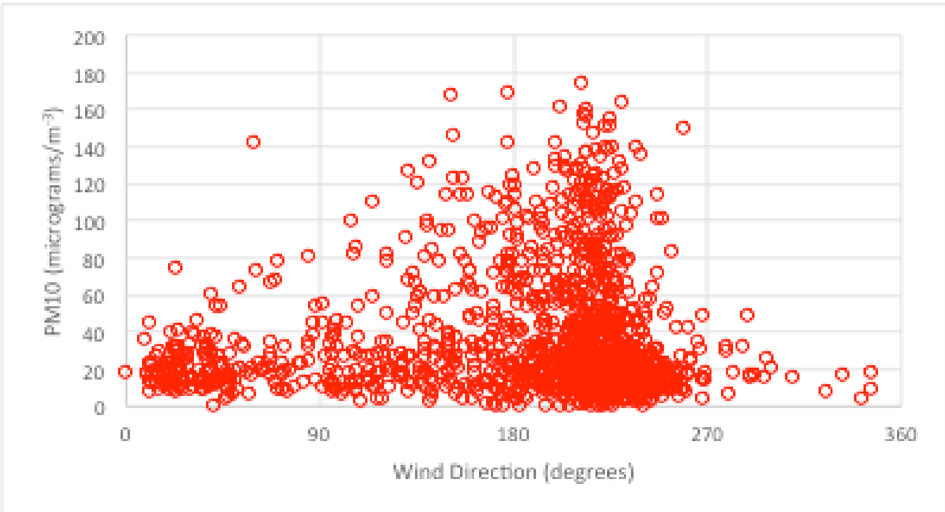

Figure 2 Scattergram of PM_{10} vs wind direction in Richmond

3. Analysis of 20 July 2018

The meteorological condition for July 20th was conducive to accumulation of PM_{10} in the Richmond area. The wind speed for this day stayed mostly below 10 km/hr (2.8 m/s; Figure 3) and the wind direction shifted from a sea-breeze regime to an off-shore regime approximately at 6PM (Figure 4).

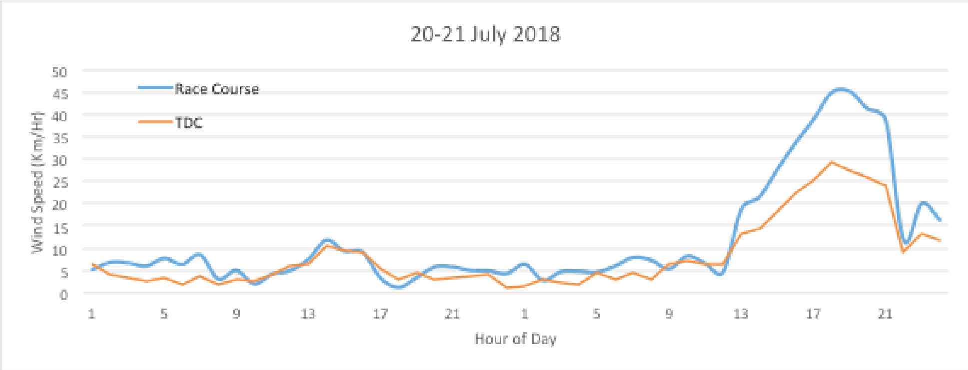

Figure 3 Time-series of wind speed for Richmond area

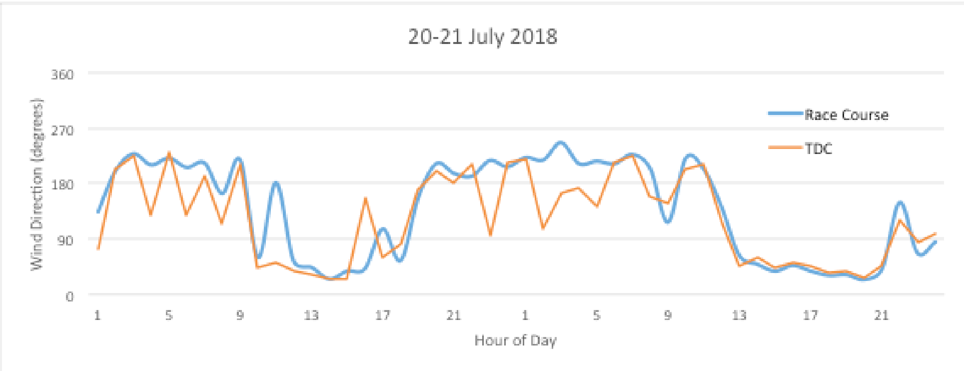

Figure 4 Time-series of wind direction for Richmond area

On average, PM_{10} trends should show a downward movement after 10PM (Figure 1), but for this case study there is a secondary peak after midnight (Figure 5), that possibly can be explained from emission sources outside of the Richmond urban area. The urbanized area up-wind of the air monitoring station stretch to approximately 2 kilometers, given that the average wind speed between 6PM to mid-night is about 3.2 km/hr, it should take less than 1 hour for PM_{10} to show a downward trend when emissions from home heating cease (here I assume this occurs at 11PM). Therefore it is highly unlikely to see a secondary peak after mid-night solely from home heating sources in the urban Richmond. Another explanation for the secondary peak could be local recirculation of PM, but that requires a wind direction shift, which did not occur in this case.

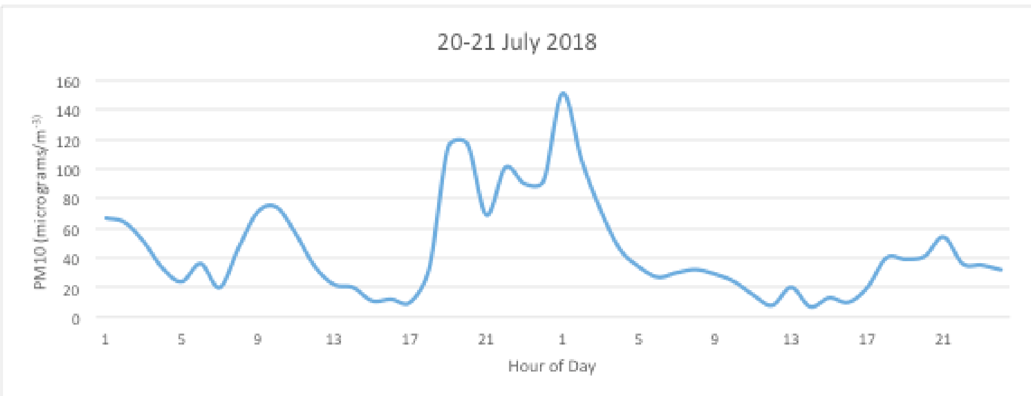

Figure 5 Time-series of PM10 for Richmond

4. Conclusion:

Neither the GNS or the Golder reports show any clear contribution from episodic rural burning of biomass to the PM_{10} concentration in Richmond, and the modelling done by Golder did not consider rural burning in the dispersion model. The Golder report states that up to 10 exceedances in PM_{10} is possible (with the emission inventory dataset they deployed) in the Richmond airshed, without the contribution from rural burning, strictly speaking this is only valid for 2008. My own cursory analysis of data in the previous sections does indicate possible contribution from rural burning. I did not see any evidence of high concentrations from rural burning during the day, the rural burning contribution seems to occur post sunset from the south-southwest quadrant. Examination of images from several days when exceedances occurred was inconclusive, but there is anecdotal (visual) evidence from observers indicating that katabatic drainage flows can be induced over the sloping terrain to the south of Richmond, advecting polluted air into the Richmond airshed proper.

5. Recommendations:

General

Given the unusual spikes in PM_{10} that occur past 10PM on some nights under settled synoptic conditions, it is highly possible that fugitive emissions from rural burning contributes to particulate matter loading of the Richmond airshed. It is recommended that *policy options(tools)* that protect Richmond airshed's air quality be extended another 6 kilometers in the south-west direction (where the katabatic winds typically flow from) to take into account areas where rural burning takes place. For example, the rules and boundaries regarding the existing 'Fire Sensitive' Area should be revised accordingly, which restricts rural burning during months of June to September inclusive. Undertaking the modelling to understand the issue should be the first step, and then how to respond through the resource management plan should be considered next. It is also recommended that further dispersion modelling be carried out that includes PM emitted from fugitive sources. The modelling should perform back-trajectory analysis to confirm the regions to the southwest of Richmond airshed that need to be protected by the policy options.

Specific

Since meteorological and dispersion characteristics of the Richmond airshed can be different from year to year depending on the frequency of cyclonic and anti-cyclonic weather systems, and the objective of this report is to recommend modelling approaches to determine the contribution from fugitive rural burning emission sources to Richmond's air quality; I recommend the following framework for dispersion modelling be carried out:

- PM dispersion modelling (CALMET/CALPUFF or any other dispersion model that accepts time-evolving meteorological input such as The Air Pollution Model (TAPM)) be carried out for the winter of 2018 with the most up-to-date emission inventory. Testing scenarios that exclude and include fugitive emission sources
  - Emission inventory dataset to be constructed to take into account emission of PM_{10} from fugitive rural sources (this dataset needs to supply the following information to the dispersion model)
    - Emission rate (weight/time) of PM_{10} from an area or a point source

    - Estimate of the most likely period and geographic location for the fugitive emission sources
    - For the days when exceedances occur, *point sources* (or area sources) for rural burning need to be included in the modelling scenario in several plausible configurations.
- Subsequently the contribution of each source be assessed as per Golder (2012). If further investigation is to be commissioned, the meteorological fields needs to be from June, July 2018. The modelled PM_{10} concentration fields need to be assessed on an hourly basis and for the different scenarios. It is essential to have modelling performed with topography that is detailed enough to simulate the role of microtopgraphy (i.e. 250m resolution might be adequate for this).
- If modelled meteorological fields for 2018 are not available, then the latest available year be utilized to drive the dispersion model, utilizing the highest modelled spatial resolution.
- I also recommend that idealized dispersion modelling be carried out to study the role and characteristics of katabatic winds in this region. This can be done by using a model such as Weather Forecasting and Research (WRF) or TAPM. In the case of TAPM, the model can be run without meteorological fields, the model in such a scenario generates thermally-generated wind systems, such as the katabatic winds. An idealized model will ignore day to day variation in meteorology and only focuses on generating katabatic wind systems, which forms as cold air ponds over sloping terrain.
- To determine how far upwind the policy tools to protect air quality in Richmond need to be applied, I recommend, at the very least, back-trajectory analysis similar to the analysis that was carried for Christchurch be conducted (Figure 6). Back-trajectory analysis can be performed by a model such as TAPM without a need for dispersion modelling since only the meteorological field is used to generate the back-trajectory.
- I also recommend that an observational field-study to be conducted to characterise the physical nature of the katabatic wind systems in the region. The field-study will need to deploy at least 3 Automatic Weather Stations (AWS) for a winter season, dispersed geographically in such a way to elucidate the spatial nature of nocturnal airflow in this region, so that cross contamination between different airsheds can be determined.

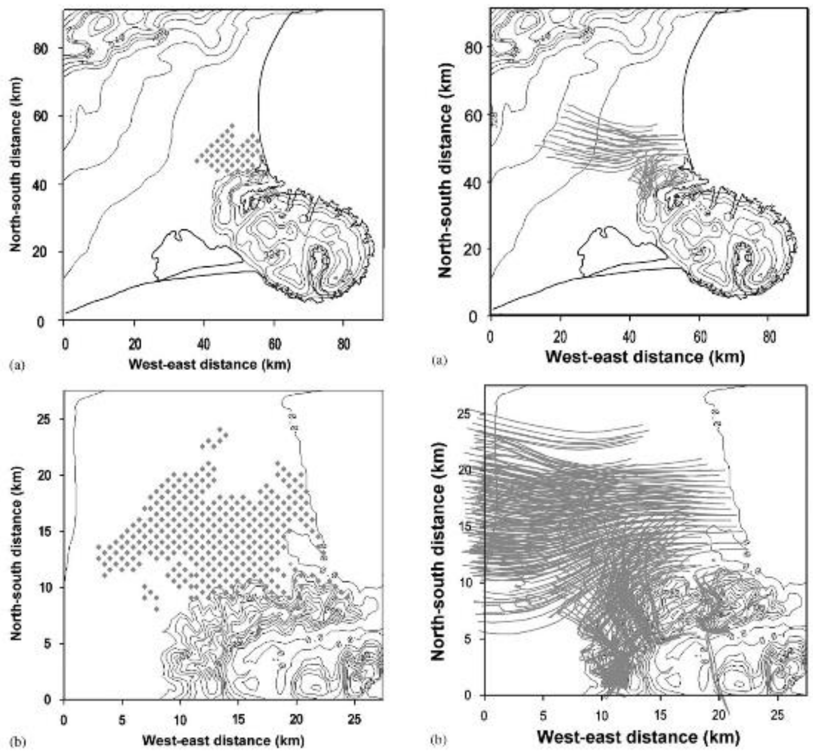

Figure 6 Figure taken from Sturman and Zawar-Reza 2002 to show back-trajectory example for delineation of Christchurch's airshed

References:

Davy, P., & Trompetter, B. (2017). Apportionment of PM10 and PM2. 5 in Richmond Airshed, Tasman District A. *GNS Science Consultancy Report*, *45*.

Golder 2012. Development of an air quality model and meteorological data sets for the Nelson-Richmond urban area. Report prepared by *Golder Associates (NZ) Limited* for Nelson City Council and Tasman District Council, February 2012.

Golder 2015. Urban airshed modeling – dispersion of PM10 Nelson air quality place – air quality technical assessment. Report prepared by *Golder Associates (NZ) Limited* for Nelson City Council and Tasman District Council, November 2015.

Sturman, A., & Zawar-Reza, P. (2002). Application of back-trajectory techniques to the delimitation of urban clean air zones. *Atmospheric Environment*, *36*(20), 3339-3350.

Appendix:

Scattergram of wind direction and time of day for:

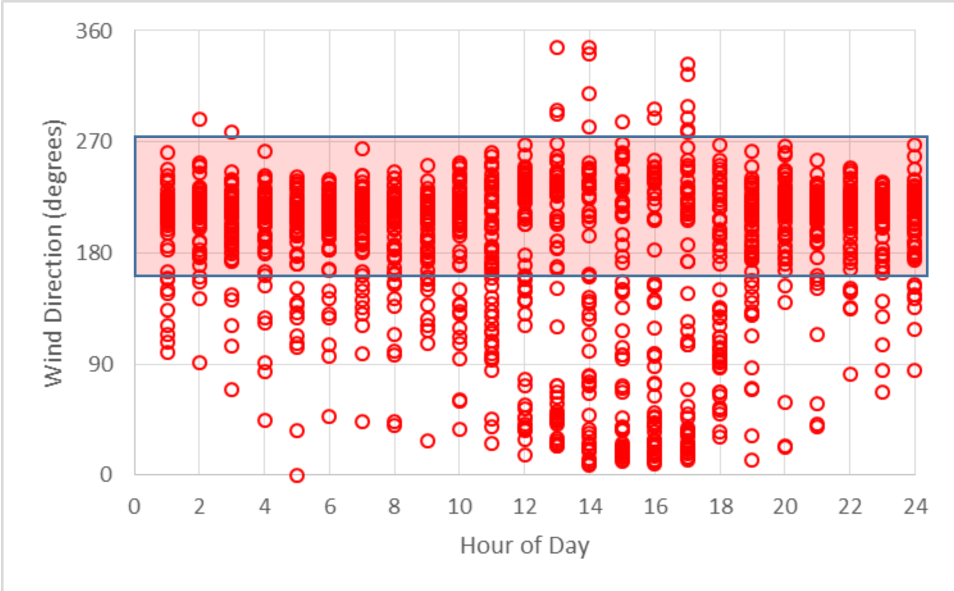

Figure 7 Race Course data

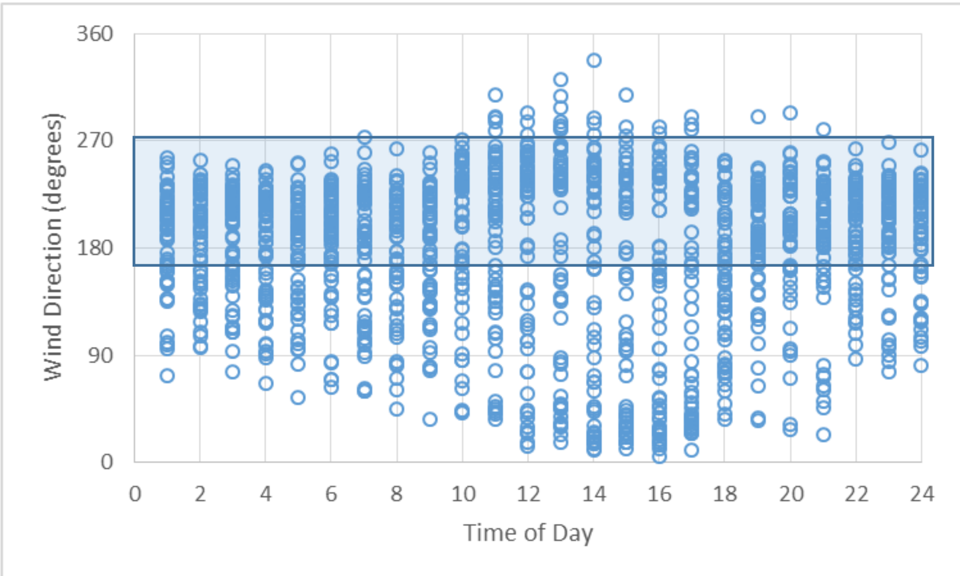

Figure 8 TDC rooftop

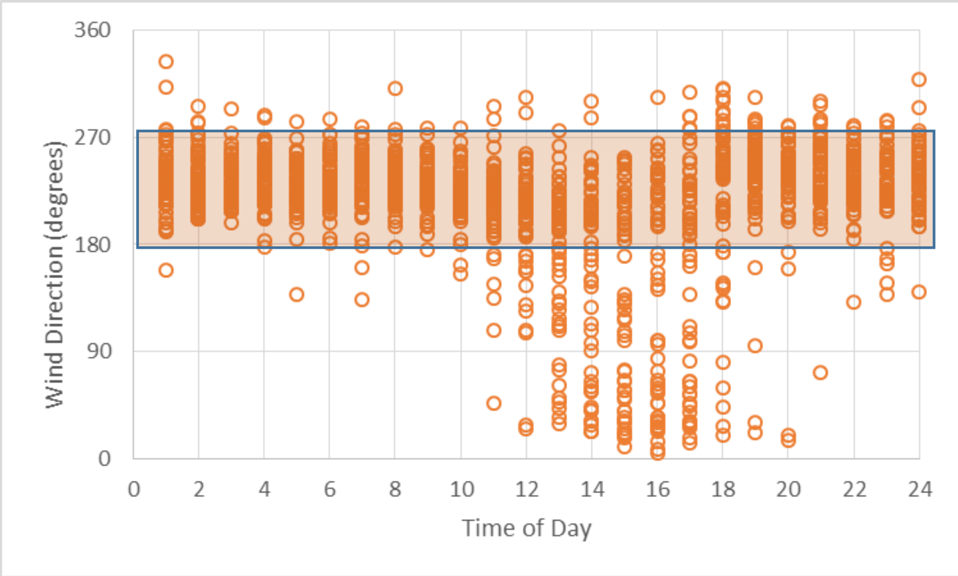

Figure 9 Motueka