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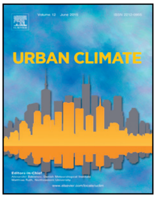

Net carbon dioxide emissions from central London

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ABSTRACT

Carbon dioxide (CO_2) emissions from cities drive increased global atmospheric CO_2 concentrations and associated climate change. Urban CO_2 emissions can be evaluated using an inventory approach (summing all know emissions and sequestrations of CO_2 within a defined area), and/or a micrometeorological approach (summing the exchanges of CO_2 through the sides of a defined volume of air, and the change in the total stored within the volume). Generally the micrometeorological approach, with the assumption that only the net turbulent vertical flux of CO_2 is significant on annual timescales, is preferred. This study evaluates that assumption with respect to storage and vertical advection of CO_2, and calculates net CO_2 emissions in central London using both methods for June 2012 to May 2013. Data sources include an eddy covariance system, switched horizontal and vertical CO_2 profiles, traffic counts and vegetation surveys. Annual total emissions were 51.4 and 53.5 kg CO_2 m^{-2} y^{-1} (micrometeorological and inventory methods, respectively) i.e., within 4% (1.3% with the assumption that the net vertical turbulent flux is the only non-negligible micrometeorological term). This study supports the use of vertical fluxes calculated from eddy covariance measurements at a single location to estimate total emissions from high density urban environments.

1. Introduction

Carbon dioxide (CO_2) is the largest component of the radiative forcing of climate change (1.82 W m^{-2} or 64% of the net change in downward radiation at the tropopause, IPCC, 2014). It absorbs outgoing

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infra-red radiation from the earth's surface and re-emits isotropically such that a portion of the radiation is returned to earth. Urban areas are an important part of the global carbon cycle, responsible for ca. 70% of total emissions of CO_2 (Canadell et al., 2009). The main urban sources of CO_2 are anthropogenic in origin, predominantly comprising of emissions from vehicles and building activities (Velasco and Roth, 2010).

Urban CO_2 concentration studies since 2002 (27 listed in Table 1) have been performed in Europe (48%), North America (22%) and East Asia (22%), with North African and Oceanic cities each having one study. This broadly reflects the distribution of tower sites as part of the FLUXNET global monitoring network (FLUXNET, 2015). Comparison of measured fluxes for different sites within the same city (e.g., Mexico City, Velasco et al., 2005 and Velasco et al., 2009; London, Helfter et al., 2011, Ward et al., 2015; Helfter et al., 2016) shows differences of equal magnitude to those observed between cities (Table 1).

Despite some studies in urban areas (Table 1) registering CO_2 concentrations below global background levels (Tans, 2009) and, in some highly vegetated suburbs, negative daytime fluxes during the leaf-on period, all studies which have reported annual emissions have found urban areas to be net emitters of CO_2. Previous studies in central London (Fig. 1a) have found a wide range of net emissions; for example, Sparks and Toumi (2010) calculated a mean CO_2 flux that would result in emissions of 25.83 kg CO_2 m^{-2} y^{-1} from eddy covariance (EC) measurements 50 m above ground level (agl), and estimated emissions to be 43.89 and 31.39 kg CO_2 m^{-2} y^{-1} using the National Atmospheric Emissions Inventory (NAEI) and London Atmospheric Emissions Inventories (LAEI), respectively (with point sources excluded). Net CO_2 emissions of similar magnitude (35.5 kg CO_2 m^{-2} y^{-1}, 40.7 kg CO_2 m^{-2} y^{-1}) were calculated by Helfter et al. (2011, 2016) from EC measurements 190 m agl and Ward et al. (2015) (46.6 kg CO_2 m^{-2} y^{-1}) from measurements made 45.1 and 46.4 m agl (Section 3).

A review of measured CO_2 emissions from urban areas, Grimmond and Christen (2012) (cited in Christen, 2014), reports a strong, positive correlation between the rate of CO_2 emission (taken as the vertical flux, Section 2) and building density. In a low-rise, low density suburb of Vancouver, Canada, Crawford and Christen (2015) attributed 70% and 26% of total annual CO_2 emissions to vehicles and buildings (combustion for space heating) respectively. Similar values are reported for Escandón (72%, 24%), a compact midrise, densely populated residential and commercial neighbourhood of Mexico City (Velasco et al., 2014). In a densely built institutional (university) and residential area of Basel, the vertical CO_2 fluxes were highly correlated with traffic density on working days (R^2 of 0.87–0.97, Lietzke and Vogt, 2013). However, in the high density business district (institutional, commercial and office buildings) of central London (the focus area of this paper), Ward et al. (2015) calculated the contributions from buildings and vehicle emissions as 70% and 19% respectively, i.e., almost the inverse of those reported for Vancouver and Mexico City. Helfter et al. (2011, 2016) measured CO_2 emissions 1.9 km to the north-west (Fig. 1a) of King's College London, Strand Campus (KS) and reported similar values for winter, but very different average annual contributions of 59% and 38% for buildings and traffic, respectively. Vegetation, bare soil and human respiration typically contribute <5% to the total flux (reduction of CO_2 emissions in central London due to sequestration by vegetation was calculated as 0.4% of total emissions by Helfter et al., 2011), but this is highly dependent on land cover/land use. In particular the contribution due to human respiration can be significant in areas with high population density; for example, Moriwaki and Kanda (2004) calculated a contribution by human respiration of 17–38% of the overall CO_2 emissions (taken as the vertical flux) from a residential area of Tokyo, Japan. In general, the agreement between overall emissions calculated from the vertical flux and those from summing over various processes (e.g. human respiration, traffic emissions) is good, typically within 20% (Table 1), though the margin of uncertainty may be high. Discrepancies between the two may arise due to the coarse spatial resolution of some fossil fuel inventory data; large ‘point’ sources of CO_2 from burning of fossil fuels may be located within the same region as the EC measurement point, but sufficiently far away that in practice the point source rarely contributes to the net vertical flux (Sparks and Toumi, 2010; Ward et al., 2015).

In this paper net CO_2 emissions calculated by two methods (micrometeorological and inventory) are evaluated and compared. The micrometeorological (MM) and inventory (IN) methods are introduced in Section 2, their components evaluated in Sections 5 and 6, respectively, and compared in Section 7. To relate results from one method to another it is necessary to know the area within which surface processes contribute to the measured net emissions – this is done by calculating the source area, described in Section 4. Site details are given in Section 3.

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