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SPATIAL PATTERNS OF 24-HOUR-AVERAGE GROUND-LEVEL CONCENTRATION OF PM_{10} IN THE CHRISTCHURCH CLEAN AIR ZONES

Dear Tim,

Canterbury Regional Council (CRC) requires airshed modelling of emissions from domestic heating and industry to determine which parts of the Christchurch Clean Air Zones are most exposed to ambient PM_{10} (particles of aerodynamic diameter less than 10 microns). The airshed modelling will be used to assist CRC's management of air quality in Christchurch. Golder Associates (NZ) Limited (Golder) has carried out airshed modelling using The Air Pollution Model (TAPM; Hurley et al. 2005). This letter[1] provides the main deliverables for this project: (i) a map of the modelled spatial distribution of peak exposure to PM_{10}, given emissions inputs supplied to Golder by CRC; and (ii) a set of recommendations for further investigation and improvement of model predictions. The letter also provides a brief summary of results – a detailed report can be provided if required but is beyond the scope of the current project.

Two domestic heating scenarios have been modelled; one with present-day emissions, and a second with reduced emissions due to compliance of all burners with CRC's wood burner standards.

TAPM Configuration – Meteorological Model

It is important to produce a sufficiently realistic meteorological model to form the basis for a simulation of the dispersion of discharged pollutants. This is a challenge for any model under calm, stable, winter conditions. The aim is to reproduce conditions of sufficiently low wind speed, low temperature and strong stability at night, under which air quality is poorest in Christchurch.

The meteorological component of TAPM was run for the winter of 2012[2] over a set of nested grids, the finest having horizontal resolution of 1 km, covering Christchurch City including Clean Air Zones and its immediate surroundings (an area 35 km by 35 km). Coarser grids 'telescope' outwards from this central area, covering the South Island and much of the North Island at 30 km horizontal resolution. In the vertical, the default set of 25 levels was specified, from 10 m above the ground, to 25 m, 50 m, 100 m, with increasing spacing to the highest (level 25) at 8,000 m above ground level.

Although TAPM may be considered a 'black box', in that there are few parameters that can be changed once the computational domain and time period are set up, there are still several options available. At least a

[1] This letter is subject to the attached report limitations.

[2] The choice of year was made in consultation with CRC.

dozen options were tested to achieve the best model performance in matching wind and temperature in central Christchurch during the winter of 2012. The results presented in this letter are based on meteorological model outputs which provided the best results and include using the following options:

1) Surface wind data were assimilated into the model, from five monitoring sites in Christchurch – Coles Place, Woolston, New Brighton Pier, Kyle Street and Christchurch Airport. A radius of influence of 10 km was used, so that much of central Christchurch would be influenced by the monitored meteorological data. This process enabled TAPM to produce surface wind speeds of less than 1.0 m/s, which are needed to more realistically simulate observed hour-by-hour peaks of PM_{10} in Christchurch.

2) Non-default surface characteristics were specified in the model. These included decreases in the sea-surface temperature, the deep-soil temperature and the soil moisture. Parameters are set once to initialize the model. The changes served to decrease the overnight surface air temperature throughout the model run to be more in line with observations at the Coles Place monitoring site (noting that a drier surface experiences a wider range of temperatures between day and night).

In addition, the number of model levels in the vertical can be increased, or the land use changed to alternative urban or rural types. These options were tested, but were not found to improve the meteorological modelling results.

TAPM Configuration – Airshed Model

A dispersion model grid was specified, with horizontal resolution 500 m, covering the area of the 35 km by 35 km meteorological grid, and the airshed model component of TAPM was run for the winter of 2012 (May to August inclusive) based on the hourly meteorological outputs produced by TAPM.

Domestic heating emissions were calculated from information on wood burner numbers. The number of wood burners in use in each mesh block in Christchurch – taken from 2013 census data – was interpolated onto a regular grid of cells, each 250 m by 250 m, covering the area of the 1 km meteorological grid. These are shown on Figure 1. The number of homes containing wood burners, per 250 m by 250 m grid cell, ranged from zero to 37. These gridded data were supplied by CRC.

A total emission of 76 grams of PM_{10} per burner per day was assumed for the first emissions scenario. This was calculated by CRC as a weighted average of compliant burner, non-compliant burner and pellet burner emissions. For simplicity, the weighted average per-burner emission rate was assumed to be constant for the whole of the Christchurch. The total 76 grams per burner per day was divided into an hourly pattern (also defined by CRC), with emissions largely confined to the evening, peaking between 5 pm and 6 pm, and decreasing to nearly zero after midnight. The hourly pattern is shown in Figure 2. For the second emissions scenario, an emission of 48 grams per burner per day was used. This value assumes that all wood burners are compliant with CRC's wood burner standards.

Note that it was originally intended to specify a 250 m dispersion model grid, and to run the airshed model concurrently with the meteorology (so that the airshed model uses the meteorological fields at the meteorological model's time step). This means that the meteorological component is run every time the dispersion model is run, and was not possible within the project's time frame. Also, the model runs take longer with the larger number of grid points. However, experience on other projects, and tests with short modelling periods, has shown that the results do not change significantly, and that the 500 m grid was sufficient for the present purposes (the emissions and dispersion model grids do not have to match in TAPM).

Emissions information from key industries was supplied by CRC, based on data from the CRC 2009 emission inventory (CRC 2011). For each source, the location, stack height and PM_{10} emission rate was given. Internal stack diameter, exit velocity and exit temperature are also required by TAPM; reasonable values of these were chosen in the absence of available data from the individual industries. The 46 industrial sources, whose locations and emission rates were supplied by CRC, were incorporated into the model. These are plotted on Figure 1 as green diamonds.

The total emission of PM_{10} input to TAPM was 2.4 tonnes per day from domestic fires, and 0.5 tonnes per day from industrial sources.

It was originally intended to run the industrial component as a set of point sources, which makes use of the stack characteristics such as height, exit velocity and exit temperature. However, for 46 sources this mode is computationally demanding and has only a small effect on results dominated by domestic heating sources. Therefore, the sources were incorporated onto the 250 m emissions grid. In this mode, the stack characteristics are not needed.

Spatial Pattern of Modelled PM_{10}

The peak 24-hour average modelled PM_{10} concentrations arising from the airshed model as configured above are shown in Figure 3. The figure shows the highest modelled PM_{10} concentration at each grid location over the winter of 2012. As the maximum PM_{10} need not have occurred on the same day at each location, the figure is a composite of worst-case concentrations. However, as the PM_{10} magnitudes shown occur under calm conditions, it is likely that the 24-hour average PM_{10} on the nights of worst air quality would resemble Figure 3. Not surprisingly, the pattern of ambient PM_{10} concentration resembles the pattern of home heating emissions shown in Figure 1, with maximum concentrations north of the city centre (30 µg/m^3 to 35 µg/m^3) and south of the city centre (35 µg/m^3 to 40 µg/m^3) and a decrease to around 15 µg/m^3 between these regions. The concentration in the centre is not zero, due to drift of PM_{10} in from suburbs where wood burners are prevalent.

This spatial pattern of PM_{10} has been observed during mobile monitoring campaigns on winter nights in Christchurch (Olivares et al. 2010). An influence of the meteorology on this pattern can be seen; inspection of the model results hour by hour shows that drainage flows from the northwest is blocked by the Port Hills and is diverted to the east or west. This leads to some stagnation of the wind in the suburbs south of city centre, which may account for the higher modelled PM_{10} concentrations there (compared to the peak concentrations in the northern suburbs). Other peaks in PM_{10} away from the central suburbs occur in New Brighton and Kaiapoi.

This spatial pattern shown in Figure 3 includes the impact of industrial sources. The model has also been run without industrial sources. The resulting peak PM_{10} concentrations are slightly lower, but by no more than 5 µg/m^3, indicating that impacts of industry on the urban area as a whole are not a large component of the total PM_{10} loading.

Under-prediction of Observed PM_{10} – missing sources

The peak modelled PM_{10} at St Albans is between 30 µg/m^3 and 35 µg/m^3. The highest (respectively 2nd-, 3rd-, 4th-, 5th-highest) 24-hour PM_{10} concentrations observed at Coles Place in 2012 were 92 µg/m^3 (respectively 81 µg/m^3, 75 µg/m^3, 74 µg/m^3, 61 µg/m^3). In other words, observed peak PM_{10} levels are significantly under-predicted by the model. This is to be expected to some extent, as some sources of air pollution have not been included in the airshed modelling. These include vehicles and natural sources of PM_{10}. However, according to the 2009 emissions inventory, vehicle emissions account for 14 % of total weekday emissions of PM_{10}, compared to 70 % for home heating and the remaining 16 % being industrial and commercial activities (CRC 2011). The natural component is around 7 µg/m^3 only. Adding these components to the model results for domestic heating and industry would not bring the modelled worst-case total into the range of the observed PM_{10} concentrations.

There are also components of the hour-by-hour time series of measured PM_{10} concentration on worst-case days, such as a persistence of elevated PM_{10} beyond midnight and a separate morning peak (at around 9 am) which are not seen in the time series of modelled concentrations. These may be due to further domestic emissions overnight, a re-lighting of fires in the morning, or motor vehicle emissions during peak traffic times. These missing emission sources are not accounted for in the emission inputs and are also likely to account for some of the model under-prediction.

Under-prediction of Observed PM_{10} – meteorological modelling aspects

As mentioned above, it is a challenge for meteorological models to simulate cold, calm and stable conditions, and the consequent accumulation of emitted air pollutants. This is true of TAPM, and also other research-grade and weather-forecasting models such as WRF, MM5 and RAMS.

The use of wind data assimilation and the changes to soil temperature and moisture in the TAPM configuration improved the simulation of night time wind speed and temperature, so with respect to these aspects, TAPM performs reasonably well. However, there is still some investigation required into TAPM's performance on worst-case pollution nights, as the extent of the dispersion of pollutants upwards in the night-time inversion layer has not been examined. Recommendations are made on this below.

Estimate of Polluted Airshed Limits

One of the aims of this project is to estimate the spatial extent of regions of Christchurch not in compliance with the National Environmental Standard (NES) for PM_{10}. Although the model under-predicts the peak PM_{10} concentrations, a simple scaling may be carried out provide a first-order estimate of these, as follows.

The modelled peak 24-hour concentration of PM_{10} at St Albans is around 30 µg/m^3. The true second-highest concentration is around 80 µg/m^3, of which around 7 µg/m^3 is naturally occurring. Hence the peak anthropogenic component of PM_{10} is 73 µg/m^3. Making the assumption that the model under-predicts by the same factor at all times and locations (despite the different source types present and uncertainties over model performance under extreme meteorological conditions), to get an improved match with observations, the modelled concentrations should be multiplied by 73/30 and 7 µg/m^3 added. This brings the modelled peak of 30 µg/m^3 up to 80 µg/m^3, as observed. Working backwards, an observed concentration of 50 µg/m^3 – the NES criterion for second-highest 24-hour PM_{10} concentration – would be modelled at 18 µg/m^3. Hence the 18 µg/m^3 contour on Figure 3 indicates the extent of non-compliance with the NES under the present-day emissions scenario (an average of 76 g PM_{10} emitted per burner per day).

A similar calculation for the emissions-reduction scenario, in which all burners are compliant with CRC's standards and the emission rate is 48 g PM_{10} per burner per day, leads to the 28 µg/m^3 contour on Figure 3 representing the extent of non-compliance with the NES. The higher contour level covers a smaller area, with the previously 'non-compliant' area just north of the city centre all but disappearing.

Recommendations for Further Investigation

Given the predominance of the impacts on air quality of domestic heating, it is considered that priority should be given to improving the simulation of the effects of this source type in the airshed modelling. Note that some of the suggestions included here may already have been the subject of investigations by CRC or other researchers in the past. Recommendations are as follows:

1) Domestic heating emissions:

If the meteorological model is performing adequately, then an explanation for the general under-prediction of PM_{10} and the observed persistence of elevated concentrations of PM_{10} beyond midnight still needs to be found. There are a number of possible reasons, related to domestic-heating emissions, which Golder has discussed with CRC, and CRC is already investigating. These include emissions in Christchurch being higher in general than those measured during voluntary real-life testing, use of wood with high moisture content, or modified wood burners emitting PM_{10} from smouldering wood after midnight.

2) Meteorological Model:

Improve the meteorological modelling, or verify that the current meteorological model is adequate. This has been examined to some extent as part of this project, but there are aspects of the structure of the night-time boundary layer and its influence on pollution dispersion (or accumulation), which need closer study. An improved meteorological model should lead to improved predictions of PM_{10} concentrations. The following tasks – examining monitoring data and the equivalent model outputs – should aid this improvement.

a. In the data, isolate the meteorological conditions under which worst-case overnight PM_{10} concentrations occur, in terms of wind speed, temperature, vertical temperature gradient.

b. Estimate the depth of the pollution layer on these nights (approximately). This may be a theoretical calculation based on observed boundary-layer parameters, or the estimate may be taken from measured vertical profiles of PM_{10} available in other towns.

c. Investigate the performance of the TAPM meteorological model under these conditions. Can it reproduce them? Should it be able to reproduce the high-ranking PM_{10} concentrations, or are the observed meteorological conditions too extreme for the model? Include examination of the depth of the pollution layer, and examine whether the model vertical resolution is sufficient to keep the PM_{10} confined to a sufficiently shallow layer.

3) Industrial emissions and motor vehicles:

The best available data on industrial and motor vehicle emissions needs to be included in the airshed model to provide a complete picture of modelled ambient air quality impacts. In the current work, some industrial stack parameters are not known for individual sources. Incorporation of these into the model, coupled with a model simulation of industry as a collection of point sources should give a more reliable estimate of PM_{10} impacts. Golder understands that updated inventories of these sources are currently in progress.

Care should be taken over the level of detail required in the modelling of the industrial source components; TAPM, as configured for this work, operates on a 250 m by 250 m grid, and modelled PM_{10} concentrations would be averaged over cells of this area. If greater detail were required, for example, to model concentration peaks at industrial site boundaries or at the roadside, TAPM would be need to be run at much higher resolution, with industry input as stack sources, which would be computationally expensive. For dispersion of PM_{10} from industry or motor vehicles, and examination of the resulting concentrations over smaller scales, other models may need to be considered.

Concluding Remarks

This project has produced spatial patterns of peak 24-hour PM_{10} over the Christchurch Clean Air Zones, arising from home heating and industry. Reasons for the shortfall in PM_{10} relative to observed concentrations at the Coles Place site have been discussed, and recommendations have been put forward to improve the modelling of Christchurch's air quality. Notwithstanding this shortfall, estimates have been made of the spatial extent of non-compliance with the NES for PM_{10}, under scenarios representing present-day emissions and an idealised case in which only compliant wood burners are in operation.

Golder trusts that the results and recommendations presented in this letter are useful to the current stage of CRC's air quality planning. If you have any questions on this work, please feel free to contact Neil Gimson (027 327 8627, ngimson@golder.co.nz) or any member of Golder's Air Team.

Yours sincerely,

GOLDER ASSOCIATES (NZ) LIMITED

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Attachments: Figures; references; report limitations

Figures

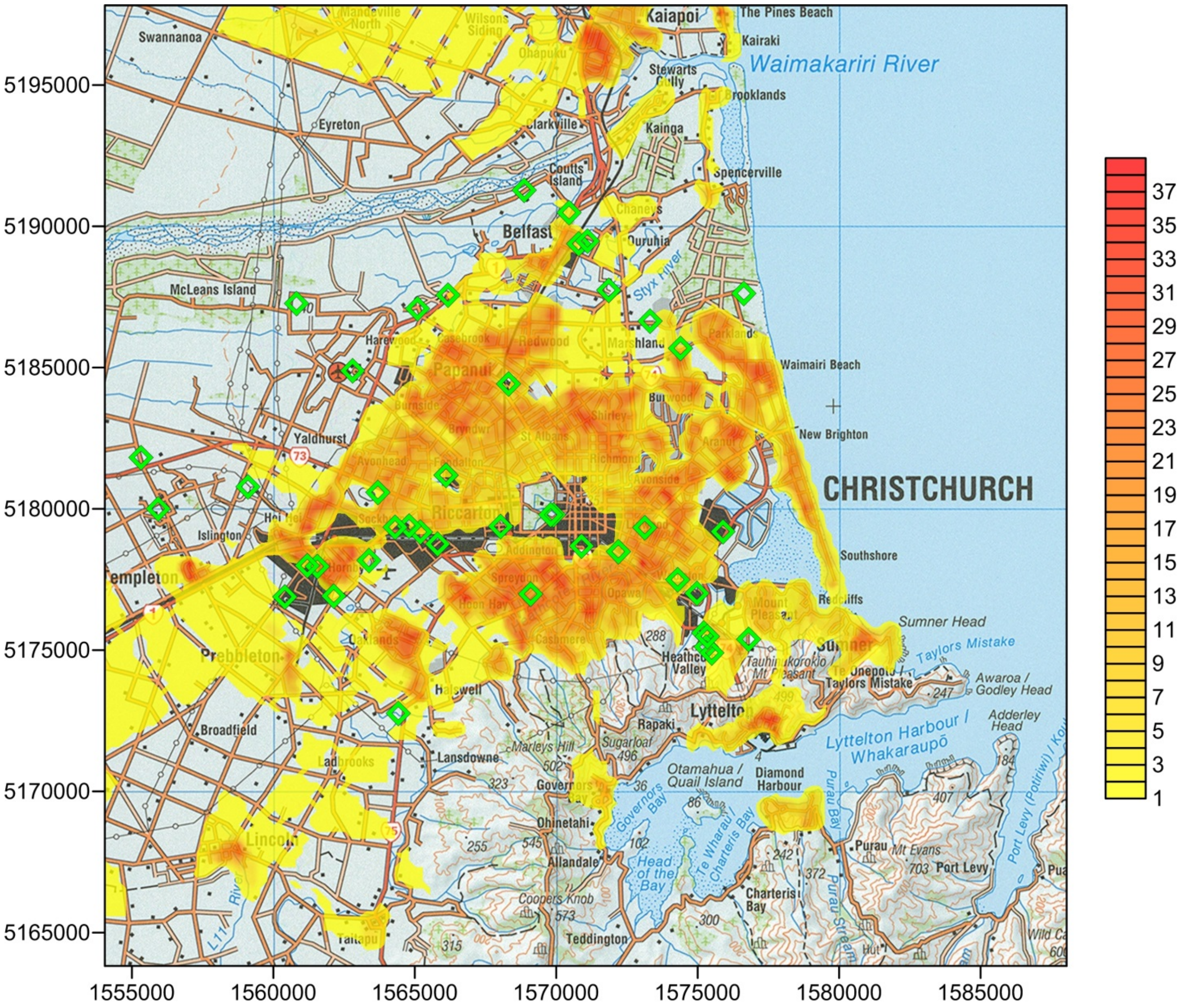

Figure 1: Area of the 1 km meteorological model domain, shaded with burner numbers per 250 m by 250 m grid cell. Industrial sources locations marked by green diamonds. Base map downloaded from Land Information New Zealand (LINZ) website. Axes in metres, New Zealand Transverse Mercator (NZTM) coordinate system.

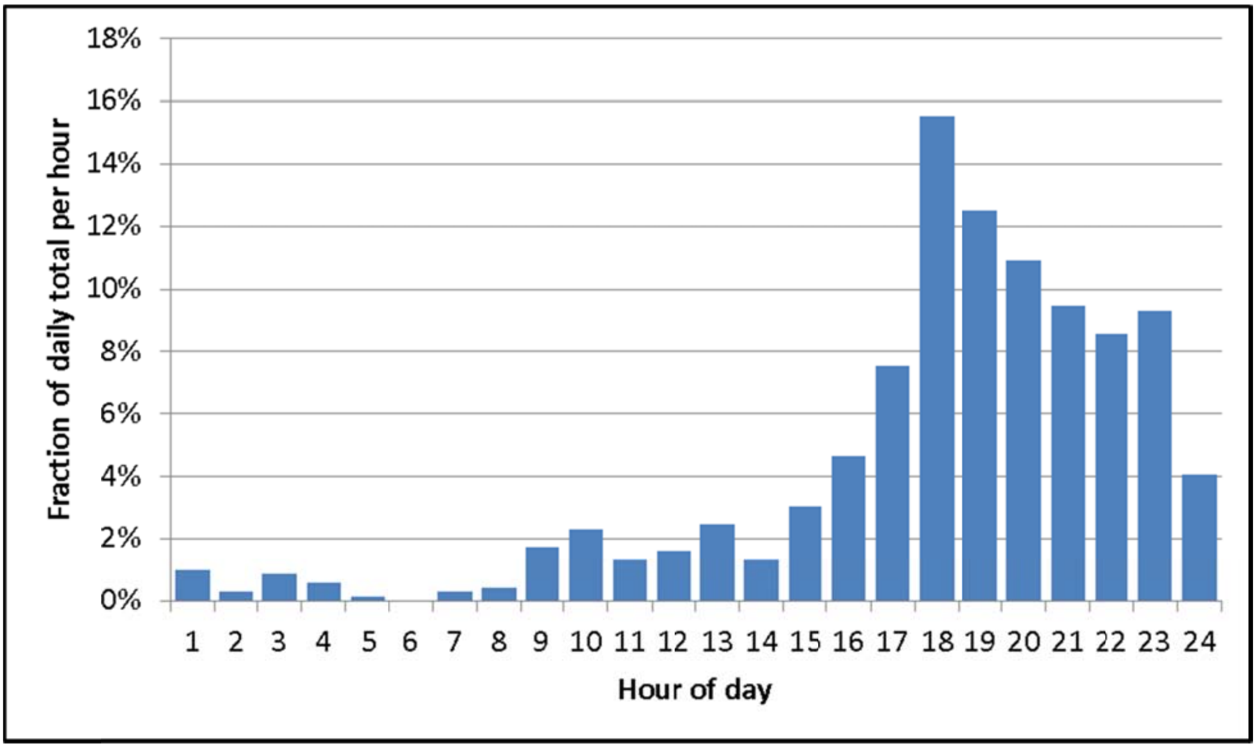

Figure 2: Percentage of daily-total domestic fire emissions at each hour of the day.

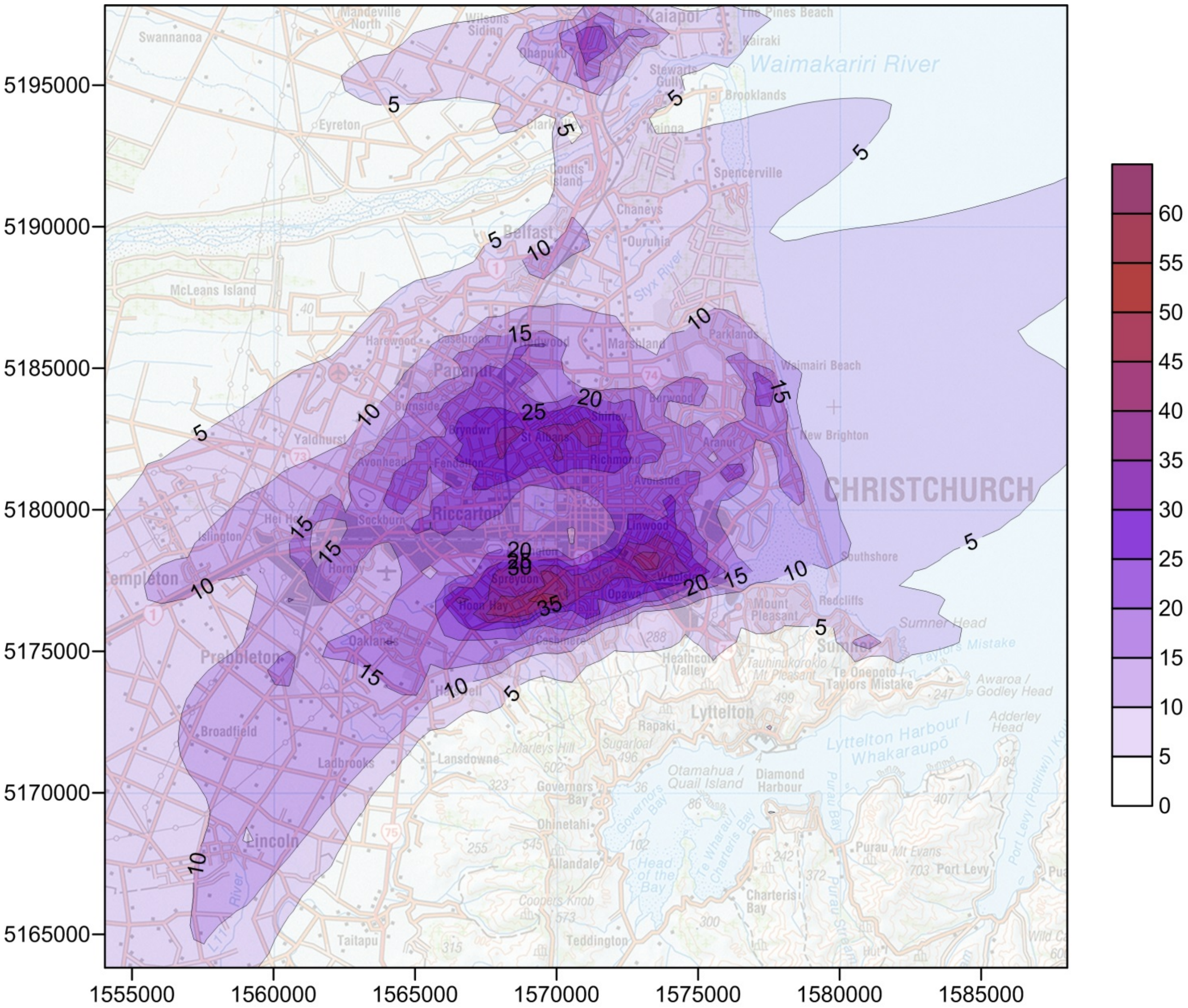

Figure 3: Composite peak 24-hour average PM_{10} over Christchurch. Concentration in units of micrograms per cubic metre (µg/m^3).

References

CRC 2011. Inventory of emissions to air in Christchurch, 2009. Environment Canterbury Regional Council Report R11/17. p. 157.

Hurley P, Physick W & Luhar A 2005. TAPM - A practical approach to prognostic meteorological and air pollution modelling. Environmental Modelling & Software. 20737–752.

Olivares G, Smith J & Bluett J 2010. Spatial variation of particulate air pollution in Christchurch and Nelson/Richmond during winter 2008. NIWA Client Report CHC2010-050, April 2010. p. 56.

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