Atmospheric Environment 75 (2013) 179–187

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Vertical and temporal variations of black carbon in New Zealand urban areas during winter

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HIGHLIGHTS

- We measured vertical temperature and BC profiles during winter.
- The BC/PM was mostly confined to a surface layer less than 50 m in height.
- Maximum concentrations were observed near midnight.
- Evening and morning peaks are separate events.
- Mid-morning peak is from new emissions due to residents re-lighting their fires.

ARTICLE INFO

Article history:
Received 8 February 2013
Received in revised form
9 April 2013
Accepted 12 April 2013

Keywords:
Black carbon
Air pollution
Particulate matter
Vertical profiles
Meteorology

ABSTRACT

During winter nights, topographically confined urban areas can experience episodes of particulate matter pollution as a result of combustion related emissions for domestic heating. Black carbon (BC) concentrations were measured vertically and temporally during winter evenings in four New Zealand urban locations as a proxy for combustion-related particulate matter (PM). Vertical temperature and BC profiles demonstrated the formation of inversion conditions, where the near-ground boundary layer becomes decoupled from layers above. The BC profiles indicated that PM was mostly confined to a surface layer less than 50 m in height from the surface. In addition, the BC concentrations exhibited a temporal pattern consistent with previously observed PM_{10} diurnal cycles, where maximum BC concentrations within the mixing height were observed near midnight. Decreasing BC concentrations during early morning were attributed to observed katabatic flows clearing the boundary layer. By dawn, BC concentrations in the vertical column were close to the much lower concentrations (<5 μg m^{-3}) observed during the daytime, revealing that the observed night-time and morning peaks were separate events. Hence, the mid-morning peak is from new emissions due to residents re-lighting their fires. This study has contributed to our understanding of how meteorological conditions influence the build-up and dissipation of BC, and by extension, PM, during winter nights, which can result in significant air pollution events for our urban communities. Critically, the mid-morning peak can significantly contribute to exceedences of the 24-h air quality standard (50 μg m^{-3} PM_{10}).

1. Introduction

Urban areas located within confining topographical features such as valleys or sheltered by hills can experience episodes of degraded air quality during winter. This is observed in many locations within New Zealand (Wilson et al., 2006; Trompetter et al., 2010; Davy et al., 2012; Ancelet et al., 2012; Wilton and Bluett, 2012) and elsewhere around the world, for example: northern Sweden (Krecl et al., 2008), an alpine valley in Switzerland (Sandradewi et al., 2008), Fresno and Bakersfield, California, USA (Magliano et al., 1999; Watson et al., 2002; Hering et al., 2007) and Launceston, Tasmania, Australia (Keywood et al., 2000). Pollution events in these locations are exacerbated during anticyclonic conditions which typically feature low wind speeds, no precipitation, clear skies, lower temperatures and stable atmospheric conditions during the evening and night (Salmond and McKendry, 2009). Source apportionment studies at many of the New Zealand locations have indicated that during winter, the primary pollution source is from domestic woodburners, where biomass is combusted for home heating requirements (Davy et al.,

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http://dx.doi.org/10.1016/j.atmosenv.2013.04.036

2005; Davy, 2007; Trompetter et al., 2010; Davy et al., 2012; Ancelet et al., 2012). Radiative cooling overnight leads to a significant decrease in surface temperatures evident by morning frosts when surface condensation freezes. The low temperatures encourage increased emissions as more residents use their solid fuel fires for heating their homes. The ability of emitted pollutants to disperse is limited when these emissions occur during stable atmospheric conditions and therefore result in higher pollutant concentrations.

Air quality monitoring data show that during winter, particulate matter (PM) concentrations typically peak at about midnight and then reduce to a minimum by dawn (Trompetter et al., 2010). However, this data is from air quality monitoring station measurements at a fixed height near ground level (2–3 m) and does not reveal how PM concentrations vary at other heights during a winter's night. In the settlements studied, a second PM concentration maxima was also observed to occur at mid-morning (0900–1000) during the winter (Trompetter et al., 2010). This mid-morning peak was hypothesized to result from a vertical mixing process where PM emitted in the previous evening was stored at an elevated height and subsequently mixed to the surface as the boundary layer's nocturnal structure is destroyed and evolves into the daytime convective regime. Surface-based measurement is unsuited to resolve this process and therefore the monitoring of the atmosphere vertically is needed to explore this hypothesis. Additionally, due to the unpredictability of topographic modification on pollutant transport pathways, vertical measurements have the potential to help resolve if processes such as katabatic drainage do indeed explain pollutant patterns; something which is anecdotally assumed.

Topographic confinement and mesoscale wind regimes can also modify the transportation pathways of contaminants and can lead to unexpected results in zones of complex terrain (McKendry and Lundgren, 2000). These unexpected processes often occur in elevated locations and are not captured by routine surface-based monitoring activities. Atmospheric parameters such as stability can have extremely influential effects on ground level concentrations of pollutants (Grange et al., 2013). Other processes such as intermittent turbulence within the nocturnal boundary layer have been shown to mix and transport stored photochemical gases aloft to the surface (Salmond and McKendry, 2002; Corsmeier et al., 1997). Therefore, the understanding of atmospheric processes in the vertical dimension can be very useful in explaining ground level pollutant concentrations.

The specific aims of this study were to: investigate the vertical extent of the elevated surface BC concentrations, whether the vertical BC profile was uniform or had layering and how the vertical profiles changed during the night and morning. Additionally, the vertical measurements were analysed to identify where BC concentrations were highest and to provide information about how the height at which compliance monitoring of PM_{10} takes place, relates to air pollution levels throughout the vertical column.

2. Methodology

2.1. Site descriptions

During the 2010–2012 winters, vertical black carbon (BC) profiles were measured at four New Zealand urban locations as part of a wider research programme designed to study the build-up and dissipation of PM during winter nights in New Zealand urban airsheds. As part of this wider programme, PM was monitored and collected on an hourly basis at different locations in each airshed, as described in Ancelet et al. (2012). The locations chosen were Alexandra, Nelson, Masterton and Auckland, as shown in Fig. 1 and described in Table 1, to represent a range of population densities

Fig. 1. Map of New Zealand identifying the urban locations in this study.

along with the climatic and geographical diversity experienced in New Zealand. At each location, the measurements were performed at or close to ambient air quality monitoring stations used for compliance monitoring by Regional Councils, the regulatory authorities responsible for air quality management in New Zealand. The average hourly PM_{10} concentrations measured at the compliance monitoring station during the winter (June–August) campaigns in this study are plotted in Fig. 2 for Masterton (2010 winter), Alexandra (2011 winter), Nelson (2011 winter) and Auckland (2012 winter). It is clearly observed how strongly the PM_{10} builds up during the night-time. These locations also represented the full range of the wintertime diurnal PM_{10} concentrations previously observed across New Zealand (Trompetter et al., 2010) where 10 urban locations where compared (Auckland (Kingsland), Hastings, Masterton, Upper Hutt, Wainouiomata, Nelson, Christchurch, Mosgiel, Alexandra and Arrowtown).

Masterton is a town located 80 km northeast of Wellington City within the Greater Wellington region on the North Island of New

Table 1
Urban airshed locations in this study.

Location	Population[a]	Latitude, longitude	Vertical transects (Helikite flights upto 300 m)	Vertical transects (to/from raised platform 30 m)
Masterton	22,623	−40.9524°, 175.6465°	30 July 2010	11 July 2010
Alexandra	4824	−45.2491°, 169.3847°	–	1–3 June 2011
Nelson	42,891	−41.2782°, 173.2735°	18–20 July 2011	29 June–3 July 2011
Auckland	1,303,068	−36.7803°, 174.7489°	10 July 2012	–

[a] Department of Statistics (2006) Census, "Usually Resident Population Count"—2006. (Note: this is the latest available data at the time of publication as the 2011 census was postponed due to the 2011 Christchurch earthquakes).