June 2015

CHRISTCHURCH AIRSHED MODELLING

Incorporation of Motor Vehicle Sources and Overnight Home Heating Emissions

Submitted to:
Canterbury Regional Council
PO Box 345
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REPORT

Report Number: 1521198_002_R_Rev0

Distribution:

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1.0 INTRODUCTION

This report describes latest results from the airshed modelling of discharges from sources in the Christchurch urban area. The goal of this project is to develop and improve the dispersion modelling reported to Canterbury Regional Council (CRC) on 1 October 2014 under a previous contract with Golder (2014a). The previous modelling, which used TAPM[1], was based on emissions from domestic heating and industrial sources, and showed a shortfall in modelled particulate matter with an aerodynamic diameter less than 10 µm (PM_{10}), relative to measurements from the Coles Place monitoring site in St Albans. The current work aims to improve the airshed model performance through the following tasks defined in the current contract between CRC and Golder[2]:

Confirmation of priorities for investigation: Confirm which tasks would yield the most improvement in the model's output in the time and budget available. Potential tasks included the following:

i) Improvement of the meteorological component of the model under stable, night-time conditions.

ii) Incorporation of new or updated emissions information, e.g., introducing motor vehicle sources, updating industrial stack and emissions parameters, re-evaluating the hourly profiles of domestic heating emissions.

iii) Investigation of potentially unaccounted-for sources which give rise to relatively high ambient PM_{10} after midnight.

iv) Provision of guidance on the modelling of motor vehicle and industrial sources, specifically whether a model other than TAPM should be used.

Following discussions on these matters (emails between CRC and Golder, 27-30 March 2015), it was decided that domestic heating and industrial emissions that were based on the 2009 inventory (CRC 2011) would not be changed, and therefore item (ii) would be concerned with motor vehicle emissions only.

The remainder of this report describes Golder's findings from the following tasks:

Meteorological model performance: Output vertical profiles of modelled PM_{10} and examine night-time mixing and, if necessary, adjust the meteorological model to bring the predicted layer depth in line with observations. This work is described in Section 2.0.

Incorporation of motor vehicle emissions: Examine the contribution to PM_{10} in Christchurch from motor vehicles, based on data supplied by CRC for individual road links. This work is described in Section 3.0.

Incorporation of unaccounted-for emissions: Examine the remaining shortfall in modelled PM_{10} (late at night and in the early-morning hours) and estimate the magnitude of modelled PM_{10} emissions which would be needed to compensate for this in the model. This work is described in Section 4.0.

Model suitability for different source types: Provide general guidance on whether TAPM should be used for all emission sources, or whether other models are more appropriate for detailed studies. This guidance is provided in Section 5.0.

Issues for further investigation, based on findings from the above tasks, are provided in Section 6.0.

Section 7.0 summarizes the findings of this work, and is followed by a reference list (Section 8.0) and a report limitations statement (Appendix A).

[1] TAPM, The Air Pollution Model (Hurley et al. 2005).

[2] Contract for Services between Canterbury Regional Council and Golder Associates (NZ) Limited, dated 5 March 2015.

2.0 METEOROLOGICAL MODEL PERFORMANCE

2.1 Updating the TAPM Meteorological Model

The modelled shortfall in PM_{10} in late-evening and early-morning hours may be due to either missing emissions, and / or an overstatement of the dispersive effects by the computational model. While there is the potential for overnight PM_{10} impacts from wood burners that have been turned down and left to smoulder, there is also a potential for the effects of calm, stable nights to be under-stated by the meteorological model. If the night is not sufficiently calm and stable in the model, emitted pollutants would undergo too much dilution and dispersion and ambient concentrations would be under-stated.

The previous work incorporated a model grid with high horizontal resolution (1 km grid size for the meteorology; 250 m for the pollution dispersion) and assimilated wind observations at several sites (Golder 2014a). This minimized the potential for unrealistic horizontal dispersion, as plumes of pollution are well resolved on the model grid. Elevated pollution levels are observed to occur in Christchurch when the wind speed is less than 1 m/s, and the assimilation of wind observations in TAPM brings the model wind speed closer to low observed wind speeds (it would have difficulty reproducing calm conditions otherwise).

Although the modelled PM_{10} is sufficiently well confined in horizontal directions, there remains the possibility that there is some unrealistic diffusion upwards, which could reduce the modelled ground-level concentration (GLC). This may be due to the nocturnal boundary layer being insufficiently resolved by the model's vertical layers. The graphical user interface (GUI) for TAPM permits a number of default sets of vertical layers. For a total of 25 levels, the first few of these are 10, 25, 50, 100, 150, and 200 metres above ground level. This is not sufficient to realistically resolve a pollution layer of, say, 50 m depth, and increasing the total number of levels within the GUI does not insert additional levels below 50 m. To resolve this, tests using idealized PM_{10} emissions were carried out. These tests employed a spatial pattern of emissions matching patterns of home heating, but with a magnitude constant in time. This allows the modelled depth of the pollution layer to be calculated directly, rather than being inferred from meteorological parameters such as wind and temperature profiles. The test used different sets of model levels. A set of 35 model levels was settled upon, with the first few of these being 10, 15, 20, 25, 30, 40, 50, 65, 90, 115, 150, and 200 metres above ground level. Hence a 50 m pollution layer can now be resolved on seven model levels.

The modelled pollution layer depth may be referred to here as the 'mixing height' as it is the height up to which near-surface releases mix (this is not the depth of the inversion layer).

An example of a modelled PM_{10} profile is shown in Figure 1. The blue profile is resolved on the new set of levels, and indicates a better-resolved PM_{10} layer, 25 metres deep, with a higher GLC.

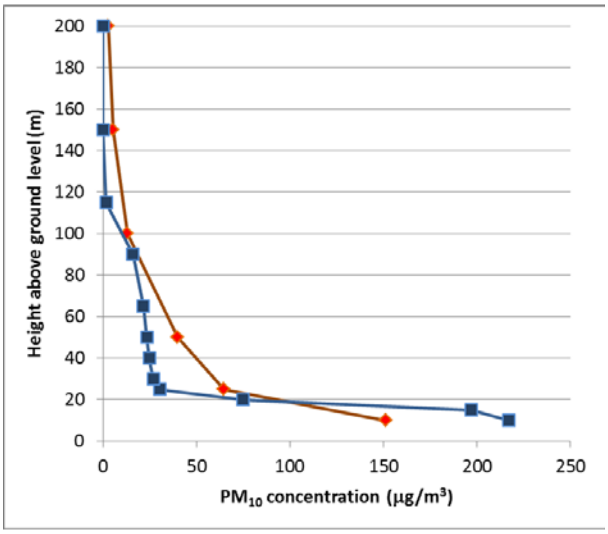

Figure 1: Example PM_{10} vertical profile on different sets of model levels. 25 default levels (red) and 35 manually-chosen levels (blue). Example model time shown is 3 May 2012, 21:00 NZST.

Figure 2 compares results for peak 24-hour PM_{10} from home heating and industry, from May to August, 2012. The left panel contains results previously presented by Golder (2014a). With the updated meteorological model, the peak GLC rises from 42 µg/m^3 to 60 µg/m^3 (Hoon Hay/Spreydon/Cashmere area). In the St Albans area, the modelled peak 24-hour PM_{10} has increased from around 30 µg/m^3 to around 40 µg/m^3. The results are now closer to observed concentrations, and there is also a slight change in the spatial pattern.

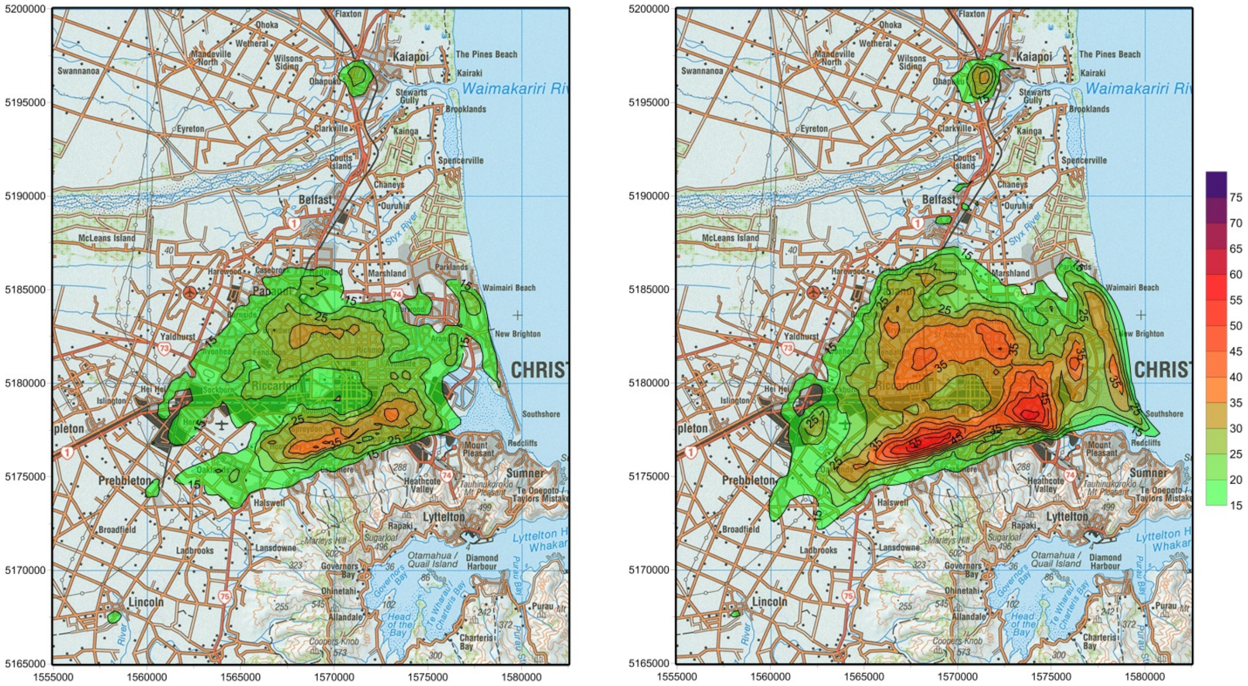

Figure 2: Peak modelled 24-hour PM_{10} GLC from domestic heating and industry. (a) Original 25-level meteorological model; (b) new 35-level meteorological model.

Further modelling described here has used the new set of model levels. The rest of the TAPM configuration is as described by Golder (2014a).

In the course of testing the model using idealized PM_{10} emissions it has been possible to examine how strongly dependent the modelled hourly PM_{10} GLCs are on the mixing height, temperature and wind speed. Results may be summarized as follows:

Modelled hourly concentrations are elevated at low wind speeds: Hourly modelled PM_{10} GLCs are above 100 µg/m^3 when the wind speed is below 1 m/s. The highest peaks occur at around 0.7 m/s.

Elevated model concentrations occur in shallow layers: PM_{10} GLCs obtained are above 100 µg/m^3 when the mixing height is 65 m or less. This is consistent with measurements of PM_{10} vertical profiles over Nelson (Trompetter et al. 2013; Grange et al. 2013).

Comparison of Modelled and Observed Peaks of PM_{10}: Some peaks in hourly PM_{10} appear to be overstated, occurring when the modelled mixing height is down to 15 m, indicating that some further investigation of meteorological model performance is needed. Also, some observed peaks of PM_{10} do not appear in the model; the model wind speed is low enough, but the modelled mixing height is up to 100 m. The observed temperature gradient shows a rise of 2 to 3 Kelvins over 10 m depth, indicating that there is a strong stratification and confinement of pollution in a shallow layer not captured by the model.

2.2 Relationship to CALPUFF modelling

CRC is carrying out similar modelling in-house, for Christchurch and Rangiora, using MM5, CALMET and CALPUFF. Hence it is useful to relate the findings of the above section to CRC's modelling.

The use of the mesoscale model MM5 and the assimilation of meteorological information into CALMET for that case are not dissimilar to the process followed in TAPM. It is important to obtain a good representation of the wind speed under near-calm conditions, which would require assimilating wind data from available monitoring sites into CALMET and MM5. As CALPUFF is not a grid-point model, computational aspects of vertical resolution discussed above are less important. However, CALPUFF still requires a good representation of (the lack of) turbulent diffusion given by the meteorological model to be able to reasonably simulate the spatial confinement of the modelled pollution puffs.

In the following sections, the discussion mainly focuses on emissions. Their findings are to a large extent independent of the dispersion model used, so are equally appropriate to CALPUFF and TAPM.

3.0 INCORPORATION OF MOTOR VEHICLE EMISSIONS

CRC requires model estimates of PM_{10} impacts from motor vehicle sources in Christchurch, as there is interest in these from stakeholders within CRC. TAPM is not an ideal model for simulating near-field impacts from line sources such as roads, such as impacts in close proximity to a roadside where concentrations are typically highest. However, TAPM is able to do model line sources, and an indication of the impacts over a wider area of motor vehicles is given here. Data on the traffic fleet from CRC's Christchurch Transport Model the year 2013 were supplied to Golder for 5,492 arterial road links in Christchurch, along with the hourly emission of PM_{10} from motor vehicles on that link. TAPM can ingest this data straightforwardly, but it does not model each of the 5,492 links individually. Rather, the links are assigned to pollution-grid cells, which are 250 m by 250 m. Hence there is some spatial smoothing of the emissions and the resulting modelled ambient GLCs – the model cannot therefore resolve pollution 'hot-spots' at the roadside.

Figure 3 shows the spatial pattern of motor vehicle emissions for a typical day, as used by the model. Peak emissions occur in the grid cells containing the main arterial roads, with maximum values at their intersections. Note that the figure gives an indication only of the spatial resolution of vehicle emissions, with localized values plotted halfway along the respective road link. Note that TAPM spreads the emission along the road link, so may partition it between neighbouring grid cells.

The total PM_{10} emission from motor vehicles in Christchurch is 527 kg/day (data supplied by CRC). The hourly proportions vary between road links, with an example shown in Figure 4. This shows morning and evening commuting traffic peaks, and a mid-afternoon peak at the end of the school day.

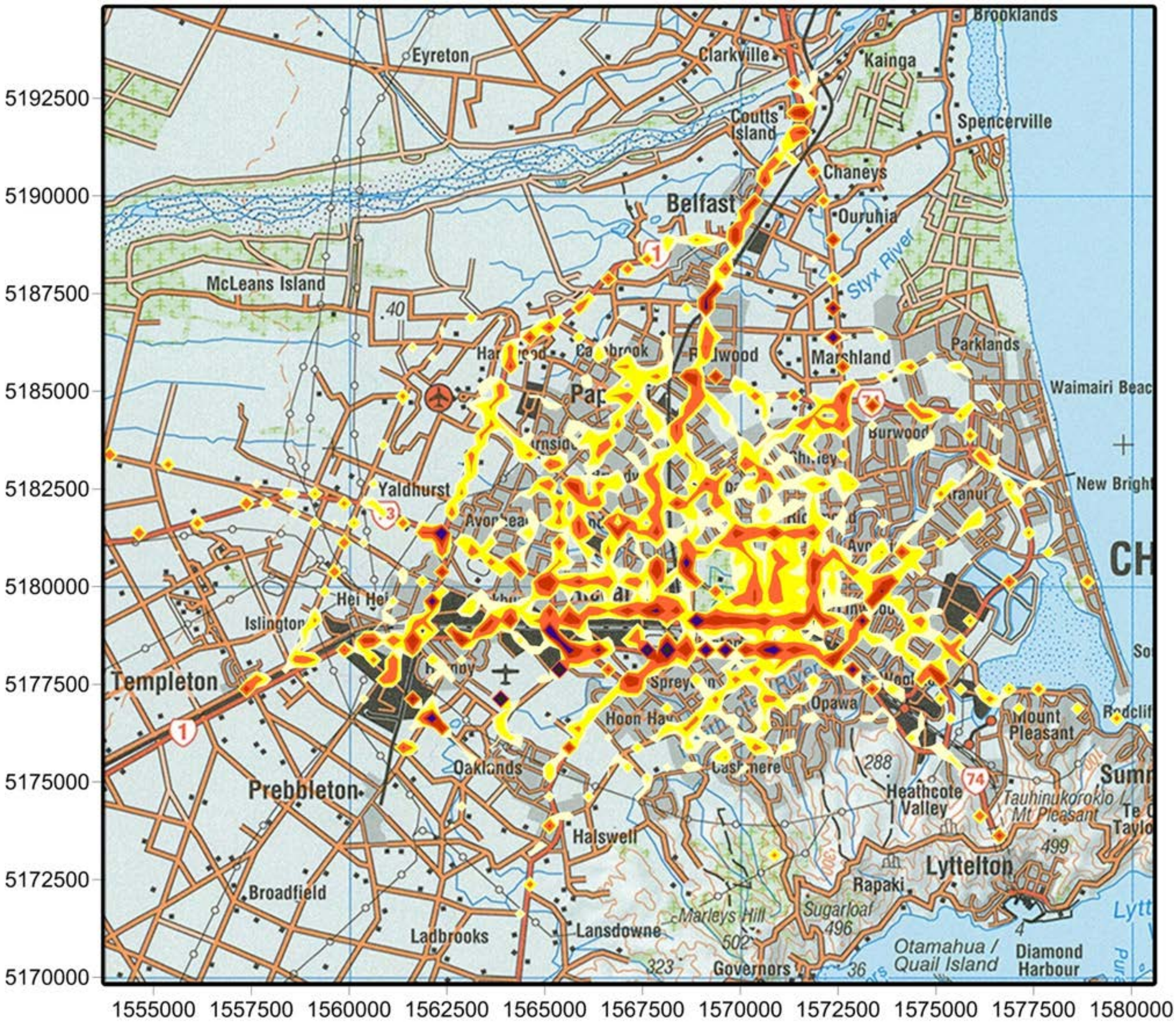

Figure 3: Daily motor vehicle emissions. The relative emission rate is on an exponential colour scale, with magnitude doubling through each contour interval.

The airshed model for vehicle emissions was run for four winter months of 2012, May to August inclusive.

Figure 5 shows the modelled peak PM_{10} impact from motor vehicles. This is a composite of the maximum 24-hour average PM_{10} over the four-month period, at each location. As expected, the spatial pattern follows the grid cells containing the main arterial roads, particularly Moorhouse Avenue, Brougham Street, with local maximum GLCs at their intersections with Lincoln Road, and at the intersection of the Christchurch Southern Motorway with Lincoln Road and Wrights Road. The peak GLC is 19 µg/m^3 at both of these intersection points. A few points are worth noting, as follows:

1) The peak GLCs at the locations mentioned above are at junctions where one of the intersecting roads is elevated. The road links have been modelled at the same height, which may overstate impacts.

2) Discharges from arterial road links have been modelled using emissions data supplied by CRC. It has therefore assumed that motor vehicle emissions from the other streets are negligible. This is reasonable if the main contribution to emissions is from congested traffic on the arterial roads.

3) The emissions and GLCs are assigned to points on a 250 m x 250 m grid, such that a spatial smoothing-out of impacts by the model is expected. The true peak PM_{10} impacts would be expected to be higher.

The run-length average PM_{10} is shown in Figure 6. This shows a similar spatial pattern to the modelled peak impacts, with the maximum GLCs in the same locations as the 24-hour peaks, but with GLCs 6 µg/m^3 as compared to 19 µg/m^3.

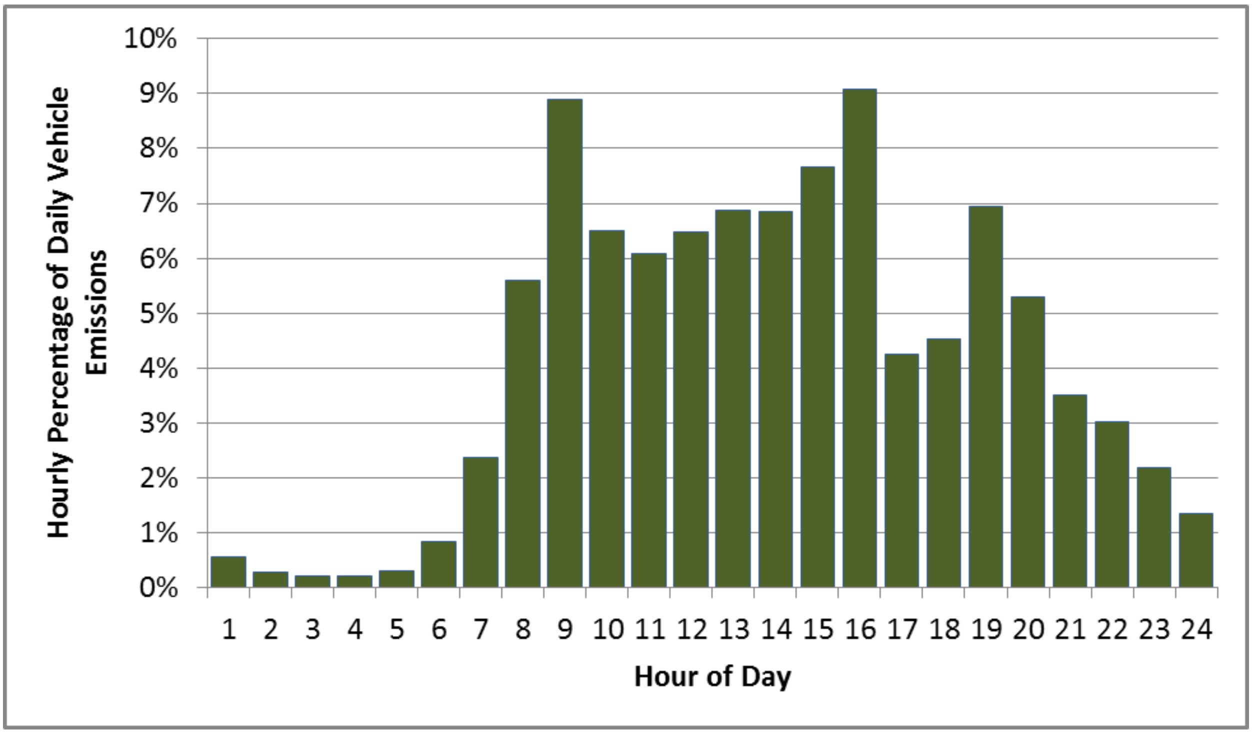

Figure 4: Percentage of daily-total motor vehicle emissions at each hour of the day for an example road link.

The use of TAPM to model impacts of motor vehicles on air quality gives an indication of spatial patterns and locations of hot spots at some intersections. For a more realistic, detailed examination of the magnitudes of impacts, an alternative model to TAPM should be selected. This is discussed further in Section 5.3.

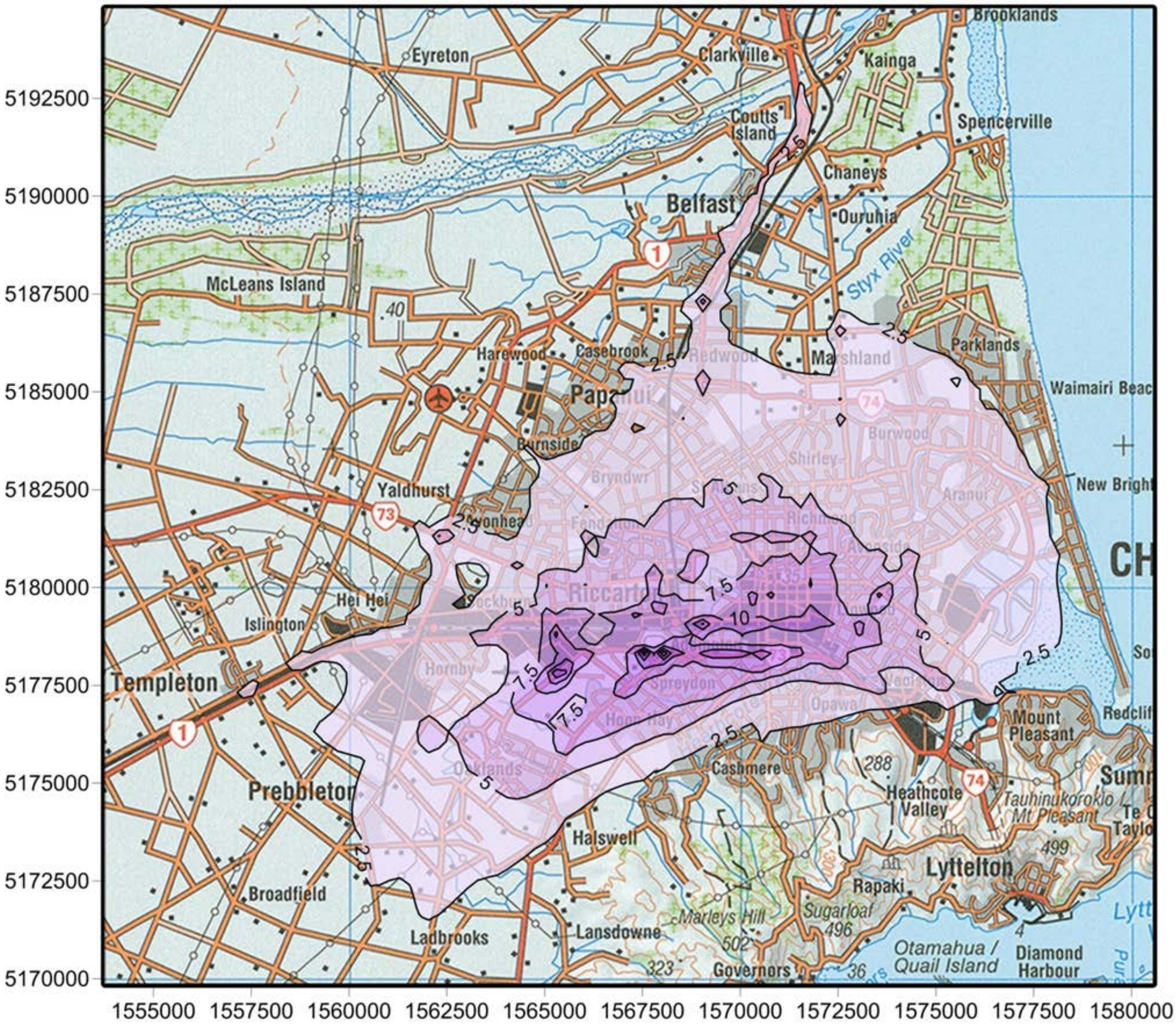

Figure 5: Composite peak 24-hour average PM_{10} over Christchurch due to motor vehicles only. GLC in units of micrograms per cubic metre (μg/m^3). Contour interval 2.5 μg/m^3, starting at 2.5 μg/m^3; maximum GLC is 19 μg/m^3.

Figure 6: Modelled average PM_{10} (in µg/m^3) over Christchurch, four-month mean over May – August 2012. Motor vehicles only. Contour interval 0.5 µg/m^3, starting at 1.0 µg/m^3; maximum GLC is 6 µg/m^3.

4.0 INCORPORATION OF UNACCOUNTED-FOR EMISSIONS

4.1 Introduction and Method

This section examines the shortfall in late evening and early morning modelled PM_{10} GLCs, makes an estimate of the unaccounted-for component, and examines the modelled PM_{10} that results when this component is incorporated.

The section aims to improve the model's match to observed GLCs, based on the following logical sequence:

1) Hourly trends in PM_{10} must be modelled reasonably well to obtain reasonable 24-hour average estimates. Obtaining 24-hour estimates that match observations, but without consideration of hourly averages may be purely coincidental.

2) Although an hour-by-hour, day-by-day match with observations should not be expected from a dispersion model, peak modelled PM_{10} GLCs should occur under the same types of meteorological conditions as peak observed GLCs.

3) The model should be able to reproduce the PM_{10} at each hour, averaged over all days, before its performance in extreme cases is examined.

In light of these considerations, the modelled average PM_{10} at each hour of the day has been compared with observations from the Coles Place, St Albans monitoring site. The resulting GLCs include 'best-fit' contributions from unaccounted-for emissions[3]. The procedure to estimate of the unaccounted-for component of PM_{10} emissions is as follows:

a) Assume a background PM_{10} of 14 $\mu g/m^3$. This is the average of all observed GLCs at 3 pm, which is the lower than the average at all other hours[4].

b) Add the contributions from industry, motor vehicles and domestic heating, as already specified. This accounts for domestic heating emissions as inventoried, which cease in the late evening. The total mass of PM_{10} emitted by domestic heating is 2,377 kg/day. This represents a specified 76 g/day per wood burner, of which there are 31,286 in total.

c) Add a contribution due to constant emissions between 11 pm and 1 am each night, with the spatial pattern matching that of domestic heating. Calculate the magnitude of emissions which minimizes the model error. This adds 170 kg/h to the total PM_{10} emissions, or 339 kg for the two-hour period.

d) Add a further contribution due to constant emissions between 1 am and 3 am each night, with the spatial pattern matching that of domestic heating. Calculate the magnitude of emissions which minimizes the model error. This adds 72 kg/h to the total PM_{10} emissions, or 145 kg for the two-hour period.

e) Add a final contribution due to constant emissions between 3 am and 6 am each morning, with the spatial pattern matching that of domestic heating. Calculate the magnitude of emissions which minimizes the model error. This adds 33 kg/h to the total PM_{10} emissions, or 100 kg for the three-hour period.

The estimated total mass of PM_{10} from the unaccounted-for emissions is 584 kg, or 25 % of the inventoried emission total of 2,377 kg from domestic heating.

4.2 Results

The modelling described in this section is based on the wintertime model run for May-August 2012, using domestic heating and industrial emissions data as supplied previously by CRC, and motor vehicle emissions as supplied for this stage of the work. The runs also incorporate changes to the meteorological model described in Section 2.1, and compare results with and without the unaccounted-for emissions.

The mean modelled and observed PM_{10} GLCs at Coles Place at each hour are shown in Figure 7 for the accounted-for emissions (domestic heating, industry vehicles and background). This shows the shortfall after hour 22 (9 pm – 10 pm) and before hour 7 (6 am – 7 am). Also there are elevated mean concentratoins between 8 am and 11 am which do not appear in the model results. The model also appears to overstate the early-evening GLCs.

[3] Modelled and observed averages are calculated for each hour of the day, so that there are 24 modelled and 24 observed values. The model error may be taken to be the root-mean-square of the differences between modelled and observed at each hour. The emission magnitudes are chosen to minimize the difference.

[4] This GLC may be considered a reasonable 'background' PM_{10} GLC due to natural sources, and has been used in the modelling. However, there may be a component due to motor vehicle emissions in the observed concentrations at 3pm.

The mean GLCs, which include the component of emissions between 11 pm and 6 am are shown in Figure 8. This component has been assumed to be a component due to smouldering emissions from wood burners, and follows the same spatial pattern as the domestic heating inventory. As the magnitude of this component has been chosen to reduce the differences between the two sets of columns, the modelled GLCs are improved.

The combination of all of the PM_{10} components leads to the peak PM_{10} GLC over the region shown in Figure 9. Figure 9 is the composite 2nd-highest 24-hour-average PM_{10} GLC. The peak GLC ranges from 14 µg/m^3 outside the urban area, to a localized maximum of 88 µg/m^3, over Hoon Hay and Spreydon. The modelled GLC at Coles Place in St Albans is 61 µg/m^3. This is still somewhat short of the observed GLC of 80 µg/m^3. However, previous modelling indicated a peak of 30 µg/m^3 to 35 µg/m^3 in St Albans, and the difference between peak modelled and monitored GLCs has been significantly reduced with the inclusion of an overnight PM_{10} component.

Figure 10 shows run-length mean GLC for the combination of all PM_{10} components. The spatial pattern is similar to that of the peak 24-hour average GLC. As this includes the motor vehicle component, the run-length peaks due to motor vehicles (of 6 µg/m^3) are visible in the contours of total PM_{10}. This is not the case for the peak 24-hour average (Figure 9), as the peak in total PM_{10} does not occur on the same day as the peak of 19 µg/m^3 from motor vehicles. On the day of peak total PM_{10}, motor vehicles contribute around 5 µg/m^3 of the approximately 24 µg/m^3 in total at the traffic hot spots.

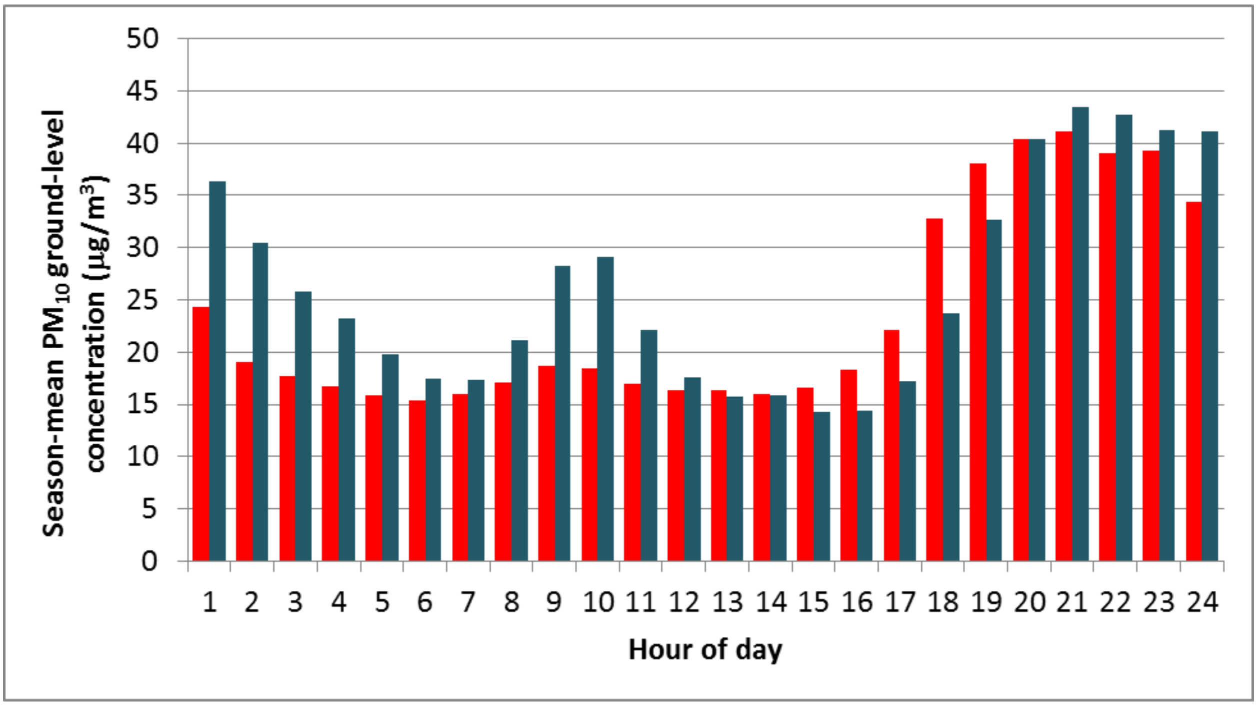

Figure 7: May-August 2012 average PM_{10} at each hour of the day. Contributions from inventoried domestic heating, industry, motor vehicles and background PM_{10}. Observations (blue columns) and TAPM results (red columns) at Coles Place.

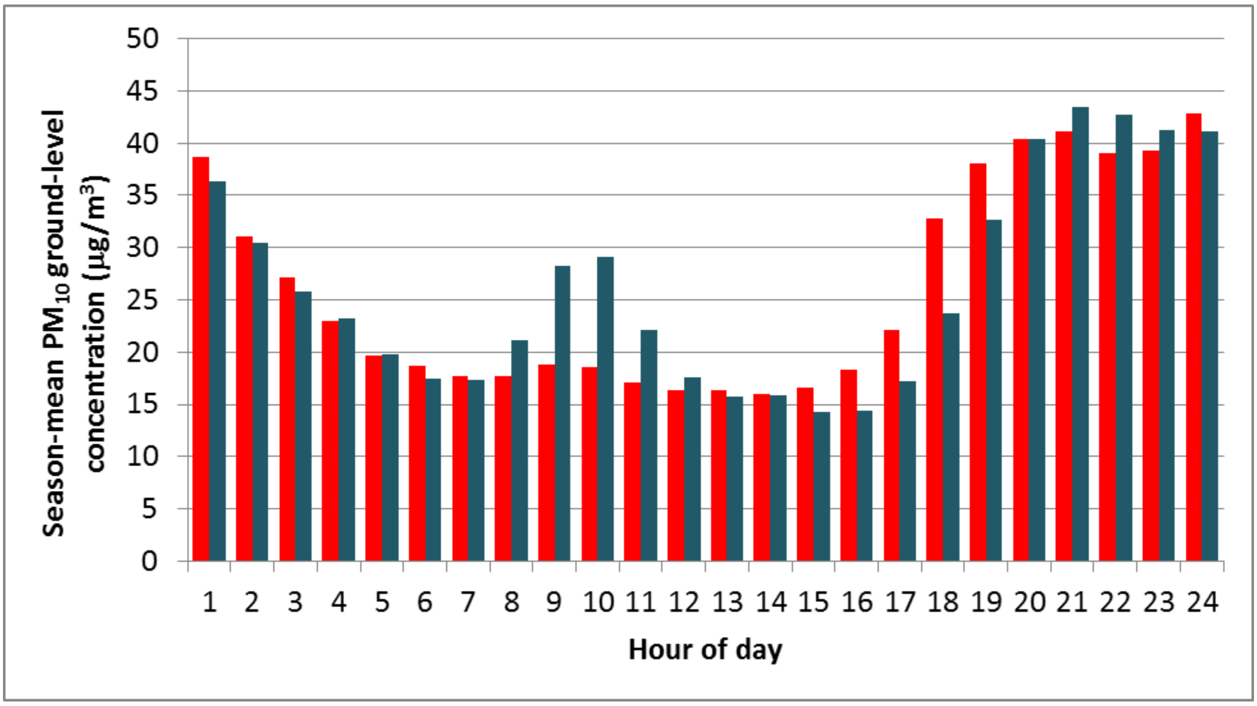

Figure 8: As Figure 7, with calculated overnight PM_{10} contributions added.

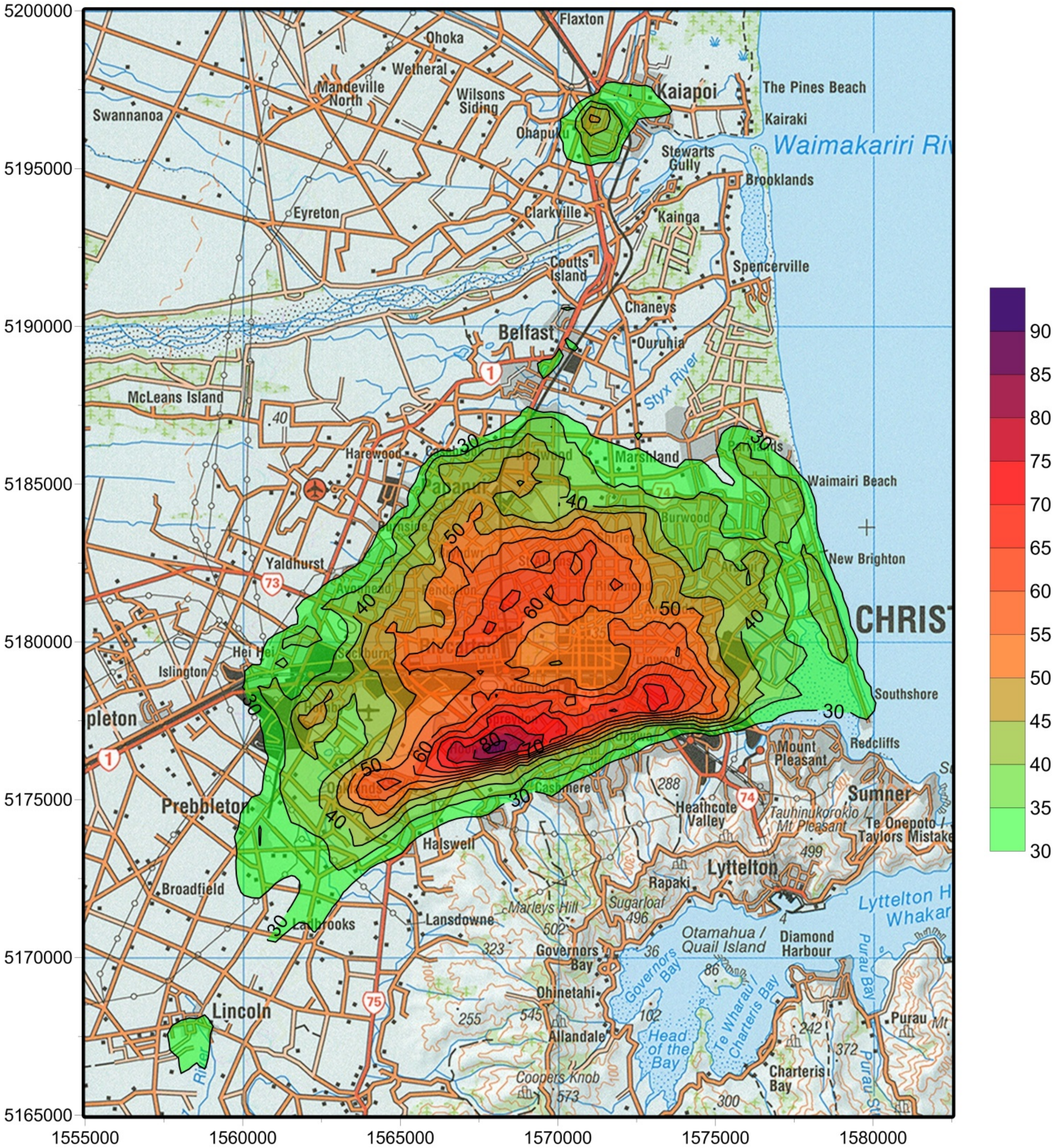

Figure 9: Modelled peak 24-hour average PM_{10} (in µg/m^3) over Christchurch (2nd highest between May and August 2012). Contributions from inventory and overnight domestic heating, motor vehicles, industry and background PM_{10}.

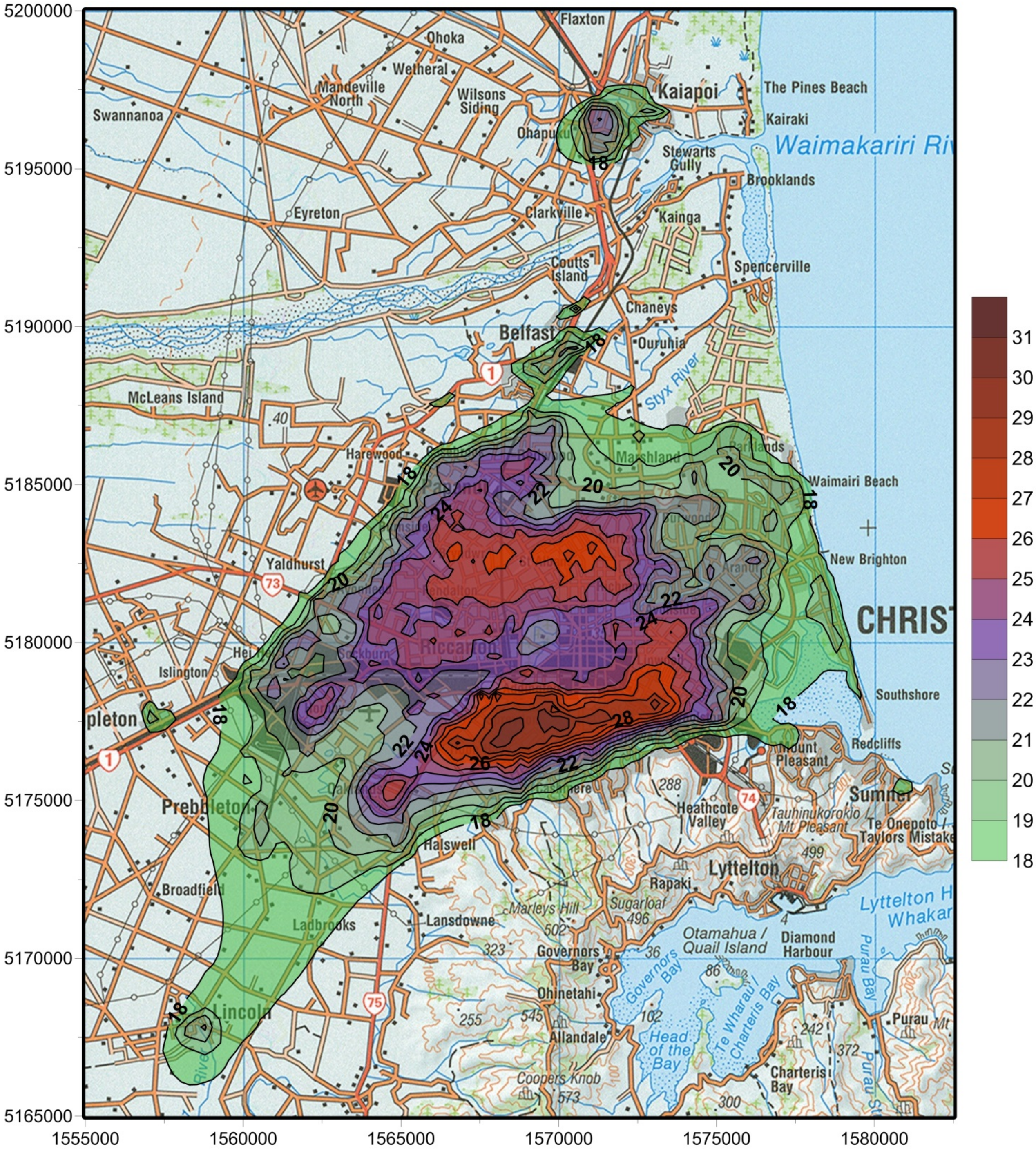

Figure 10: Modelled average PM_{10} (in µg/m^3) over Christchurch, four-month mean from May to August 2012. Contributions from inventory and overnight domestic heating, motor vehicles, industry and background PM_{10}.

5.0 DISCUSSION – SUITABILITY OF TAPM FOR DIFFERENT SOURCE TYPES

5.1 Domestic Heating

TAPM has several modules for pollution dispersion, which allow discharges from several source types to be modelled. These include point, line and area sources, and emissions distributed over a regular grid of cells. Air discharges from domestic heating are most suitably modelled by emissions over a regular grid. This reflects the spatial distribution of sources well, and modelled ambient PM_{10} GLCs on the grid provide a good representation of the spatially-varying effects.

5.2 Industry

In this work, industry has been modelled as a set of discrete point sources. TAPM simulates the emissions as a release of idealized particles from each source. Although the subsequent dispersion can potentially be resolved in fine spatial detail, transporting a large number of particles through the model domain is computationally expensive. To alleviate this, once the particles are 15 minutes old, they are assigned to a grid cell and transported using the grid model. At this point, it is assumed that the dispersion can be resolved well enough on the 250 m grid. This is computationally cheaper, as the number of grid cells is typically several orders of magnitude smaller than the number of model particles that would remain.

Output GLCs from TAPM are assigned to the regular grid. This includes the GLCs from discharges which are less than 15 minutes old, meaning that the near-field dispersion pattern that would be seen from the model particle positions is not available to the model user. The user only has access to 250 m by 250 m grid cell averages. As the actual spatial patterns of GLCs are on scales smaller than any reasonably available in a grid-point model such as TAPM, the modelled GLCs near the source will be sensitive to the grid spacing. This would not be considered acceptable for an industrial modelling application, and near-source dispersion would be simulated using a more suitable model, such as CALPUFF or AERMOD. In these, the receptor points may be located anywhere, so may be clustered around a source to any level of spatial detail. GLCs are calculated in these models at each receptor point, are not averaged over a cell volume, and so are not sensitive to the distance between receptors. Moreover, these models are computationally cheaper, as they represent pollutant releases by discrete puffs or plumes, respectively, rather than clouds of particles.

In summary, for resource consent applications by individual industries, CALPUFF or AERMOD would be more suitable, and would require detailed information on stacks, buildings and emissions. For examination of policy options, TAPM's representation of industry is sufficient, particularly as those options would be focused on domestic heating.

5.3 Motor Vehicles

Motor vehicle impacts have been input to TAPM as a set of discrete line sources, representing the arterial road links in Christchurch. However, TAPM does not simulate the initial release (the first 15 minutes) as model particles, but assigns the line source emission to a grid cell. Hence there is an immediate averaging onto the 250 m by 250 m grid, no matter where (within each grid) the road links are located. Just as for industry, it is not considered acceptable to use TAPM to model the near-field effects of motor vehicle sources. It cannot simulate levels of pollution that would be found close to the highway. Unlike the algorithms for dispersion from point sources, TAPM does not realistically simulate the initial stages of dispersion from motor vehicles.

There are specialist models available for the simulation of vehicle emissions and dispersion over entire urban areas. These include ADMS-Urban, ADMS-Roads and CAR-FMI (from the Finnish Meteorological Institute). For smaller sets of road links, CALINE4 or CAL3QHCR are often used (CAL3QHCR is based on CALINE3, and includes impacts from queued traffic at controlled intersections). [AUSROADS is based on the CALINE series of models, but has not been reviewed or updated for many years and runs on the obsolete Windows XP platform[5]].

The New Zealand Transport Agency (NZTA) provides guidance on road transport assessments[6]. It also provides a 'Tier 2' screening tool for roadside effects, and recommends more advanced modelling at locations where given significance criteria are exceeded.

A final choice on how to model motor vehicle emissions would depend on the level of detail required by CRC. Potential options are as follows:

a) A 'Tier 2' screening for motor vehicle impacts at locations of interest (defined by peaks in the TAPM results presented above), could be applied following NZTA guidance, incorporating TAPM's outputs for domestic heating as the baseline.

b) Use of CALINE4 or CAL3QHCR to explicitly model key road links at those locations of interest, combining spatially varying results for vehicle PM_{10} with spatially varying results for PM_{10} from domestic heating.

c) Use of a more advanced model such as ADMS-Urban, ADMS-Roads or CAR-FMI for the whole urban area, combined with modelled PM_{10} from domestic heating. Golder staff have experience in the use of all of these models. [It may be worth considering the particle dispersion model, GRAL. This is available from GRAZ University, Austria, although it is likely to be exceedingly computationally expensive for long-term studies of a large number of sources].

These options may or may not include industrial impacts and natural PM_{10}.

Note that all of the motor vehicle dispersion models mentioned here are Gaussian-plume line-source models, and would be based on spatially-uniform meteorological inputs. Care would be needed if the results from these models were to be combined with outputs from TAPM or CALPUFF, which are based on spatially-varying meteorology.

It is also worth noting that there is some room for improvement in the motor vehicle hourly emissions profile used in this study, as the one used in the modelling in this project was an estimate based on land-use changes after the Christchurch earthquakes. It may not account accurately for patterns of traffic congestion, but would need to be improved if the use of these more advanced dispersion models were being considered.

6.0 ISSUES FOR FURTHER INVESTIGATION

This section identifies issues for further investigation, which should lead to further improvement of the airshed modelling for Christchurch, based on the findings of Sections 2.0, 3.0 and 4.0 above. Some of the tasks involve the airshed model directly, and are focused on the meteorology of calm, winter nights. Others do not involve the model directly, but are concerned with improvements in the description of sources of PM_{10} in Christchurch, which should be made through independent investigations. However, the model would be used to guide such work inasmuch as it can be used to identify gaps in the emissions inputs and provide indications as to how they could be filled.

The issues are discussed below in the order in which they should be addressed, from those which would lead to a general improvement in the modelling of PM_{10}, to refinements aimed at specifically worst-case conditions and peak 24-hour PM_{10} GLCs.

[5] Personal communication by email 21/22 May 2015, between Neil Gimson of Golder and Paul Torre, Principal Air Quality Expert at EPA Victoria.

[6] See https://air.nzta.govt.nz/sites/default/files/Air_quality_assessment_guide_v2.0_Draft.pdf. This draft was released in December 2014.

1) **Meteorology of the stable boundary layer:**

   a. *Modelling* – Some peaks in observed PM_{10} under calm, stable conditions are missed by the model. The meteorological component of TAPM produces sufficiently low wind speeds, but the model does not completely capture the stable stratification of the nocturnal boundary layer and its consequent confinement of PM_{10} in a shallow sub-layer.

   b. *Data Analysis* – There also remains the challenge of determining how the occurrence of high or low 24-hour PM_{10} depends on measured meteorology. Studies on this have been carried out over the years under CRC's auspices, but this problem has not yet been fully solved. Conditions *necessary* for high-PM_{10} events have been found, but they are not *sufficient* to always predict a high-PM_{10} event. That is, PM_{10} can remain low when the known meteorological parameters indicate otherwise. This may be complicated by variability in emissions due to human behaviour.

2) **Refinement of emissions inputs:**

   a. *Early evening PM_{10}* – The model overstates on average the early evening PM_{10} GLCs (seen in Figure 7 and Figure 8). This may be related to the assumed hourly profile of PM_{10} emissions from home heating, and the peak hourly emissions could possibly arise an hour or two later in the evening. Some small changes to the hourly home heating profile may lead to an improvement in early-evening PM_{10} predictions, which may be justified on the grounds of the modelled profiles being based on measurements from a small number of households.

   b. *PM_{10} peaks between 7 am and 11 am* **–** There are observed elevated PM_{10} levels in mid-morning, which are discernible in Figure 7 and Figure 8, but which the model has missed. Some investigation is required to determine the source of this PM_{10} and incorporate it adequately into the model. There are no home heating emissions in the input data between these times, but there are households that use their burners in the morning. It is unlikely, given the location of the monitoring site against whose data the model results are being compared, that this missing component is from motor vehicles. This component is not accounted for in the model, and a brief examination of observed PM_{10} time series indicates that it may add several µg/m^3 to the 24-hour average PM_{10} on worst-case days.

   c. *Late evening/early morning PM_{10}* – An overnight source of PM_{10} has been postulated which aims to account for elevated observed GLCs in the hours after home heating emissions, as quantified in the inventory, have ceased. However, there is as yet no verification of this PM_{10} component. Further investigation is required to independently determine the nature of this overnight source, and estimate its PM_{10} emissions. This project has made improvements to the meteorological component of the model, and, although there may still room for improvement in the meteorology, it is considered unlikely that the observed overnight PM_{10} remains in the urban area having been emitted several hours previously. If there turns out to be a significant component of PM_{10} emission after 11 pm, this has consequences for emissions inventory development and prediction of the impacts of emissions changes on ambient PM_{10}.

3) **Case studies of peak PM_{10}:**

   This work has aimed to improve the previous dispersion modelling of PM_{10} in Christchurch by focusing on the hourly trends in PM_{10}, before calculating 24-hour averages. Having improved the seasonal-mean GLC at each hour, there is still a shortfall in the peak 24-hour GLCs. At Coles Place, the modelled peak 24-hour-average is around 20 µg/m^3 less than observed, although the modelled PM_{10} magnitude matches observations well at the 5th-highest GLC and below. Having provided a reasonable estimate of average conditions, it is appropriate to refine the modelling and study the worst-case conditions, investigating the meteorological conditions and emissions patterns which lead to the highest observed and modelled 24-hour PM_{10} GLCs. This is related to item 1(b), but incorporates aspects of model performance.

Regarding peak 24-hour PM_{10}, the worst-case observed GLCs seem to occur when high hourly GLCs occur at both the beginning and end of the midnight-to-midnight period and there are elevated GLCs mid-morning. That is, high hourly PM_{10} GLCs occur on two consecutive nights. This appears to not occur as frequently in the model as in reality. Taking the 24-hour period from 3 pm to 3 pm, to include a single night, increases the 2nd highest modelled PM_{10} at Coles Place from 61 µg/m^3 to 73 µg/m^3, and decreases the observed PM_{10} from 81 µg/m^3 to 76 µg/m^3. This implies that the improvements in the meteorological model are still required to produce pollution events sufficiently frequently so that elevated levels on consecutive nights can contribute to a single 24-hour event. Also, improvements are needed in the emissions to account for elevated PM_{10} levels after midnight and during the mid-morning period.

7.0 SUMMARY AND CONCLUSION

The current stage of the airshed modelling of Christchurch has improved the meteorological component of the model, incorporated motor vehicle emissions, and provided an estimate of the shortfall in PM_{10} emissions which would be needed to improve the modelled ambient PM_{10} GLCs. This required an increase in emissions of 25 %, with the additional emissions occurring between 11 pm and 6 am on each night. The modelled PM_{10} GLCs are now much closer to those observed, compared with the previous modelling (which only included early-evening PM_{10} emissions from home heating). However, the presence of such emissions and their magnitude and time-dependences needs to be validated independently.

There is further room for improvement in the modelling, with recommendations given above relating to the meteorological conditions on winter nights, further potentially missing mid-morning PM_{10} emissions, and the specific conditions of worst-case pollution nights.

Discussion has been provided on the use of TAPM and a number of alternatives for refined modelling of pollution dispersion from industry and motor vehicles. Alternative models would be employed for specific applications which focus on these sources, but, relative to home heating impacts, they are a less important component of the PM_{10} loading in Christchurch city, and it is considered that TAPM gives a reasonable representation of industry and motor vehicles for current purposes.

The projects that Golder has carried out for CRC recently have approached the airshed modelling in stages, beginning with the incorporation of the major sources and addressing their shortfalls, examining seasonal-mean hourly PM_{10} GLCs, before considering 24-hour GLCs in general and PM_{10} GLCs under worst-case conditions.

The current work aims to improve the airshed model performance through resolution of the defined tasks. The progress made by the current project should result in robust estimates of PM_{10} over Christchurch city that can be used in scenario development and policy making by CRC.

8.0 REFERENCES

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APPENDIX A

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