Masterton winter wood-smoke survey, 2018

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Executive summary

The Masterton urban area experiences numerous high particle air pollution days (measured as $PM_{2.5}$) during the winter months when emissions from wood burning for home heating coincide with calm and cold weather conditions. To better understand patterns in wood smoke emissions, a vehicle containing a "SmokeTrak" monitoring instrument was driven around Masterton over several winter evenings in June and July 2018.

These mobile monitoring results were used to map wood smoke levels across the Masterton urban area. The maps show that levels of $PM_{2.5}$ from wood smoke varied considerably, with the highest concentrations found later in the evening, after 10 pm, in the low-lying suburbs of Masterton East, Lansdowne and Solway South. Concentrations of $PM_{2.5}$ in these areas were likely higher than those measured at the GWRC Masterton East monitoring station over the same time period. The lowest concentrations were found outside the main urban area and at higher elevations in Lansdowne.

The mobile survey was carried out by GWRC and Masterton District Council as a first step towards identifying areas with high wood smoke that could potentially receive targeted education and assistance to reduce emissions of fine particles from wood smoke.

Contents

1. Introduction

Masterton (Whakaoriori) is a rural town situated in the Upper Ruamahānga valley which is prone to air pollution episodes. These arise from the use of solid fuels for home heating during the winter months. The Masterton urban airshed is currently designated as a "polluted airshed" under the National Environmental Standard for Air Quality (NES-AQ). This is due to the multiple days per year when the PM_{10} 24-hour average of 50 µg/m^3 is exceeded. The NES-AQ requires the number of exceedances to be reduced to three per year by 1 September 2016 and then to one per year by 1 September 2020. The 1 September 2016 target was not met.

Recently the Government has signalled their intention to review the NES-AQ with a view to adopting a $PM_{2.5}$ standard. Whilst, $PM_{2.5}$ is a subset of PM_{10}, it is more strongly associated with adverse health effects than PM_{10} and is a better indicator of combustion sources such as wood or coal burning. Over the past five years (2014 to 2018) air quality in Masterton failed to meet the World Health Organization 24-hour guideline for $PM_{2.5}$ of 25 µg/m^3 (World Health Organization 2006).

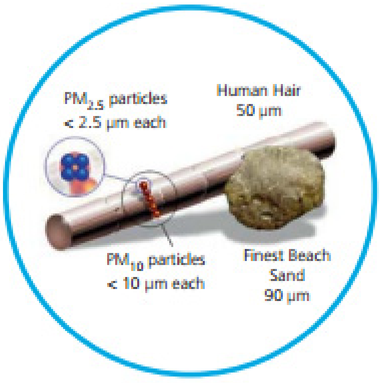

Figure 1.1: Size of PM_{10} and $PM_{2.5}$ particles compared to a strand of hair and to fine beach sand (Ministry for the Environment)

The purpose of this study was to investigate the spatial variation of $PM_{2.5}$ at a fine scale across the Masterton urban area to determine whether there are persistent areas of high wood-smoke particle emissions. These areas could then be targeted for assistance and/or education to reduce local emissions. It is thought that high emitting wood burners have a disproportionate impact on air quality and therefore reducing 'hot spots' of high air pollution may reduce exposure for the whole community (McGreevy & Barnes 2016).

2. Background

2.1 Study location

Masterton (Whakaoriori) is a rural town situated in the Upper Ruamahānga valley (Figure 2.1) with approximately 20,000 residents. Masterton's winters are cooler on average and less windy than other parts of the Wellington region (Chappell 2014).

Air quality is currently monitored at two fixed stations, Masterton West and Masterton East (Figure 2.1). Masterton West is the long-term station that measures long-term average air quality trends, while Masterton East is located to measure the highest concentrations of particles (PM_{10}) as required by the NES-AQ. The stations are named after the Census Area Units that they are located in. We do not know how well these stations represent unmonitored parts of Masterton and whether there are persistent localised 'hot spots' of elevated wood smoke in other locations around Masterton. Understanding the variation in wood-smoke dispersion across the town provides a starting point for identifying neighbourhoods that could benefit from targeted assistance to improve air quality, both in their own neighbourhoods and in down-slope areas that they might be affecting.

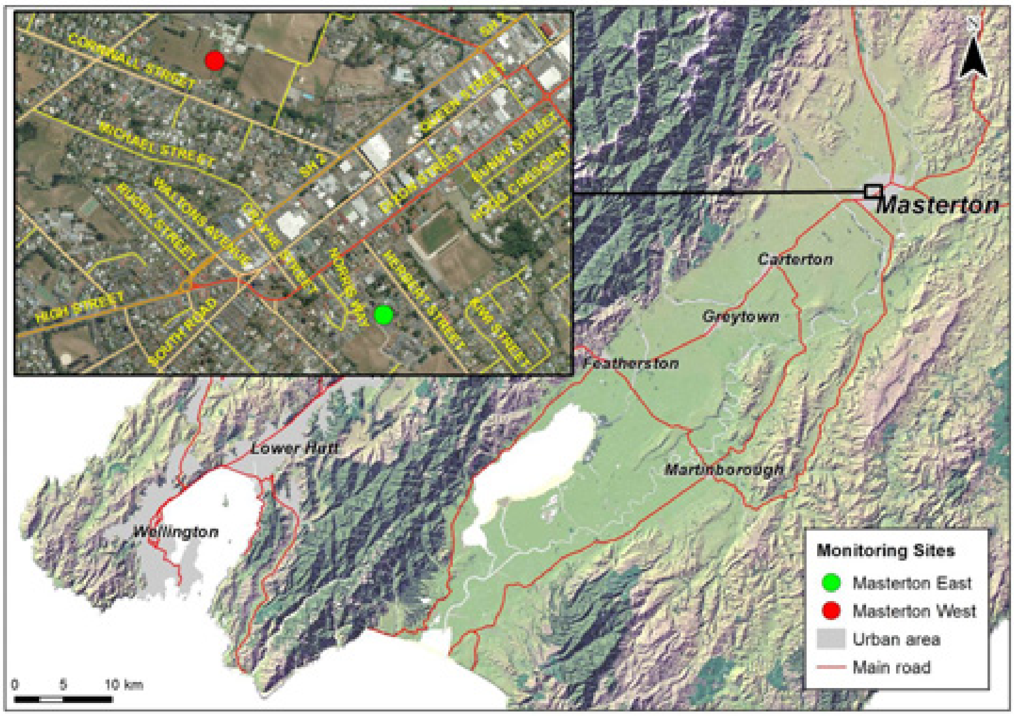

Figure 2.1: Map showing location of Masterton in the Upper Ruamahānga valley and location of current fixed monitoring stations

The majority of Masterton's households (around 68%) burn wood for home heating during the winter months and it is estimated that there are about 5,000 wood-burners in use (Figure 2.2, Statistics NZ 2013). Being able to affordably heat your home is important for health and wellbeing. Firewood, especially if self-collected, may cost less than electricity or gas for the same amount of heat provided.

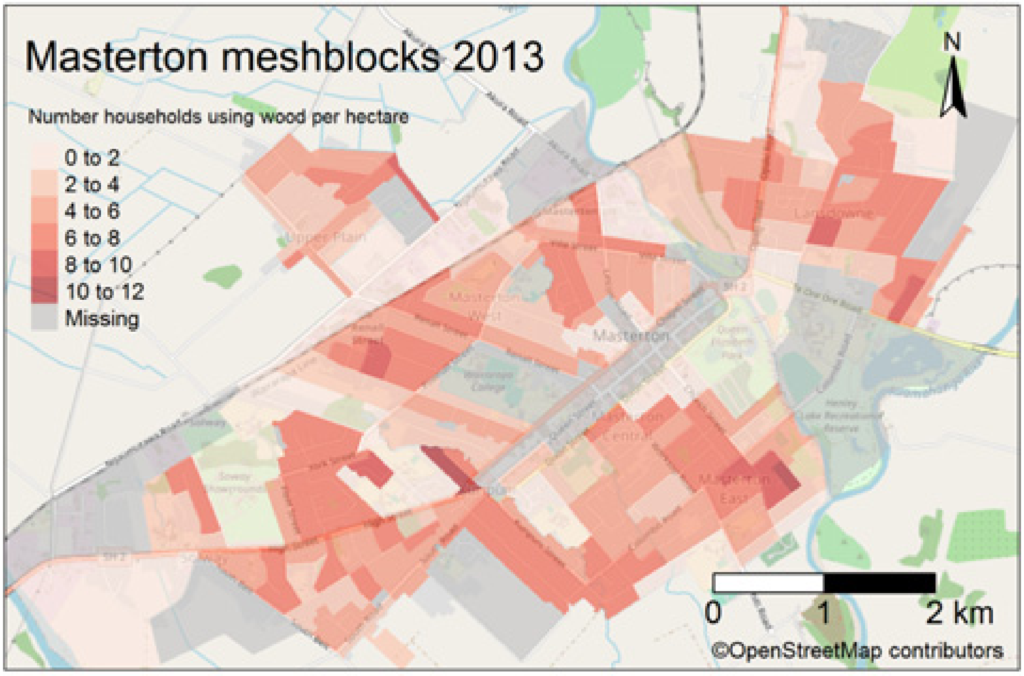

Figure 2.2: Density of wood-burning households per hectare by mesh block (Statistics NZ 2013)

The downside of burning wood is that the smoke emitted contains fine particles and other harmful chemical pollutants. On cold and still evenings, when many people need to use their wood burners, particle air pollution levels accumulate and reach levels that breach the 24-hour National Environmental Standard for PM_{10} and the 24-hour World Health Organization guideline for $PM_{2.5}$. A study by GNS Science found that emissions from wood burners were the dominant source of fine particles in Masterton during the winter months and motor vehicle emissions made only a minor contribution (Ancelet et al. 2012).

2.2 Wood-burner operation and particle emissions

Air pollutant emissions from wood-burners can be very high when wet firewood is used. This is because the heat required to evaporate the moisture in the wood, before it will burn, lowers the temperature of the fire leading to incomplete combustion producing a smouldering fire with large quantities of smoke emitted (Todd 2003). Another cause of high smoke-producing fires is insufficient air flow to burn off gases released in the initial wood burning stage during start-up or following re-fuelling (Todd 2003). The products of incomplete combustion are unburnt gases and tars that condense as they cool to form fine particles in smoke. Attached to these fine particles are carcinogens, such as benzo-a-pyrene (Ancelet et al. 2013).

Fine particle emissions from wood burning can also be reduced by using a low-emission wood-burner from the Ministry for the Environment's authorised list[1]. Only dry and untreated wood should be used and the wood-burner operated

[1] https://www.mfe.govt.nz/air/home-heating-and-authorised-wood-burners

optimally - including using appropriately sized wood pieces (i.e., not too big) and the correct air flow to avoid a low-heat, smouldering high smoke fire[2].

2.3 $PM_{2.5}$ concentrations from home heating

2.3.1 Daily winter air quality profile measured at air quality monitoring stations

During winter, average hourly $PM_{2.5}$ concentrations show a typical pattern of low concentrations during the middle of the day, increasing rapidly between 4pm and 7pm, peaking around 10pm with the duration of the peak persisting till after midnight at Masterton East station (Figure 2.3). Concentrations of $PM_{2.5}$ decline overnight and then show a second smaller peak around 9am. This diurnal pattern observed in Masterton is very similar to other places in New Zealand where wood burners are used for home heating (Trompetter et al. 2010).

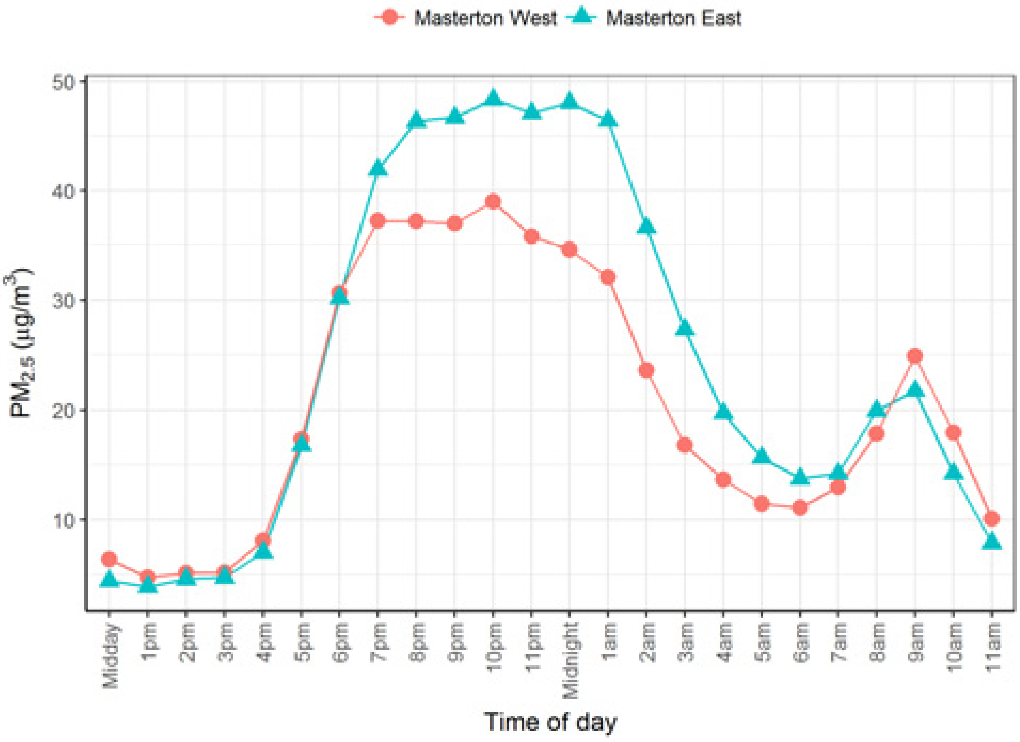

Figure 2.3: Average winter (June-July 2016 to 2018) $PM_{2.5}$ (hourly average) measured at Masterton air quality monitoring stations (East and West) plotted against hour of day (midday to midday)

Within day and between day variability in $PM_{2.5}$ concentrations is due to a combination of household burning habits and weather patterns.

2.3.2 Wood-burner use

Intensity of emissions is driven by peoples' need to heat their homes. Wood-burner use follows a general daily pattern, with some differences in use reported for the weekend compared to week days. Daily variation in start-up times for wood burners and the quantity of wood being burnt is influenced by lifestyle and social factors, habits, availability of wood, and temperature

[2] http://www.gw.govt.nz/better-burning/

(Wilton 2012). In Masterton, most people report lighting their wood-burners between 17:00 and 19:00 on week nights (Siridha & Wickham 2013). On the weekend wood burners are used by more people during the middle of the day and later in the evening compared to weekdays (Figure 2.4).

Wood-burner emissions are not necessarily linearly related to air pollution levels. There is an approximately four hour time lag between peak wood burner use (estimated in 2013 by a home heating survey) and peak $PM_{2.5}$ concentrations measured at both Masterton West and Masterton East air quality monitoring stations (Figure 2.4).

It is possible that this late peak is due to wood-burner operators re-loading their fires, then turning down the air supply overnight before the wood has ignited fully, leading to high smouldering emissions (Innis et al. 2013). There also appears to be a higher peak in $PM_{2.5}$ later at night on the weekend that is not evident in the emissions inventory data (Figure 2.4). A further reason for the time lag between peak wood burner use and peak night-time concentrations of $PM_{2.5}$ measured at the fixed monitoring station is the influences of meteorology and topography which are discussed in section 2.3 and 2.4 below. A smaller morning peak in PM2.5 concentrations was also observed and analysis of air particulate samples shows that is this due to residents re-lighting their fires in the morning (Ancelet et al. 2012).

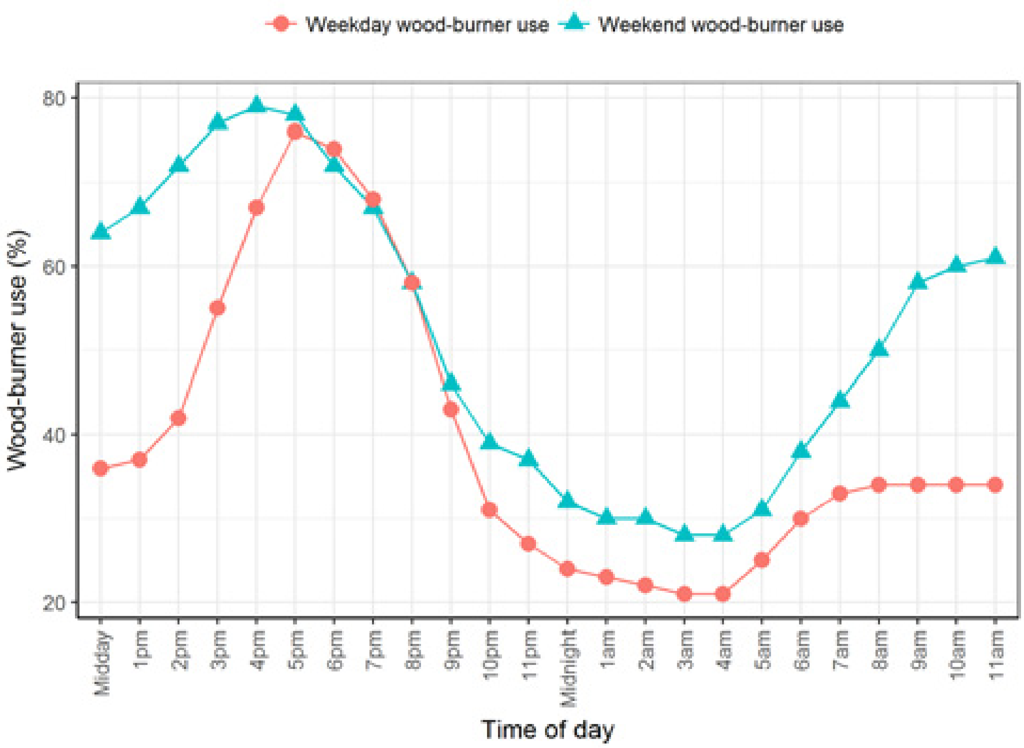

Figure 2.4: Typical percentage of wood-burners being used in Masterton by time of day based on home heating survey (Siridha & Wickham 2013)

2.3.3 Impact of weather patterns and terrain

Weather conditions, as well as emission patterns, strongly influence the day-to-day variability in measured $PM_{2.5}$ concentrations. During the winter months $PM_{2.5}$ concentrations are lowest during the middle of the day when the air is typically windier and warmer and therefore pollutants are more readily dispersed. Furthermore, fewer home fires are in use during the middle of the day, especially during week days. Typically, temperature and wind speed drop in the late afternoon and remain low overnight.

On calm and clear nights a radiative temperature inversion can form whereas the ground cools and heat is lost to space. As air is a poor conductor of heat only the thin layer of surface air is cooled leaving the air above almost unaffected. This leads to a layer of warmer air over the top of the cold air underneath, preventing the cold air from moving upwards and dispersing the wood burner emissions which have been emitted close to ground level. In this situation even when people stop using their wood burners, levels of $PM_{2.5}$ remain elevated for some time. The temperature inversion can be further strengthened in the Wairarapa Valley due to cold air drainage from nearby hills leading to cooler air pooling in lower-lying areas, cooling the ground even further (Griffiths 2011). The temperature inversion usually breaks up at sunrise when the ground is warmed and the air becomes more buoyant and moves upwards.

Terrain or landscape also influences the dispersion of emissions as lower lying areas tend to accumulate air pollution that has drifted down from upslope areas. Although the Masterton urban area is relatively flat, there is still a gradual higher north to lower-lying south elevation gradient (Figure 2.5). It has been suggested that this explains the higher concentrations of fine particles measured at the lower elevation Masterton East monitoring station compared to the higher elevation Masterton West station (Ancelet et al. 2012).

Figure 2.5: Digital elevation map (1m resolution) centred on the Masterton urban area. Darker areas show higher elevation. (Figure courtesy Gareth Palmer, GWRC)

3. Objectives

- To test the ability of mobile monitoring, using a SmokeTrak instrument, to identify spatial patterns in wood-smoke concentration.
- To assess how well the fixed monitoring stations represent wood-smoke levels in un-monitored areas.
- To identify suburbs or parts of suburbs with elevated wood-smoke concentrations that may warrant further investigation.

4. Methodology

4.1 Car-based monitoring

Mobile air quality monitoring was conducted across Masterton using a "SmokeTrak" instrument mounted inside a car. The survey was undertaken on a number of evenings during June and early July 2018. The SmokeTrak instrument was developed by Kenelec Scientific Pty Ltd (Australia) for the Firewood Association of Australia Inc. and is based on the Travel BLANkET[3] system first developed by the Tasmanian Environmental Protection Authority for smoke survey measurements (Innis et al. 2013). This technology has been used in the Tasmanian domestic smoke management programme "Burn brighter this winter", a community education project which has been running since 2012.

The SmokeTrak unit, hired from Kenelec Scientific Pty Ltd (Australia), is specifically designed for mobile monitoring of wood-smoke. The instrument consists of a TSI DustTrak Aerosol Monitor (model 8533) with an in-line $PM_{2.5}$ filter housed in a travel case together with a GPS sensor, a modem and a tablet for displaying measured $PM_{2.5}$ concentrations. The unit was placed on the passenger side inside the vehicle with the sample inlet attached to the outside the front window of the car. The unit was powered using the vehicles 12-volt power outlet (Figure 4.1). When switched on, a pump in the SmokeTrak sampled air from outside the car at a rate of 3 litres per minute through the inlet tube. The sampled air was passed through the auto zero module which corrected for zero drift in the DustTrak at 1-hour intervals. Particle concentration readings (µg/m^3) were sent continuously to the Agent G2 data logger which transmitted the readings to the Pervasive Telemetry website every 5 seconds together with the current GPS co-ordinates. The SmokeTrak data was able to be viewed in real-time on the Pervasive Telemetry website using the tablet provided. The vehicle containing the SmokeTrak was driven at approximately 30 km/hour meaning a $PM_{2.5}$ measurement was captured at roughly 8 m intervals along the route. Each measurement was timestamped and geo-referenced by a GPS connected to the SmokeTrak.

Figure 4.1: SmokeTrak measuring system set up in monitoring vehicle

[3] Base-Line Air Network of EPA Tasmania

4.2 Sampling route

The driving route was planned to cover as much of Masterton's urban area as possible within a three-hour period. Approximately 70 km of a driving route was able to be monitored at a speed of 30km/hr over a three hour period. Sampling was undertaken between 17:00 and 23:00 to capture the range of wood-smoke concentrations, from initial start-up through to later in the evening. It was originally planned to monitor on 12 nights that were clear and calm to minimise the night-to-night difference in wood-smoke levels due to meteorological effects. Due to the above average June rainfall[4] there were fewer dry and low wind speed nights only eight nights were both suitable for monitoring and had personnel available to carry out the monitoring.

4.3 Data processing and GIS analysis

(i) The SmokeTrak 5-second measurements were downloaded as a csv file from the Pervasive Telemetry website after each sample run. These files were merged and calibration data points, when the instrument was in auto-zero mode, were removed.

(ii) $PM_{2.5}$ and meteorological measurements (10 minute averages) from the fixed stations (Masterton East and Masterton West) were then matched to the nearest minute of the timestamped SmokeTrak measurement.

(iii) On two separate evenings, the SmokeTrak unit was parked close to the Masterton East monitoring station for a period of several hours so that the SmokeTrak measurements could be compared to measurements made by the fixed reference monitor (Beta Attenuation Monitor, model 5014i) at Masterton East. The 10-minute average SmokeTrak measurements were approximately three times higher than those measured by the reference monitor. This difference arose as the SmokeTrak as supplied was calibrated with latex spheres (A1-ultrafine dust) and needed to be re-calibrated to report appropriate mass concentrations for smoke aerosols (John Innis pers. comm. 22/10/2018). To account for the difference in measurement between the fixed reference monitor and the SmokeTrak, the mobile 5-second averages were adjusted downwards based on the collocated measurements as described in Appendix A1.

(iv) The SmokeTrak data were converted to a spatial data points file based on the latitude and longitude coordinates captured by the GPS. The spatial data points were then clipped to the boundary of the Masterton urban area so that measurements outside the urban area were removed.

(v) To simplify visual representation of the data, the SmokeTrak measurements were aggregated over a 200m x 200m grid which was superimposed on an OpenStreetMap of the Masterton urban area.

(vi) A single high emitting chimney can produce very high levels of $PM_{2.5}$ which can be measured if the SmokeTrak passes through the plume.

[4] http://www.gw.govt.nz/assets/2018-uploads/Climate-and-Water-Resource-SummaryColdSeason-2018.pdf

To remove the influence of extreme SmokeTrak values due to transient high chimney smoke events, the SmokeTrak dataset was trimmed to remove the top 5% of measurements. This trimmed dataset is closer to the distribution of the Masterton East $PM_{2.5}$ reference monitor measurements (Appendix A1).

(vii) Data analysis, plots, spatial aggregation and mapping were carried out using R (R Core Team 2017) using the following packages:

- tmap/tmaptools (Tennekes 2018)
- rgdal (Bivand et al. 2018)
- rgeos (Bivard & Rundel 2017)
- dplyr (Wickham et al. 2017)
- sp (Pebesma & Bivand 2005; Bivand & Pebesma 2013)
- RColorBrewer (Neuwirth 2014)
- ggplot(Wickham 2009)
- openair(Carslaw & Ropkins 2012)

The Masterton base map was downloaded from OpenStreetMap[5].

[5] https://www.openstreetmap.org/#map=10/-41.1264/175.4723

5. Results and discussion

5.1 Summary of SmokeTrak measurements

We collected approximately 21,000 5-second $PM_{2.5}$ measurements using the SmokeTrak over eight separate evenings and two mornings (Table 5.1). The daily average wind speed, minimum daily 1-hour temperature and 24 hour average $PM_{2.5}$ measured at Masterton East are shown in Figure 5.1. The sampled evenings covered a range of meteorological conditions (Table 5.2).

Table 5.1: Summary of SmokeTrak-adjusted and Masterton East air quality monitoring station $PM_{2.5}$ (μg/m³) concentrations (SD in brackets)

Date	Day of week	Start	End	SmokeTrak-adjusted $PM_{2.5}$	Number of data points	Masterton East $PM_{2.5}$ (averaged over same period as SmokeTrak)	Masterton East $PM_{2.5}$ (6hr-average 17:00-23:00)	Masterton East $PM_{2.5}$ (24-hour average midnight to midnight)
14/6/2018	Thu	17:04:30	21:14:40	61.2 (30.7)	2426	41.6 (7.5)	42.7	19.7
15/6/2018	Fri	08:32:00	09:21:45	43.5 (28.5)	517	20.2 (15.9)	NA	18.7
20/6/2018	Wed	19:11:50	22:15:15	41.6 (49.2)	1321	37.5 (11.0)	39.2	16.3
21/6/2018	Thu	08:32:30	09:15:50	65.6 (24.3)	460	43.5 (11.5)	NA	39.1
23/6/2018	Sat	19:05:10	22:55:25	116.3 (59.7)	2514	146.2 (42.3)	130.6	49.9
27/6/2018	Wed	17:16:00	22:19:35	34.7 (26.3)	3010	33.4 (21.3)	36.8	21.6
28/6/2018	Thu	18:50:40	22:14:25	68.3 (45.7)	2319	58.5 (32.7)	42.7	24.6
30/6/2018	Sat	17:26:40	23:39:40	121.8 (68.8)	3276*	134.8 (57.5)	135.4	60.7
3/7/2018	Tue	17:12:30	22:13:20	65.5 (56.1)	2855	65.7 (45.8)	65.7	23.7
4/7/2018	Wed	19:08:20	23:05:45	98.5 (57.1)	2594	94.3 (22.3)	85.6	39.1

*includes mobile monitoring in Carterton from 17:42 to 20:13

Table 5.2: Summary of weather conditions for mobile sampling evenings (17:00 to 23:00) as measured at the Masterton West air quality monitoring station (10m)

Date	Mean wind speed 1-hr (m/s)	Mean temp 1-hr (°C)	Tmin 10-min (°C)	Tmax 10-min (°C)	Wind direction	Rainfall accumulation (mm)
14/6/2018	0.6	8.7	5.9	10.8	NW	0
20/6/2018	1.1	4.7	4.0	5.6	SW	0.4
23/6/2018	0.8	6.1	4.1	9.1	NE	0
27/6/2018	1.3	6.5	3.4	8.8	SW	0
28/6/2018	1.1	4.5	1.5	8.3	NW	0
30/6/2018	0.9	3.2	0.7	7.9	N	0
3/7/2018	0.9	3.6	0.2	6.7	SW	0
4/7/2018	1.0	3.2	0.0	8.5	W	0

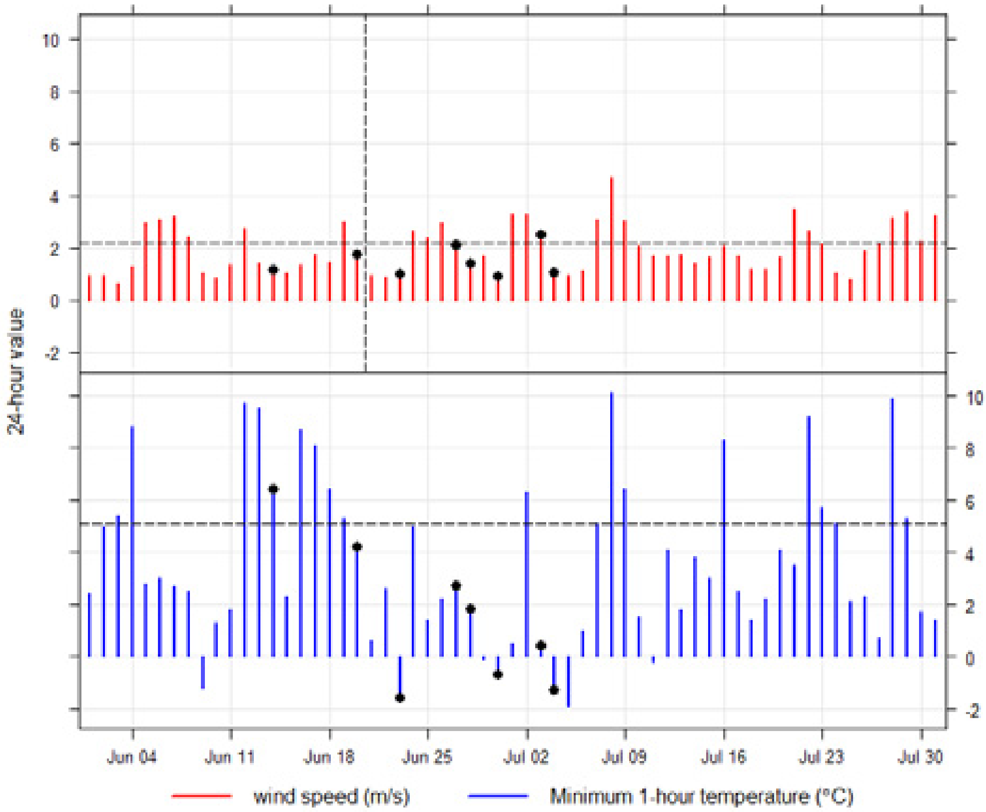

Figure 5.1: Daily average wind speed and daily 1-hour temperature minima recorded at Masterton West (10m) during June and July 2018. The dashed line shows the five year average (2012-2017) for wind speed and minimum temperature. The black dots show the mobile monitoring dates.

The altitude measurements of the mobile GPS were not as accurate as the latitude longitude coordinates. Nevertheless, the GPS measurements (Appendix A2) showed the same general pattern as the 1-m digital elevation map of the Masterton urban area and so were adequate for data interpretation (Figure 2.5).

5.2 'Smokiness' of the sampling nights

Figure 5.2 shows the distribution of all $PM_{2.5}$ 6-hour averages (17:00 to 23:00) recorded at the Masterton East monitoring for all evenings during June and July for the past five years. In this box plot the boxes range from the 25th to 75th percentile. The range between these percentiles is known as the interquartile range (IQR). The horizontal lines through the boxes represent the median. The whiskers start from the edge of the box (ie, the 25^{th} and 75^{th} percentiles) and extend to the furthest data point that is within 1.5 times of the IQR. Any data points that are past the ends of the whiskers are considered outliers (or extreme values) and are displayed with dots. The 6-hour averages recorded at the Masterton East station during the mobile sampling nights are annotated with labelled dates.

Four of the sample evenings (14/6, 20/6, 27/6 and 28/6) had moderate $PM_{2.5}$ levels (ie, 10-50 $\mu g/m^3$), two evenings (3/7 and 4/7) had high $PM_{2.5}$ levels (ie, 50-100 $\mu g/m^3$) and two evenings (23/6 and 30/6) had very high $PM_{2.5}$ levels (ie, above 100 μg/m³). No low pollution nights were sampled and so the SmokeTrak monitoring was skewed towards higher levels of wood smoke than an average winter's evening. Figure 5.3 shows the relative concentrations of $PM_{2.5}$ for each evening in June and July 2018 and the wind direction and wind speed.

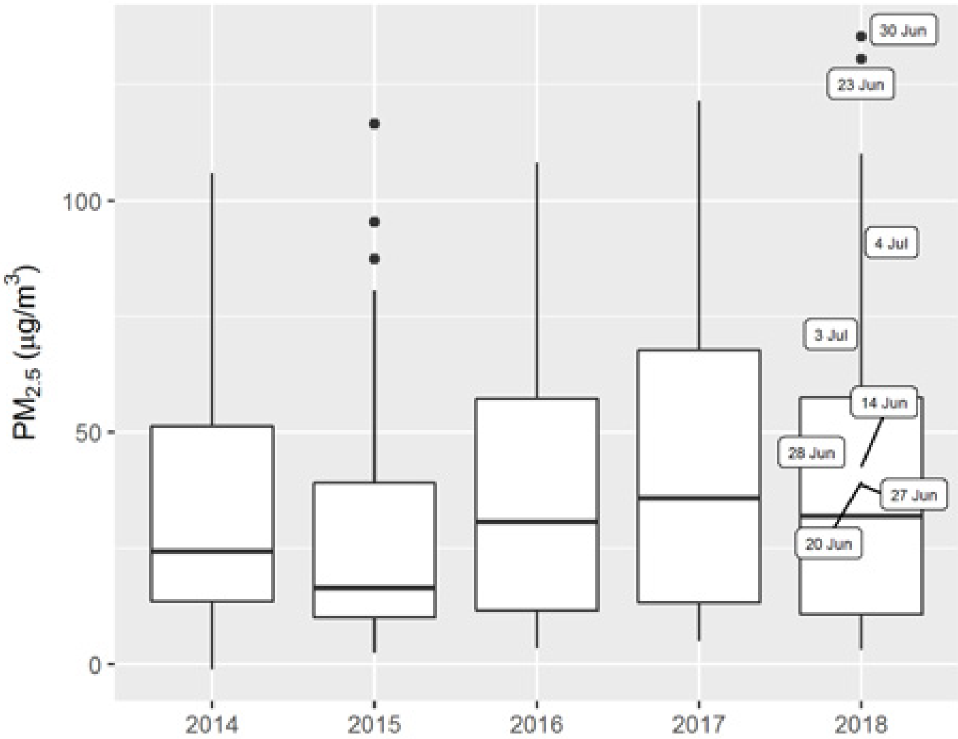

Figure 5.2: Distribution of 6-hour average $PM_{2.5}$ (17:00 to 23:00) measured at the Masterton East air quality monitoring station for June-July from 2014 to 2018. Labels show the location in the distribution of evening $PM_{2.5}$ measured at the Masterton East station for the dates of SmokeTrak mobile monitoring. The horizontal lines show the median $PM_{2.5}$ concentration for the evening period for each year.

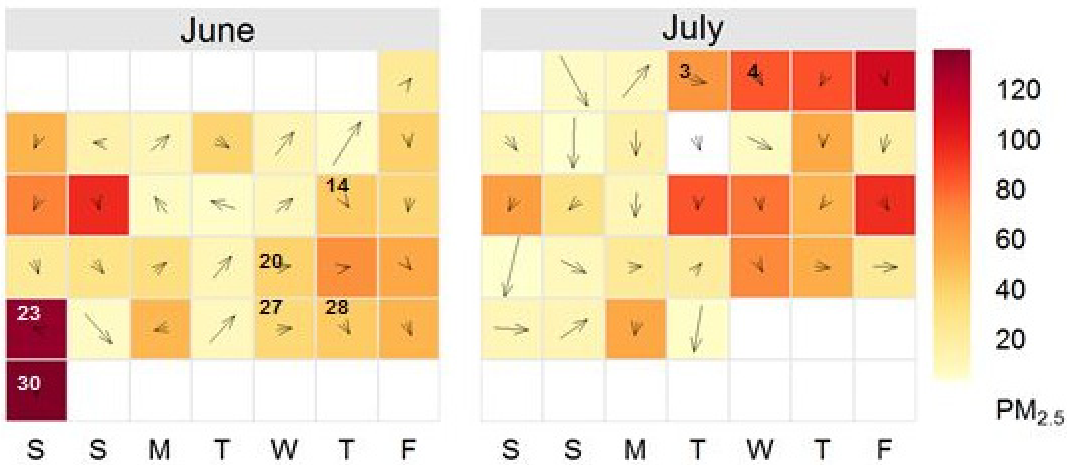

Figure 5.3: Calendar plot (Saturday to Friday each week) showing daily average $PM_{2.5}$ (μg/m³) measured at the Masterton East air quality monitoring station. The arrows show wind direction scaled to wind speed (ie, longer the arrow the higher the wind speed) for the period 17:00 to 23:00 for June and July 2018 with dates of sample nights shown.

5.3 Time variation in wood smoke measurements

The time variation in SmokeTrak $PM_{2.5}$ measurements (10-minute averages), averaged over all evening sample runs, follow roughly the same pattern as $PM_{2.5}$ measured at the Masterton East air quality monitoring station (during the sample evenings) until 22:00 (Figure 5.4). After 22:00 the SmokeTrak measured higher concentrations relative to Masterton East. This may be a consequence of sampling having been biased towards lower-lying areas of town during 22:00 and midnight as shown in Appendix A4 where all SmokeTrak measurements are mapped by hour of the evening.

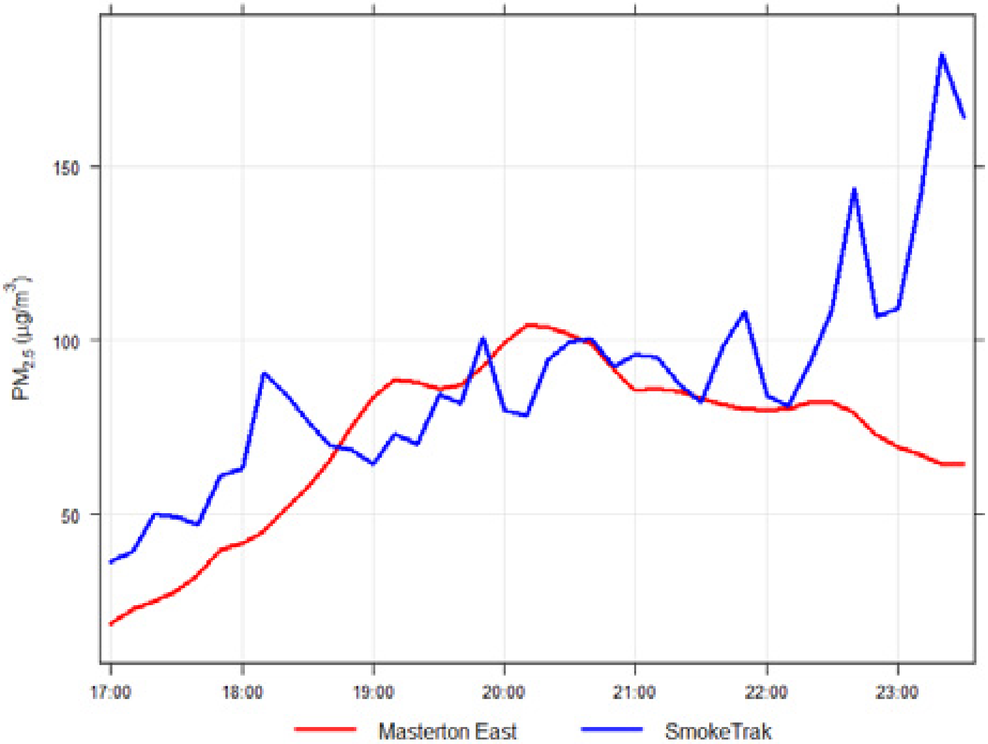

Figure 5.4: Ensemble of $PM_{2.5}$ (10-minute averages µg/m³) aggregated over all monitoring evenings measured by SmokeTrak-adjusted (blue) and at the Masterton East air quality monitoring station (red)

5.4 Wood smoke maps

5.4.1 SmokeTrak 5-second averages

Figure 5.5 shows the individual 5-second $PM_{2.5}$ averages collected by the SmokeTrak over the eight evenings sampled in Masterton. There was large variation in fine-scale wood-smoke measurements. Some streets had both high and low concentrations representing monitoring occurring on different nights or different times of the evening. The individual SmokeTrak data points (with top 5% removed) for all monitoring runs are shown by the evening sampled in Appendix A3 and by hour of day in Appendix A4. Figure 5.5 shows that higher concentrations of $PM_{2.5}$ were mainly found to the east, south and southwest with the lowest concentrations outside of the main urban area and at higher elevations in the suburb of Lansdowne.

Only two short mobile monitoring runs were undertaken in the morning period between 08:30 and 09:15 (Figure 5.6). Whist there are not enough data points to be definitive, there appears to be a similar pattern to evening concentrations, with lower-lying areas being worst affected.

At very local spatial scales, tens of metres, a single excessively smoke emitting chimney can produce very high levels of $PM_{2.5}$. Mobile measurements may capture very high readings if the monitor passes through the plume. Likewise the high readings may not be captured if the mobile monitor is upwind of this high concentration plume. The 95th percentile of SmokeTrak-adjusted measurements are shown in Figure 5.7. These are the top 5% of measurements and may represent local ‘hot spots’ due to high emitting chimneys. These clusters of extremely high short-term $PM_{2.5}$ levels were mainly found in parts of the Solway North, Solway South, Masterton East and lower lying areas in the Lansdowne suburb. Most of these top 5% of measurements were made on the high to very high pollution nights between 19:00 and midnight.

5.4.2 SmokeTrak grid cell averages

Figure 5.8 shows the SmokeTrak-adjusted $PM_{2.5}$ measurements averaged over a 200m grid - where each grid area was visited on at least five separate monitoring nights (sample runs). This is a reduced dataset because some cells received fewer than five visits with the SmokeTrak. This map shows that some areas of Masterton appear to be more impacted by wood smoke than others and lower lying areas show a consistent pattern of high wood-smoke levels. These low-lying areas were disproportionally sampled at 22:00 and midnight which means that the high concentrations will be reflecting the time variation as well as spatial variation.

5.4.3 SmokeTrak grid cell ratio to fixed monitoring station

Figure 5.9 was produced by taking the ratio of each SmokeTrak-adjusted $PM_{2.5}$ mobile measurement to what was measured at the Masterton East station over the matching time period and then averaging all the ratios over a 200m grid. Each grid cell therefore represents an average of all the ratios, where each grid area was visited on at least five separate monitoring nights (sample runs).

This is a reduced dataset because some cells received fewer than five passes with the SmokeTrak. The blue areas were on average lower or similar to what was measured at the Masterton East air quality monitoring station. The yellow to orange areas were, on average, higher than what was measured at Masterton East air quality monitoring station and the dark brown areas were very elevated compared to the Masterton East air quality monitoring station. This suggests that some areas such as parts of Solway North may experience much higher wood-smoke at times than measured at the air quality monitoring station.

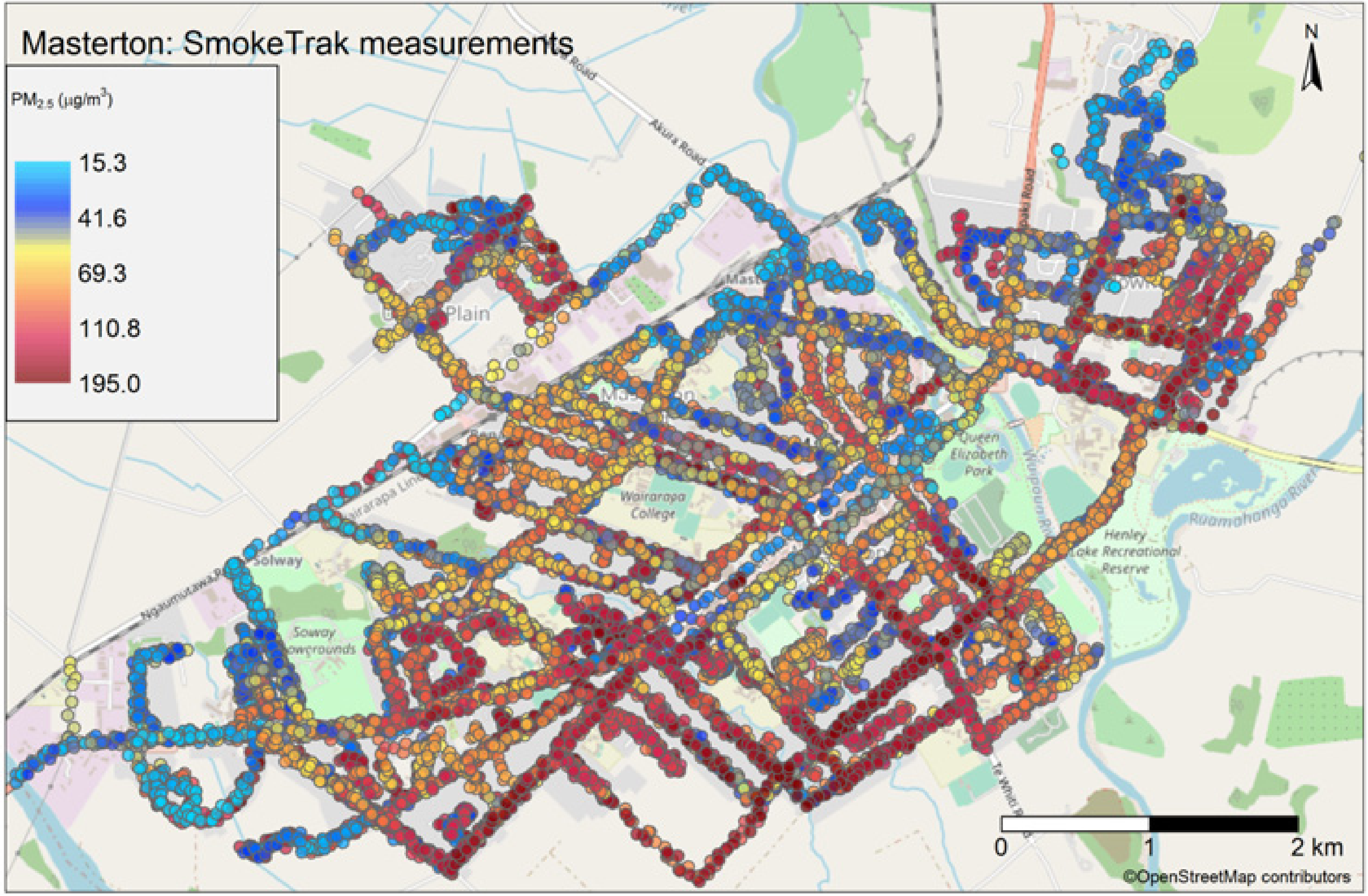

Figure 5.5: SmokeTrak-adjusted $PM_{2.5}$ µg/m³ (5-second averages) measured in Masterton over eight evenings in June and July 2018 (top 5% of measurements removed), n=17,839. Points are 'jittered' to minimise overlapping data points

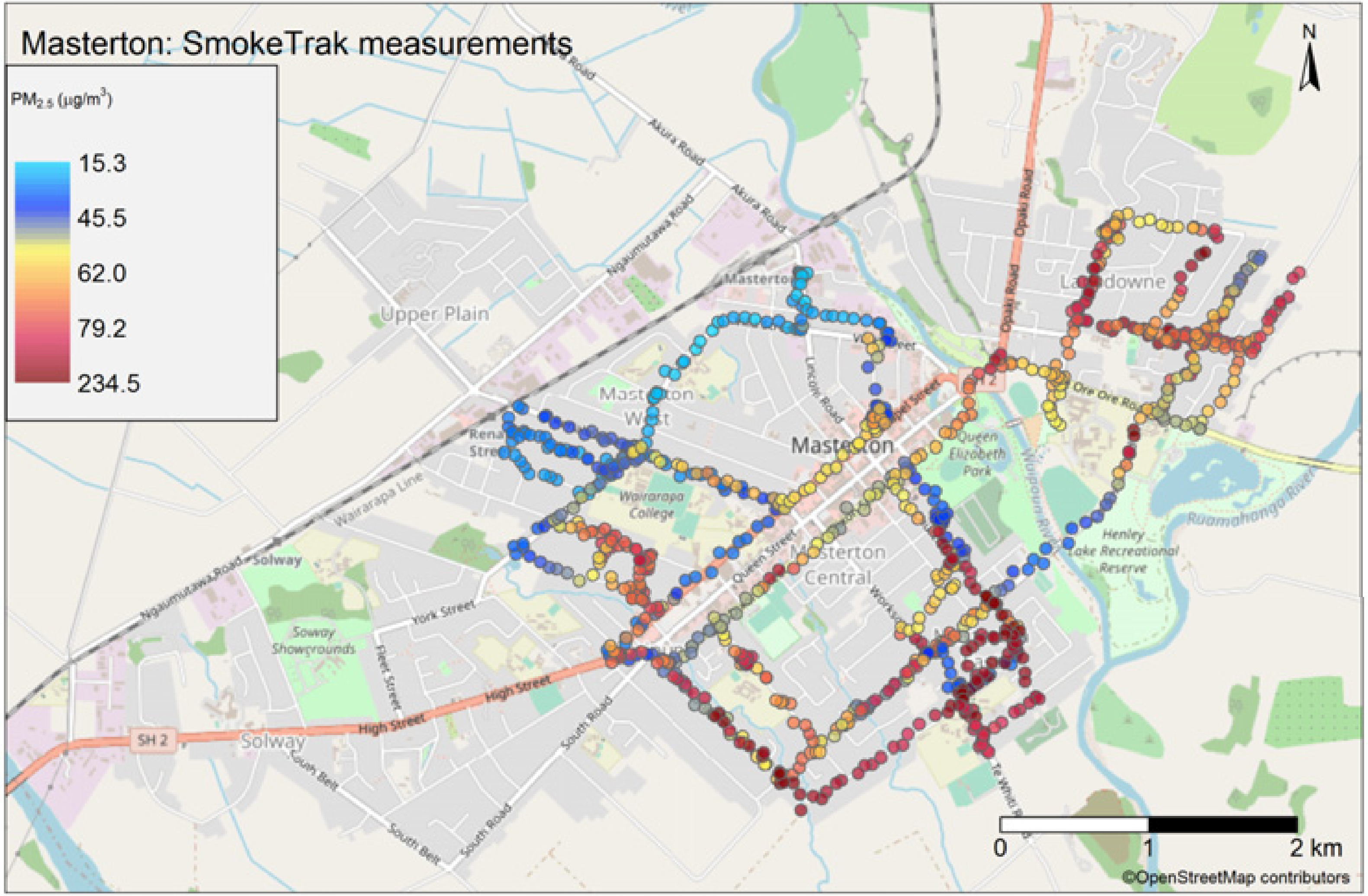

Figure 5.6: SmokeTrak-adjusted PM2.5 µg/m³ (5-second averages) measured in Masterton over two sampled mornings in June 2018, n=971. Points are 'jittered' to minimise overlapping data points

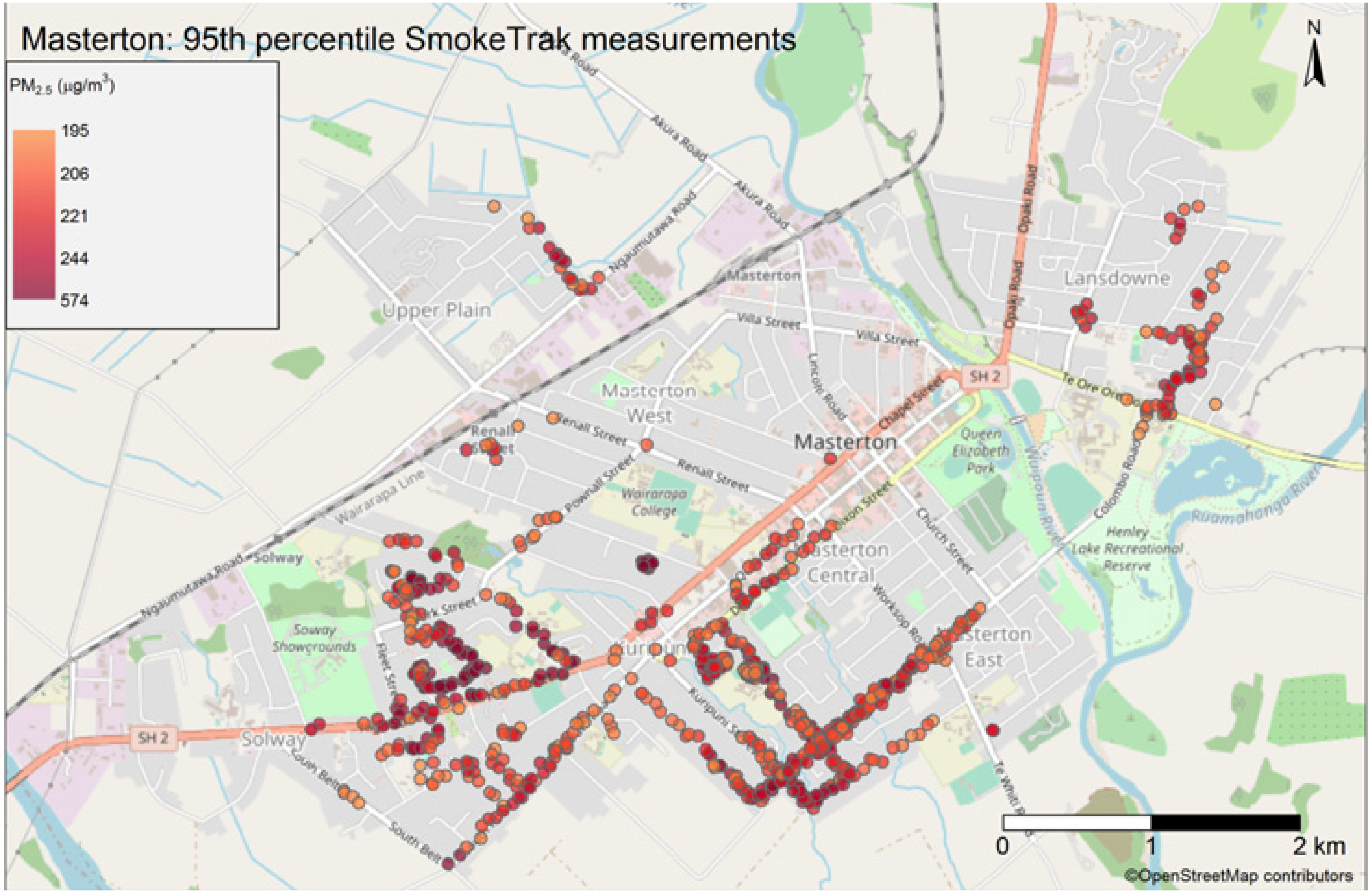

Figure 5.7: 95th percentile SmokeTrak-adjusted $PM_{2.5}$ µg/m³ (5-second averages) collected during the eight evening sample runs through June and July 2018 (top 5% of measurements), n=936

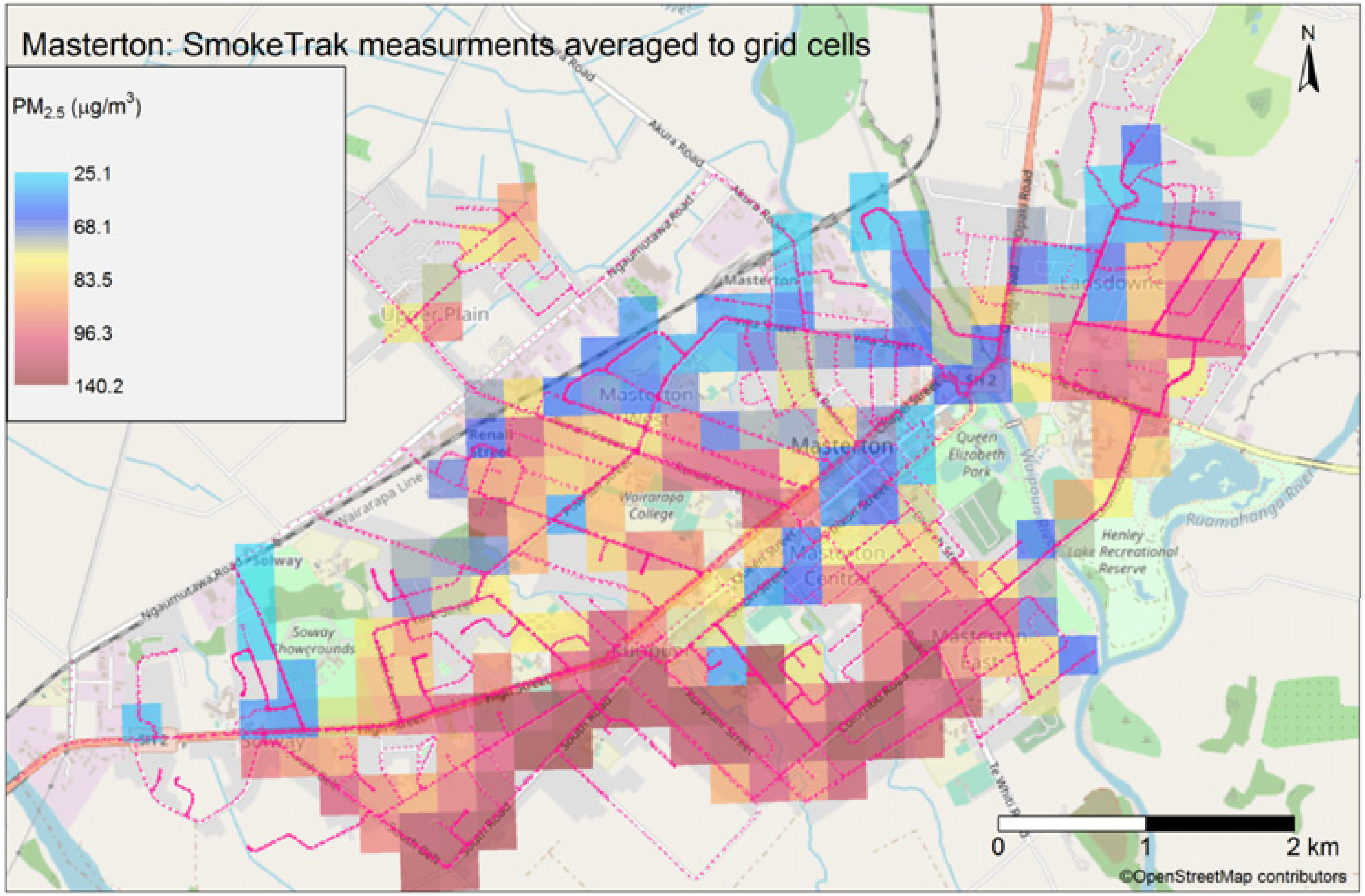

Figure 5.8: SmokeTrak-adjusted $PM_{2.5}$ µg/m³ (5-second averages) (trimmed dataset with top 5% of measurements removed) aggregated to a 200m x 200m grid, where each grid cell represents the average of measurements from at least five separate monitoring evenings. Mobile monitoring data points shown as pink-coloured dots.

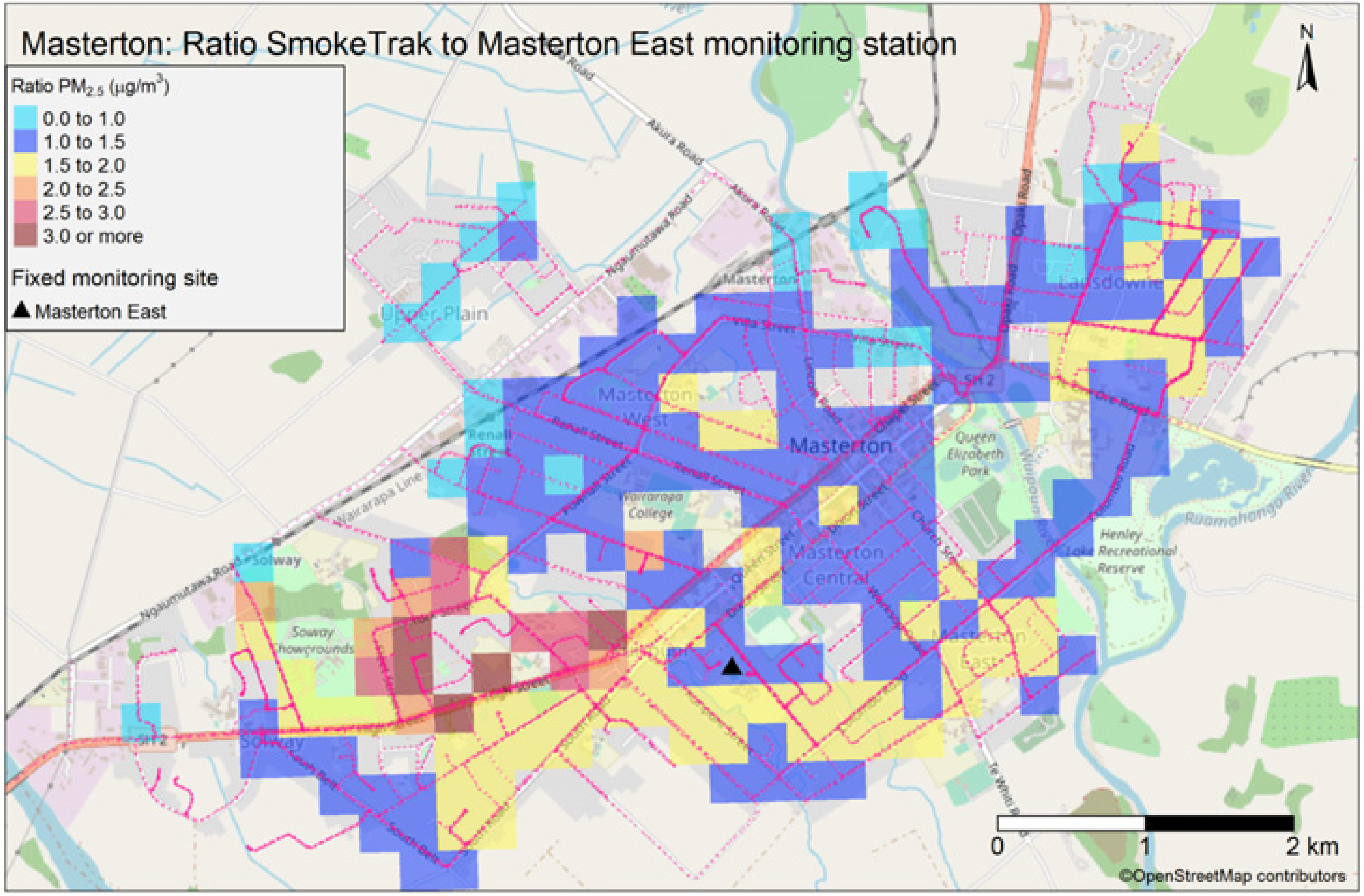

Figure 5.9: Ratio of mobile SmokeTrak-adjusted $PM_{2.5}$ ($\mu g/m^3$) measurements (top 5% removed) to $PM_{2.5}$ recorded at the same time at the Masterton East air quality monitoring station (black triangle). All measurements averaged to a 200m x 200m grid, where each grid cell represents the average of ratios of measurements from at least five separate monitoring evenings. Mobile monitoring data points shown as pink-coloured dots.

5.4.4 Limitations

As these maps were generated from a relatively small number of sample evenings they may represent a ‘snapshot’ of air quality at a particular location and not necessarily reflect overall winter air quality patterns. The mobile monitoring path was restricted to roads and therefore doesn’t cover all areas impacted by wood smoke. There is a time lag of approximately 10 seconds between the intake of smoke and its detection by the SmokeTrak which is not compensated for by the instrument’s software. This means that the SmokeTrak measurement is spatially located to where the car was 10 seconds earlier. In most cases this effect is small, but needs to be considered, particularly if the SmokeTrak was to be used to identify individual chimneys – which was not a monitoring objective of this study.

6. Conclusion

The car-based monitoring method using the SmokeTrak instrument provided useful information on the spatial variation of wood-smoke across the Masterton urban airshed. The method shows that with sufficient sampling runs persistent ‘hot spots’ of high wood-smoke can be identified.

On high pollution nights, peak concentrations occurred later in the evening (after 10 pm) in the low-lying areas of Masterton East, Lansdowne and Solway South. Concentrations of $PM_{2.5}$ in these areas were likely higher than those measured at the Masterton East monitoring station as cold air slowly moved from higher to lower altitude areas, leading to an accumulation of wood-smoke in the lower-lying areas.

Clusters of very high transient $PM_{2.5}$ measurements were identified in some parts of the suburbs of Solway, Kuripuni, Masterton East and Lansdowne. More on the ground observations are needed to confirm whether these high $PM_{2.5}$ observations were due to consistently high emitting chimneys that could be targeted for some form of assistance to reduce emissions.

Mobile-monitoring is labour-intensive and it is recommended that a further complementary study be carried out using a distributed network of low-cost sensors that could set up for a one to two month campaign to include the potential hot spot areas identified in this study.

Acknowledgements

This project would not have been possible without the contributions of Matt Noora, Agnes Piatek-Bednarek and Alex Carter (MDC) who assisted with the mobile monitoring. John Innis (Tasmanian Environmental Protection Agency provided valuable technical advice on survey design and data analysis and mapping. Roger Uys (GWRC) helped with technical aspects of GIS and GPS measurements and provided helpful comments on the report.

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Appendix A1: Co-location relationship – SmokeTrak and air quality monitoring station $PM_{2.5}$ measurements

The SmokeTrak measures $PM_{2.5}$ using an optical method (light-scattering photometer) and the instruments at the fixed monitoring stations (5014i Thermo Scientific) use beta attenuation. These two methods produce different results. The instruments at the fixed station are reference methods that are used for assessing compliance with the national environmental standards. In order to compare SmokeTrak measurements to the fixed station measurements, the vehicle containing the SmokeTrak was parked close the Masterton East station on two evenings for several hours to obtain co-located measurements. The 10-minute averages from both instruments were correlated with the SmokeTrak consistently measuring higher concentrations than the instrument at the monitoring station (Figure A1.1). Based on this relationship the 5-second SmokeTrak measurements were adjusted downwards so they can be compared to those at the fixed station. The distributions of the measurements made at the stations and of the adjusted SmokeTrak 5-second averages are shown in Figure A1.2).

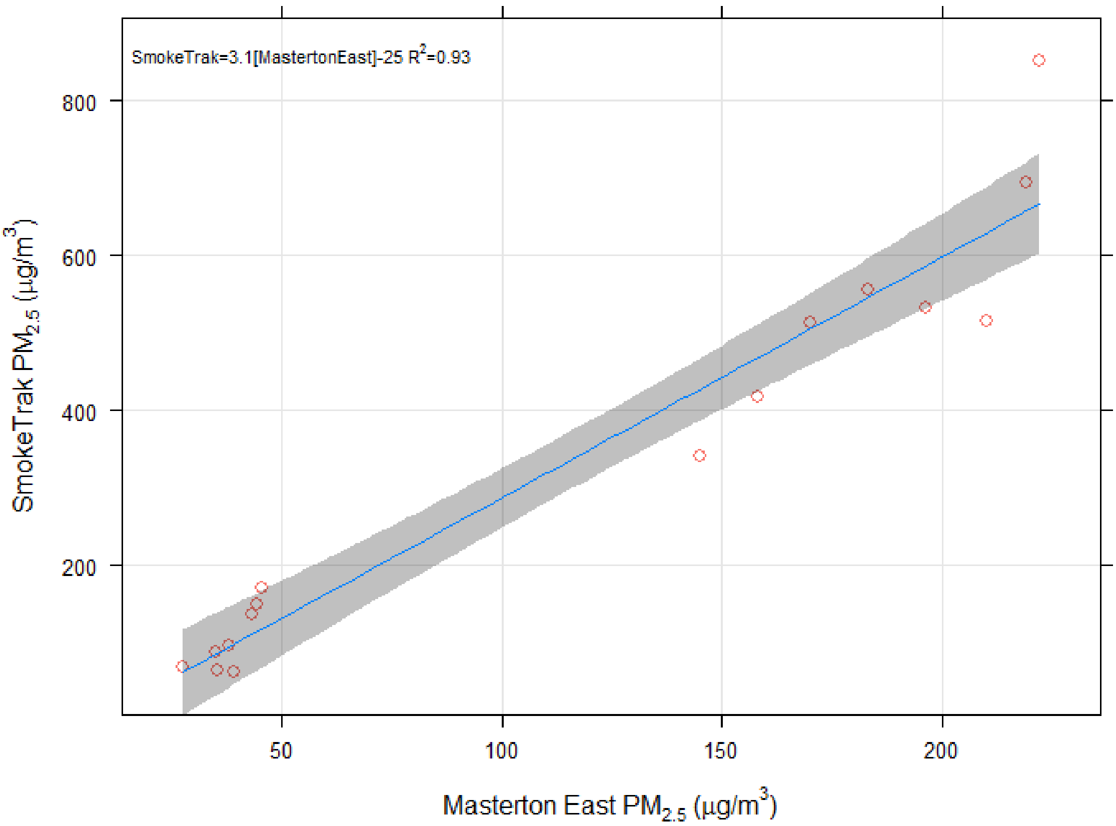

Figure A1.1: Correlation between SmokeTrak and the Masterton East air quality monitoring station instrument (5014i) 10 minute averages

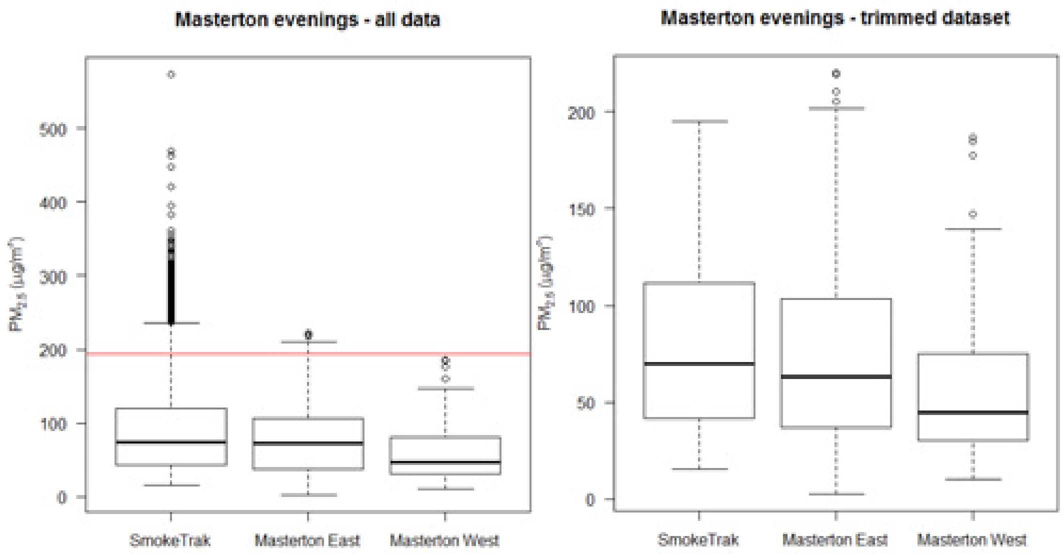

Figure A1.2: Left: Boxplot SmokeTrak-adjusted $PM_{2.5}$ (5-second averages) and fixed station $PM_{2.5}$ (10-minute averages) over all monitoring evenings in Masterton. The red line is the 95th percentile of SmokeTrak-adjusted measurements, n=18,775. Right: Boxplot SmokeTrak-adjusted 5-second averages and air quality monitoring station 10-minute for all measurements below the 95th percentile (ie, top 5% removed), n=17,839.

Appendix A2: GPS-recorded measurements of altitude along monitoring route

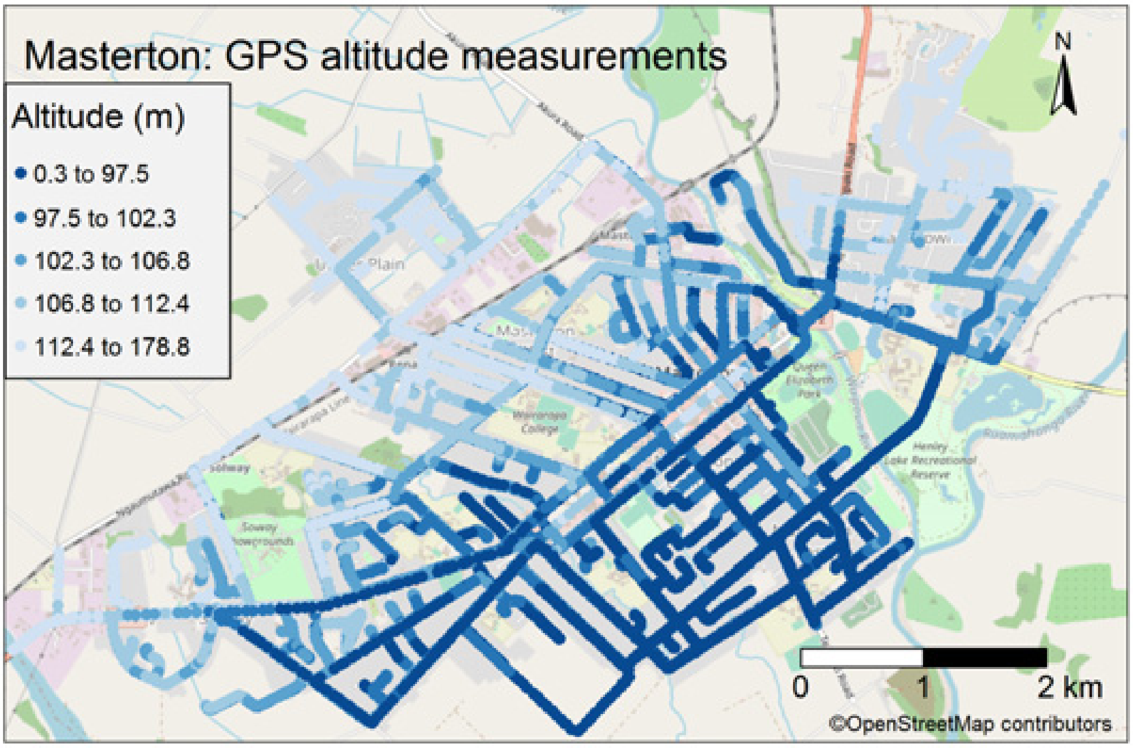

Figure A2.1: Altitude (m a.s.l.) measurements recorded by GPS during the mobile measurements. Dark blue shows the lowest lying areas.

Appendix A3: Masterton SmokeTrak measurements by sample date

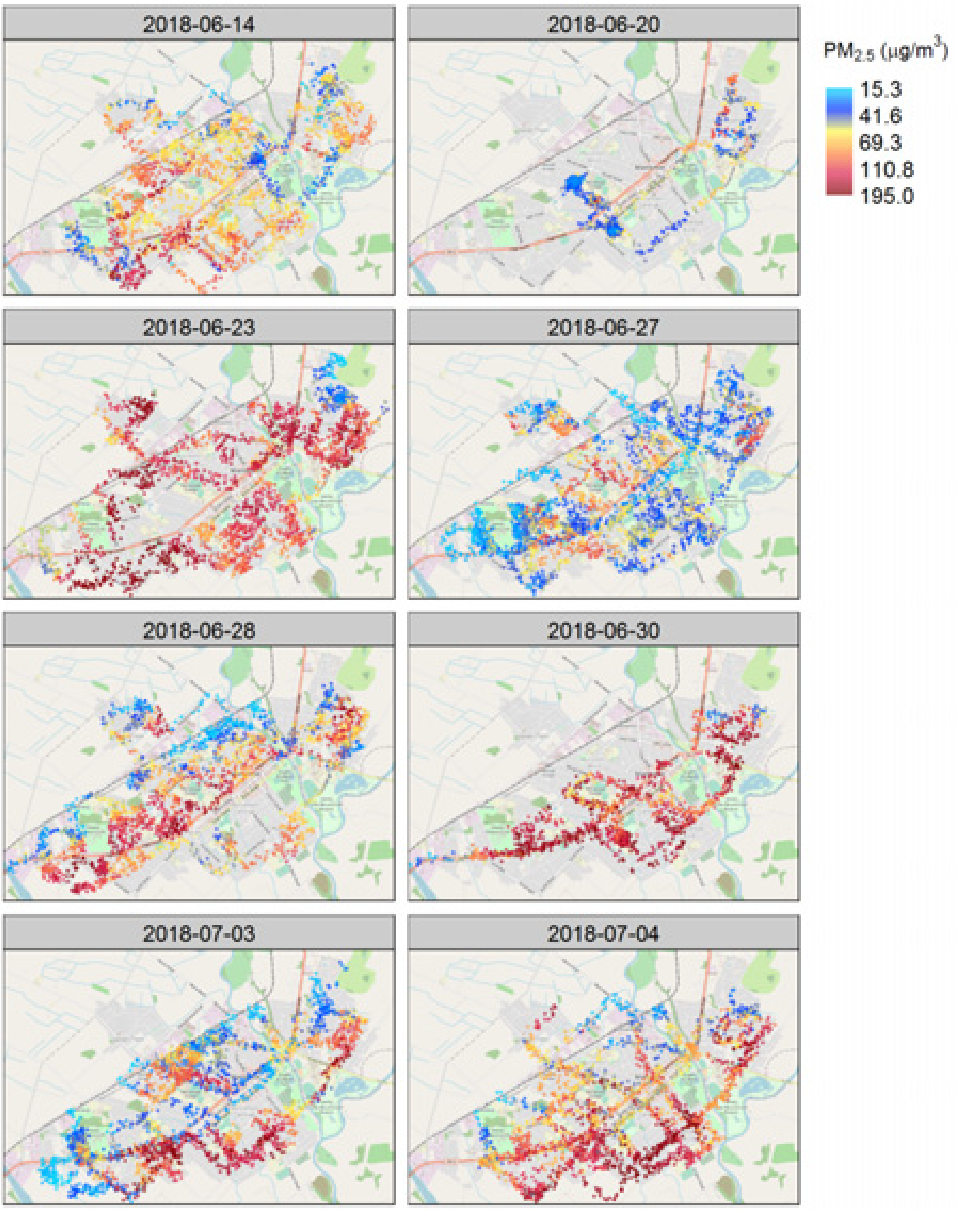

Figure A3.1: Trimmed SmokeTrak-adjusted $PM_{2.5}$ µg/m³ (5-second averages) measured in Masterton over all hours between 17:00 and 23:39 (top 5% of measurements removed) by sample date

Appendix A4: Masterton SmokeTrak measurements by hour

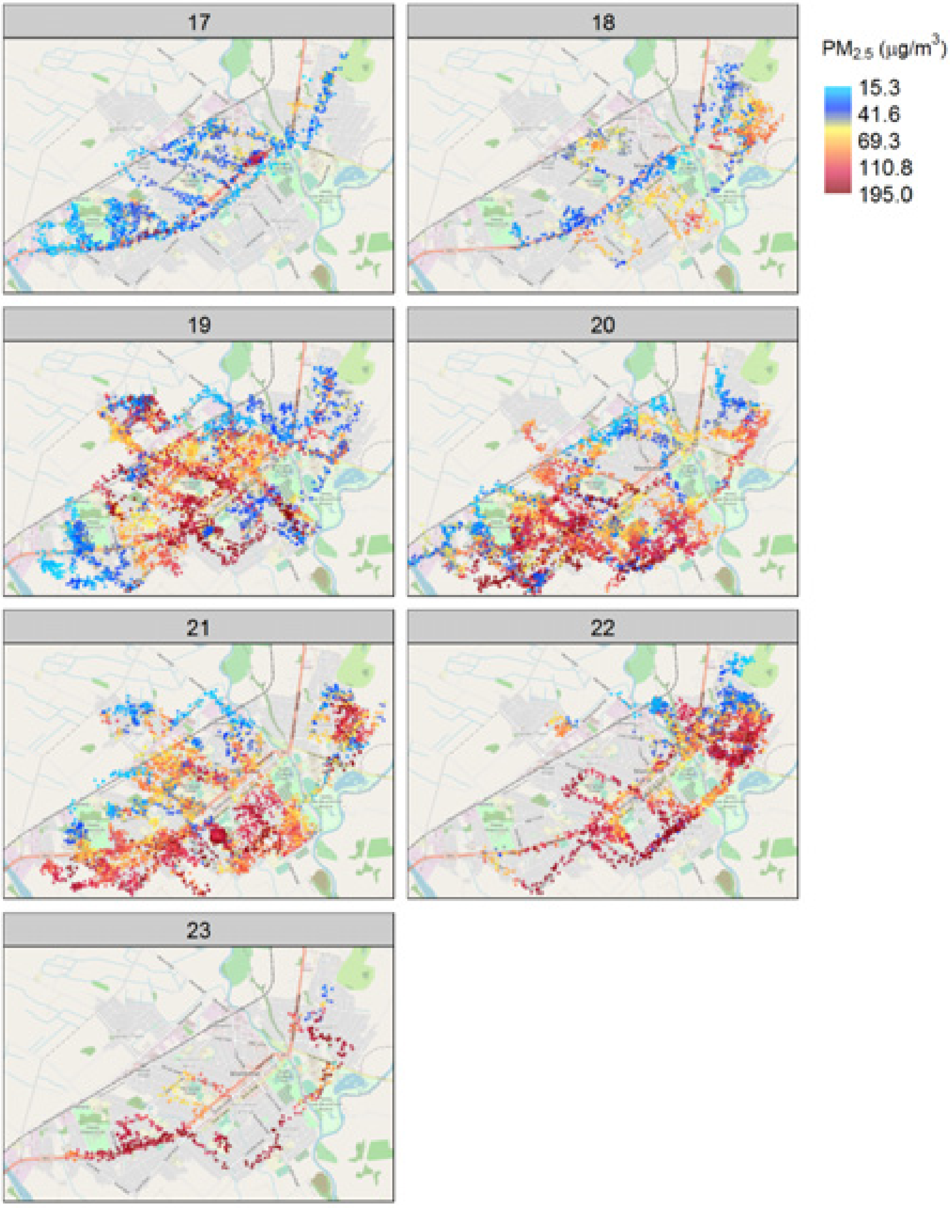

Figure A4.1: Trimmed SmokeTrak-adjusted $PM_{2.5}$ µg/m³ (5-second averages) measured in Masterton during all sampled evenings (top 5% of measurements removed) shown by hour of day. Note the 23:00 hour subplot is based mostly on observations during the evening of 30/06/2018 when sampling continued until 23:39.