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Effect of seasonal variability and land use on particle number and CO_2 exchange in Helsinki, Finland

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ABSTRACT

Turbulent fluxes of particle number and CO_2 were analysed in Helsinki between July 2011 and June 2013. The fluxes were measured using the eddy covariance method in a dense city centre and suburban location next to a large road allowing the study of the mutual connections of the two fluxes and their dependencies between different high intensity road traffic areas.

In the city centre, the median particle (F_p) and CO_2 fluxes (F_c) were 0.18×10^9 m^{-2} s^{-1} and 9.8 μmol m^{-2} s^{-1}, and at the suburban site 0.17×10^9 m^{-2} s^{-1} and 5.7 μmol m^{-2} s^{-1}, respectively. F_c was larger in the city centre than at the suburban site whereas particles were emitted with a similar strength from a single large road as from the city centre. F_p had the largest net fluxes in winter and the smallest in summer, whereas seasonal variability in F_c was minor. Partly this can be explained by increasing particle emissions in colder temperatures. Also the different vertical transfer efficiency of the two scalars affects the different behaviour. This study demonstrates how the behaviour of two seemingly similar urban pollutants vary already at a kilometre scale and with different meteorological conditions.

1. Introduction

Aerosol particles are identified as a major health risk especially in urban areas. Long-term exposure to particulate matter has been observed to be in close relationship with adverse severe health effects, particularly in the pulmonary and cardiovascular systems (Chow et al., 2006). According to the World Health Organization, urban air pollution was estimated to have caused up to 3.7 million premature deaths worldwide in 2012 and the main cause was a constant exposure to particulate matter (WHO, 2014). Fine particles (aerodynamic diameter < 2.5 μm) have been regarded as most harmful, but ultrafine particles (UFP, aerodynamic diameter < 0.1 μm), apart from growing to fine particles through condensation and coagulation, seem to have potential to damage other organs as well (Kreyling et al., 2006). Carbon dioxide (CO_2), instead, is one of the most important and well known greenhouse gases that has a strong warming effect on our atmosphere. Aerosol particles also modulate Earth's energy budget both directly by scattering and absorbing light, and indirectly by acting as cloud condensation nuclei. However, the cooling effect of anthropogenic aerosol particles is still far more uncertain compared to the warming effect of CO_2 (IPCC, 2013). Studies of vertical exchange of these particles and CO_2 between the surface and the atmosphere provide important knowledge for improving both numerical air quality and climate models.

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Over half of the world's population live in urban areas (53% in 2012) and the number is constantly growing (World Bank, 2014). In these high intensity traffic and densely built surroundings, particle and CO_2 emissions are elevated and the cities act as net sources (e.g. Järvi et al. (2009b) for particle and Nordbo et al. (2012a) and Lietzke and Vogt (2013) for CO_2 fluxes). A major source of particles and CO_2 in city centres is road traffic, which produces fine and ultra fine particles and CO_2 in combustion processes, and coarse particles mechanically as road, tyres and break-linings wear (Vogt et al., 2011b). UFP are additionally formed in atmospheric photochemical reactions from precursor vapours and fine particles as transformation products of UFP. Large amount of particles are formed in engines running with diesel compared to gasoline due to the higher burning temperatures, and especially heavy-duty vehicles contribute to particle emissions (Lähde et al., 2014). The combustion emissions are highest in cold ambient temperatures and fast accelerations (Kittelson et al., 2004; Virtanen et al., 2006).

The most direct way to measure the vertical trace gas and particle fluxes from areas of neighbourhood or local scales is the eddy covariance (EC) method (Aubinet et al., 2012). The method has been widely used in vegetated homogeneous environments, but within the past few decades a growing number of EC measurements have been carried out at urban measurement sites with heterogeneous surface covers. An increasing number of articles have reported urban EC flux measurements of trace gases and particles over extended periods (i.e. >1 year) (Järvi et al., 2009b; Ripamonti et al., 2013; Vogt et al., 2011a), but still only a few studies have examined simultaneous flux measurements of particles and CO_2 and similarities in their sources and sinks (Contini et al., 2012; Vogt et al., 2011a). Furthermore, the intra-city variation of particle fluxes and its dependencies from different urban surface covers has not been quantified before.

In cities, air quality is usually monitored by measuring mass concentrations $PM_{2.5}$ or PM_{10} (particles with aerodynamic diameter smaller than 2.5 μm or 10 μm, respectively) whereas particle number flux and concentration measurements with the EC method are less common despite their ability to observe UFP, in particular. In Helsinki, UFP comprise only a minor fraction of particle mass concentrations but 70–90% of total particle number concentrations when no long-range transport or road dust re-suspension episodes are present (Hussein et al., 2014; Ripamonti et al., 2013), and hence particle number fluxes measure mainly the vertical transport of UFP.

In this paper we provide a study of particle and CO_2 fluxes measured with the EC method in a densely built city centre (Hotel Torni, Nordbo et al. (2013)) and at a suburban site (SMEAR III Kumpula, e.g. Järvi et al. (2009a)) in Helsinki over two years. The emphasis is on temporal and spatial variations of the two scalars and in their mutual behaviour, which can be used to get information about the emission sources. In addition, we will analyse the effect of different factors, such as storage flux, stability, presumable sources within the source areas and turbulent transport efficiency on fluxes. The main focus is on the city centre site from where no previous particle flux measurement studies exist.

2. Measurements

2.1. Site description

Helsinki, the capital of Finland, is the biggest city in the country with a population of 615,000 in 2013 (PRC, 2014). The population of the Helsinki metropolitan area (770 km^2) reaches 1.1 million when the nearest surrounding towns are included (City of Helsinki, 2013). Located at high latitudes, but on the coast of the Gulf of Finland, the weather in the city is either maritime, coastal or mixed depending on the air mass history (Hussein et al., 2014). Especially the winter temperatures are higher than the latitudinal average mainly due to the influence of North Atlantic Drift.

In central Helsinki, the measurements of turbulent particle number and CO_2 fluxes were carried out on the tower of Hotel Torni building (Fig. 1). The tower (60°10′04.09″N, 24°56′19.28″E, 15.2 m above sea level (a.s.l.)) is a 57.7 m tall structure in the highly busy central Helsinki (Table 1). The site belongs to the local climate zone 2 as classified by Stewart and Oke (2012), and the surroundings are densely built urban area with a mean building height of 24.1 m. Within a 1 km radius circle around the tower, buildings cover 55%, paved area 42% and vegetation 3% of the total area (Nordbo et al., 2013). The central railway station is located 400 m northeast, and an year-round passenger and cargo harbour West Harbour is located 1.5 km south-west from the site. Despite a bulky structure of the building tower, Hotel Torni was chosen as the measurement site in order to reach a measurement height suitable for EC measurements. The site (hereafter called Torni) is situated 120 m south-west from the main road of central Helsinki, Mannerheimintie. Traffic rates decrease towards the centre, being around 20,000 motor vehicles per day next to the site (HCPD, 2013).

The EC measurements of particle number and CO_2 were also performed at the SMEAR III (*Station for measuring the ecosystem-atmosphere relationship*) Kumpula site (Järvi et al., 2009a). The site (hereafter Kumpula) is located outside city centre, 4.1 km northeast from Torni, and it is representative for local climate zone 6. The university campus is located in the area with a lot of green areas around the station. The surrounding area can be divided into three surface cover sectors, with the road sector in east and southeast, where one of the main roads leading to city centre passes the station. The other two sectors are the vegetation sector in west and northwest and the building sector in north and northeast, but in this study we only focused on measurements from the road sector due to similar particle and CO_2 sources. In this sector, the mean building height is 11.5 m within a 1 km radius circle and the area is covered 15% by buildings, 39% by paved surfaces and 46% of vegetation (Table 1, Järvi et al. (2014)). A band of vegetation between the measurement site and the road might influence the particle fluxes by acting as a buffer for the road emissions.