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Spatial variation and characterisation of ambient aerosols from domestic solid fuel burning in a New Zealand town

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Here we present results of early trials of a car-borne mobile aerosol monitoring platform. The purpose of the platform is to map spatial variations of aerosols and to identify the relative contributions of different sources to the ambient aerosol. Ambient concentrations of PM_{10}, $PM_{2.5}$, PM_1 and black carbon (BC) were measured in Alexandra (a town of 6,000 people in the foothills of the Southern Alps on the South Island of New Zealand) during the southern hemisphere winter of 2007. The town sits in a valley and is subject to wintertime inversions leading to high PM_{10} concentrations related to residential combustion. There is very little traffic in Alexandra so the spatial variations of pollutants are directly related to the distribution of sources, which are expected to be primarily solid fuel burning used for domestic heating. Measurements were carried out at night time to capture the effects of domestic solid fuel burning and to identify the types of fuel burnt i.e. coal or wood. The system is still in the prototype stage so these results are presented as an indication of what will be possible. These results indicate that it is possible to use such a system to map spatial variation and identify hotspots not identified by a conventional fixed monitoring network. The system is also capable of differentiating between combustion aerosols and mechanically derived ones as well as distinguishing between combustion aerosols derived from wood and fossil fuels.

1. Introduction

Many towns and cities in New Zealand suffer from poor air quality in winter due to the widespread use of wood and coal for domestic home heating. Source apportionment studies suggest that in Hastings (a city of 28,000 people, on the east coat of the North Island), during winter days when the National Environmental Standard for Air Quality's PM_{10} limit was exceeded, domestic solid fuel burning accounted for 87% of the measured PM_{10} (Wilton et al. 2007). In Auckland (a city of 1.4million people), which has a much higher contribution from motor vehicles, domestic solid fuel burning still accounts for 50% of average ambient PM_{10} in winter and as much as 90% on high pollution days (Wilton et al. 2007). Almost all PM_{10} and $PM_{2.5}$ measurements in New Zealand have been recorded at fixed point monitoring sites and hence very little information on the spatial variation of pollutant concentrations and the representativeness of monitoring is available. If population exposure to pollutants is to be better understood, an understanding of how concentrations measured at a fixed point translate into concentrations elsewhere is required.

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Recent developments in air quality monitoring technology mean that it is now possible to build a relatively low cost mobile monitoring system that provides good quality, real time data at high spatial resolution. Such a mobile measurement system could provide data to allow the assessment of the variation of contaminant concentrations across an airshed for the purposes of identifying hot spots for monitoring sites, validating airshed dispersion models, or for input to the development or improvement of air quality management strategies. Several groups have built road based (car, van or lorry) mobile measurement platforms. These have been largely for characterising traffic emissions (Hussein et al., 2008; Kittelson et al., 2004; Pirjola et al., 2006; Seakins et al., 2002) or spatial variation compared to fixed monitors (Bukowiecki et al., 2003). Johnson et al. (2005) were able to apportion emissions between diesel and petrol engines by comparing size distributions. Larson et al., (2007) used a Nephelometer on a mobile platform correlated against fixed measurements of levoglucosan to characterise woodsmoke concentrations in Vancouver.

In order to both improve estimates of the spatial distribution of aerosols and to characterise their physical and chemical composition, we have built a car-borne aerosol mobile monitoring platform, which underwent initial trials during the southern hemisphere winter of 2007. Ambient concentrations of PM_{10}, $PM_{2.5}$, PM_1 and black carbon (BC) were measured in Alexandra: a town of 6,000 people in the foothills of the Southern Alps on the South Island of New Zealand. The town sits in a valley and is subject to wintertime inversions leading to high PM_{10} concentrations related to residential combustion. There is very little traffic in Alexandra so the spatial variations of pollutants are directly related to the distribution of sources, making it ideal for a mobile monitoring campaign, as the sensor is moving through a series of fixed sources.

2. Method

2.1 Instrumentation

Instruments were located both inside the vehicle and in a rooftop enclosure. A purpose-built conduit was used to bring cables and sample tubes through the vehicle rear passenger window, to and from the rooftop enclosure. A Magee Scientific (Berkeley, California) AE22 dual wavelength aethalometer was housed in the vehicle with a sample tube passing through the window conduit into the rooftop enclosure. The dual wavelength measurement may be used for identification of different sources; for example, vehicle emissions vs. wood smoke from home heating or biomass combustion. Near real time measurements are possible with a time resolution from five second to one hour. A GRIMM Model 107 Dust Monitor (Grimm Aerosol Technik GmbH & Co. KG, Germany) was housed in the rooftop enclosure, with power and data cabling via the window conduit. The GRIMM monitor is a low-volume sampler that uses a light scattering technique to continuously measure particle number concentration and size distribution in an air stream. The GRIMM is well suited to this mobile application due to the fast response time with near-continuous (six second time resolution), simultaneous measurements of PM_{10}, $PM_{2.5}$ and PM_1 mass values. A PB100 (AIRMAR

Technology Corporation, MILFORD, New Hampshire) ultrasonic weather station was mounted on the system's rooftop enclosure (Figure 1). The PB100 includes a global positioning system (GPS) that allows the mobile system to record the exact location of measurements as they are logged. The weather station also provides measurements of wind speed and wind direction (both absolute and relative to the vehicle movement), air temperature, relative humidity and barometric pressure.

Instruments were interfaced with a Starlog (Unidata Pty Ltd, O'Connor, Western Australia) data logger that stored all data once every two seconds. This interval is shorter than the update interval of all the instruments and it was used to coordinate the signals from the GRIMM (every six seconds), the Aethalometer (every 5 seconds) and the GPS (every 10 seconds). A laptop PC interrogated the data logger in real time and provided an on-screen display of instantaneous data as they were recorded by the logger. A Sony HDD video camera was mounted on the vehicle dashboard and was operated throughout the monitoring, to provide a record of vehicles and other particulate sources encountered during each run. Trials of the system were conducted in Alexandra during the southern hemisphere winter of 2007. Eight runs were carried out between 8 June and 3 July 2007. Alexandra was chosen for the initial demonstration mainly because of its small size, high particulate concentrations during winter and relatively well identified emission sources. Alexandra's small size allowed mapping of particulate matter concentrations over most of its area. A Map of Alexandra is shown in Figure 2.

3. Results

Figure 1 shows the concentration fields of PM_{10}, $PM_{2.5}$, PM_1 and black carbon (BC) as an average of all the runs performed in Alexandra. The fields in Figure 1 show similar patterns of high and low concentrations for all the measurements. High concentrations in the south west of the city and low concentrations in the outskirts of Alexandra are apparent for PM_{10}, $PM_{2.5}$, PM_1 and BC.

The PM_1:PM_{10} ratio provides information about the relative abundance of the coarse and fine fraction of PM. As shown in Figure 2, the PM_1:PM_{10} ratio is very high throughout the Alexandra area. This indicates that the major source of PM_{10} is combustion and that most of ambient aerosol has a size of 1μm or less. This result has potential implications for air quality management. The WHO guidelines for air quality include a limit for $PM_{2.5}$ of 25 $\mu g/m^3$ for 24-hour averages. If PM_{10} is almost 90% PM_{10}, then even when PM_{10} concentrations are below 50$\mu g/m^3$ it is possible that the WHO $PM_{2.5}$ guideline is being exceeded and an associated risk of health impacts exist. On the other hand, only small areas in the west and south-east of the town have PM_1:PM_{10} ratios lower than 0.6 which is an indicator of areas where mechanically derived dust is a major component of particulate matter. Nevertheless, one must bear in mind that the results presented here are only for the period where measurements were taken (evenings and night) and may not represent the distribution of small particles at other times of the day.

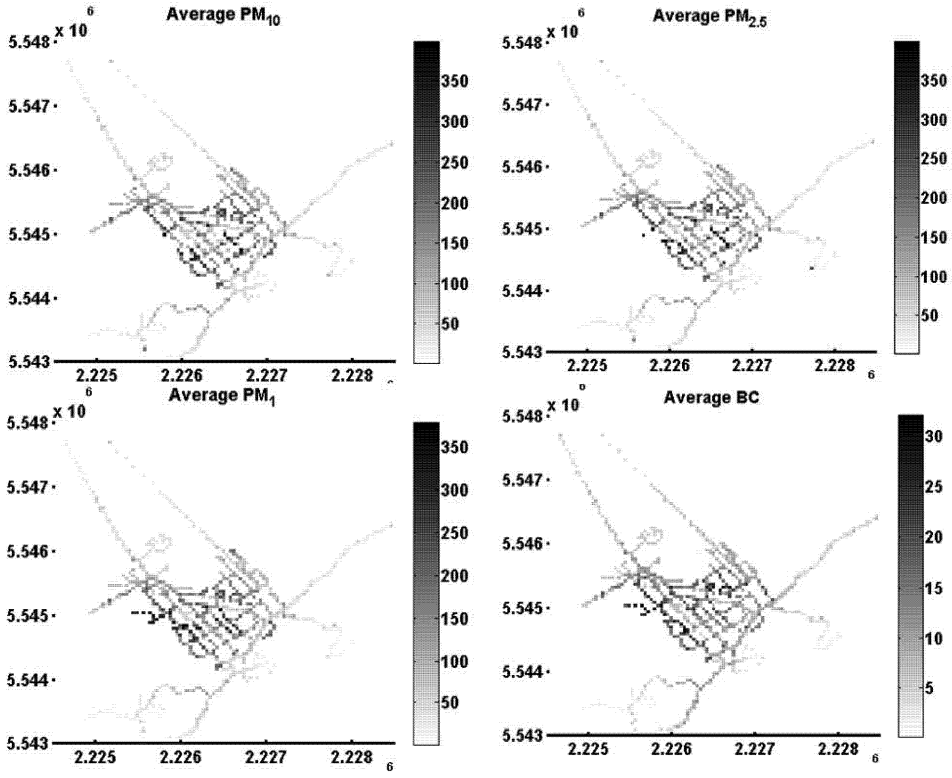

Figure 1. PM_{10}, $PM_{2.5}$, PM_1 and BC concentrations ($\mu g/m^3$) averaged for all the runs undertaken in Alexandra. Note that the map coordinates are NZMG.

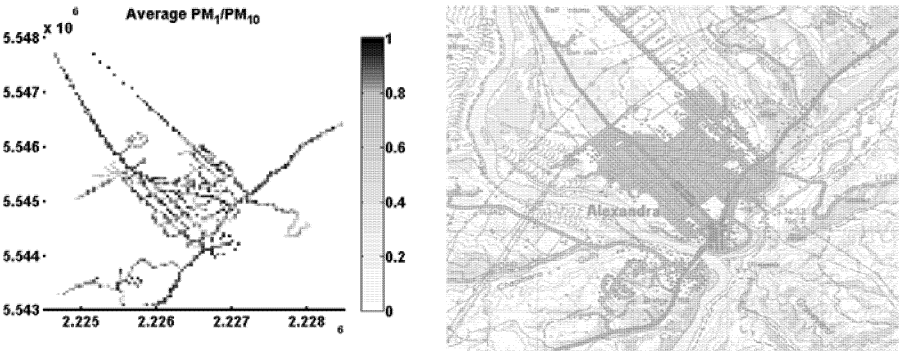

Figure 2. Left, PM_1:PM_{10} ratio averaged for all the runs undertaken in Alexandra. Note that the map coordinates are NZMG. Right, a Map of Alexandra

3.1 Black carbon – an indicator of source type

Information about other particulate measures, particularly black carbon (BC), can provide clues about the types of emission sources present in the area. As BC is emitted at different intensities from different sources, a map of the relative abundance of BC in the particulate matter would help map different combustion sources in the area. Even

though it is possible to find black carbon in the coarse fraction of PM, it is not normally associated with dust and it is used as a tracer of combustion sources (Allen et al. 2004). Only in areas where coal is handled in open spaces is it possible to find black carbon particles of sizes large than 1μm. Therefore, the BC:PM_{10} (Figure 3) ratio could provide clues about the distribution and type of combustion sources in the area. Not all combustion sources produce the same amount of black carbon. Diesel combustion has been shown to produce about 10 times more BC per unit of fuel burnt (Imhof et al. 2005). Wood combustion aerosols tend to be less black and absorb less light than fossil fuel combustion (Olivares et al. 2008a). Therefore, areas with high values of BC:PM_{10} ratio would indicate areas where fossil fuels are dominant while areas with smaller ratios may be associated with wood burning activities.

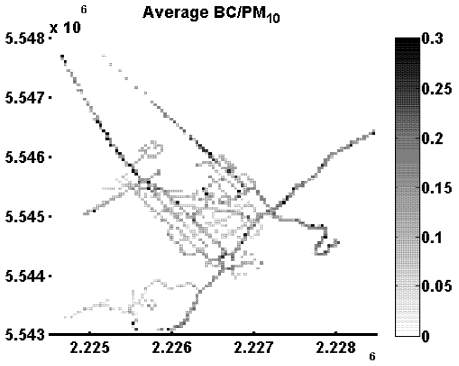

Figure 3. BC:PM10 ratio averaged for all the runs undertaken in Alexandra. Note that the map coordinates are meters NZMG.

Figure 3 shows that there are relatively large areas in Alexandra where the BC:PM_{10} ratio is relatively low, indicating areas where wood burning may be the relevant source of carbonaceous materials. On the other hand, high values of BC:PM_{10} ratios were observed along the major roads indicating probably that diesel traffic also has an impact on the observed BC concentrations. Of particular interest are the north-west exits of the town where there are areas of high BC:PM_{10} ratios that do not extend far from the town. This is different from what is observed in the north-east to south-west link, where high ratios are observed throughout. One explanation may be that those roads are more used by diesel vehicles. However, because the measurements were performed during late evenings and nights, there was very little traffic and therefore, it seems likely that the combustion of coal in that area is responsible for those high BC:PM_{10} ratios. Figure 3 shows that the two high PM_{10}concentration areas (Figure 1) have relatively high BC:PM_{10} ratios, indicating that either traffic or coal burning are likely to be significant sources of particulate in those areas. Nevertheless, the same caution applies as for the PM_1:PM_{10} ratio: the BC:PM_{10} ratios presented here may not represent the distribution of particles at other times of the day.

3.2 Ultraviolet and Infrared measurements of Black Carbon

The Aethalometer measures BC at two different wavelengths; Ultraviolet (UV) and Infrared (IR). However the current data acquisition set up makes the comparison between the UV-BC and the IR-BC signals difficult, particularly putting them on the same map. Notwithstanding, a preliminary analysis of this data was performed for **a** single run in Alexandra (03 July 2007). The difference between UV-BC and IR-BC (Δ-C) has been used as an indicator of aromatic compounds within the black carbon (Allen et al. 2004). Because wood smoke contains a larger fraction of aromatic compounds than other combustion sources, it is possible to use Δ-C as a qualitative tracer for wood burning.

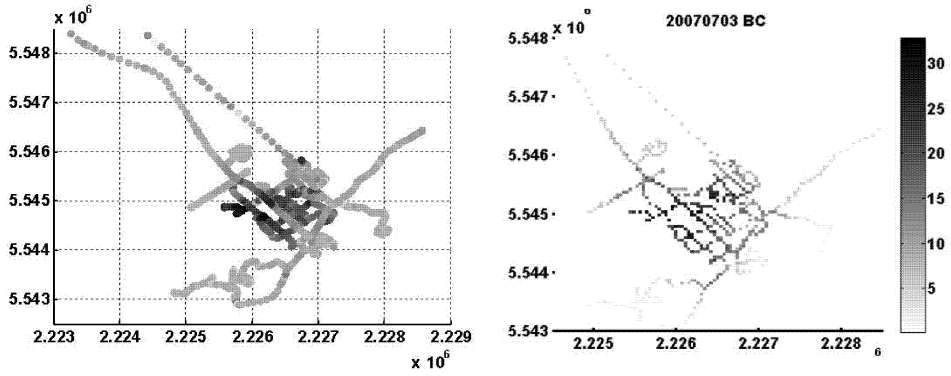

Figure 4. Δ-C and black carbon horizontal distribution in Alexandra for the measurements taken on July 3rd 2007

Figure 4 shows the horizontal distribution Δ-C (left hand plot) and black carbon (right hand plot) in Alexandra. Note that even though the gray scale is the same for both plots, only the BC plot represents absolute measurements. The Δ-C plot should be read only as relative concentrations. The areas of high black carbon concentrations are also associated with high Δ-C values indicating that wood burning is probably a major contributor to the observed black carbon concentrations. However, the relatively high BC concentrations observed to the north of the central part of the town correspond to an area of relatively low Δ-C values and therefore is a location where sources other than wood burning contribute to the carbonaceous aerosols. This is consistent with the BC:PM_1 plot presented earlier that indicates that the north part of the town may be impacted by particulate matter discharged from the burning of coal as well as wood.

4. Conclusions

Here we present results of early trials of a car-borne mobile aerosol monitoring platform. The purpose of the platform is to map spatial variations of aerosols and to identify the relative contributions of different sources to the ambient aerosol.

Ambient concentrations of PM_{10}, $PM_{2.5}$, PM_1 and black carbon (BC) were measured in Alexandra (a town of 6,000 people in the foothills of the Southern Alps on the South

Island of New Zealand) during the southern hemisphere winter of 2007. The town sits in a valley and is subject to wintertime inversions leading to high PM_{10} concentrations related to residential combustion. There is very little traffic in Alexandra so the spatial variations of pollutants are directly related to the distribution of sources which are expected to be primarily solid fuel burning used for domestic heating. Measurements were carried out at night time to capture the effects of domestic solid fuel burning and to identify the types of fuel burnt (i.e. coal or wood).

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Further trials have also been conducted in Auckland and Christchurch (Olivares et al 2008b) and identified potential improvements to the system including improved inlets, improved interface and control systems and an upgrade of the GRIMM to 32 channel number counting mode. The upgraded system will be trialed during the southern hemisphere winter of 2008

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