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Soil respiration contributes substantially to urban carbon fluxes in the greater Boston area[☆]

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ABSTRACT

Urban areas are the dominant source of U.S. fossil fuel carbon dioxide ($FFCO_2$) emissions. In the absence of binding international treaties or decisive U.S. federal policy for greenhouse gas regulation, cities have also become leaders in greenhouse gas reduction efforts through climate action plans. These plans focus on anthropogenic carbon flows only, however, ignoring a potentially substantial contribution to atmospheric carbon dioxide (CO2) concentrations from biological respiration. Our aim was to measure the contribution of CO_2 efflux from soil respiration to atmospheric CO_2 fluxes using an automated CO_2 efflux system and to use these measurements to model urban soil CO_2 efflux across an urban area. We find that growing season soil respiration is dramatically enhanced in urban areas and represents levels of CO_2 efflux of up to 72% of $FFCO_2$ within greater Boston's residential areas, and that soils in urban forests, lawns, and landscaped cover types emit 2.62 ± 0.15, 4.49 ± 0.14, and 6.73 ± 0.26 $\mu molCO_2\ m^{-2}\ s^{-1}$, respectively, during the growing season. These rates represent up to 2.2 times greater soil respiration than rates found in nearby rural ecosystems in central Massachusetts (MA), a potential consequence of imported carbon amendments, such as mulch, within a general regime of landowner management. As the scientific community moves rapidly towards monitoring, reporting, and verification of CO_2 emissions using ground based approaches and remotely-sensed observations to measure CO_2 concentrations, our results show that measurement and modeling of biogenic urban CO_2 fluxes will be a critical component for verification of urban climate action plans.

1. Introduction

The global urban population is forecast to grow by 2.5 billion people by the year 2050, with seven of every ten people projected to reside in an urban area by mid-century (United Nations, 2014). The spatial extent of urban areas is also projected to triple, increasing by over 1 million km^2 between 2000 and 2030 (Seto et al., 2012). Though fossil fuel carbon dioxide ($FFCO_2$) emissions from cities produce the preponderance of global $FFCO_2$ emissions (Energy Information Administration, 2013), a growing urban population also has the potential to engender per-capita emissions reductions, as cities, particularly in the United States, form the vanguard of the civic response to climate change through local climate action plans (Rosenzweig et al., 2010; Wang, 2012). For climate action plans to be effective, they must be evaluated rigorously and regularly, which requires accurate reporting of greenhouse gas fluxes (e.g. the 2010 CalNex campaign; Ryerson et al., 2013), combined with monitoring and verification of atmospheric carbon dioxide (CO_2) concentrations from ground based measurements and satellite remote sensing (Duren and Miller, 2012; McKain et al., 2012; Rella et al., 2015). However, both of these approaches currently ignore the biogenic contribution to urban atmospheric CO_2 concentrations; bottom-up emissions data treat the urban carbon cycle as entirely driven by fossil fuel emissions (Kennedy et al., 2010; Hutyra et al., 2014) and measurements of column-averaged atmospheric CO_2 concentrations, such as those made by NASA's Orbiting Carbon Observatory (OCO-2) satellite (Boesch et al., 2011), are made without specific attribution between anthropogenic and biogenic sources.

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As early as 1979, researchers suggested that separating anthropogenic and biogenic CO_2 fluxes would be critical for the understanding of urban carbon cycling (McRae and Graedel, 1979). Photosynthesis has been shown to periodically reduce urban atmospheric CO_2 concentrations in diverse locations (McRae and Graedel, 1979; Day et al., 2002; Clark-Thorne and Yapp, 2003; Moriwaki and Kanda, 2004; Coutts et al., 2007; Kordowski and Kuttler, 2010; Pawlak et al., 2011), while ecosystem respiration is known to produce measureable amounts of CO_2 in urban areas (Pataki et al., 2003; Zimnoch et al., 2010; Górka and Lewicka-Szczebak, 2013). Using radioactive isotope tracers, Miller et al. (2012) detected the constant presence of biogenic CO_2 in the lower troposphere near cities and suggested that CO_2 attribution to anthropogenic sources requires measurement and exclusion of biological sources. Despite the evidence that biogenic urban CO_2 fluxes can be important, we still know little about the magnitude of the urban biogenic CO_2 flux relative to $FFCO_2$ emissions on a landscape scale. Rates of CO_2 efflux from soil respiration, a critical component of the biogenic CO_2 flux, have only been measured in a handful of urban studies in mesic systems, and the majority of these studies were either spatially or temporally limited (Kaye et al., 2005; Groffman et al., 2006; Vesala et al., 2008; Groffman et al., 2009; Chen et al., 2014; Chun et al., 2014; Smorkalov and Vorobeichik, 2015; Ng et al., 2015) precluding extrapolation and hindering comparisons with $FFCO_2$ emissions. As total CO_2 efflux from soil respiration dwarfs anthropogenic CO_2 emissions worldwide, urban soil respiration merits a closer look.

The objectives of this study were to quantify rates of growing season CO_2 efflux from soil respiration at high temporal and spatial resolution across the greater Boston, Massachusetts (MA) area and to use these rates to create a spatially explicit model of soil CO_2 efflux along an urbanization gradient. We expected to find higher rates of soil respiration in areas with more intensive landowner management, such as residential areas with pervious surfaces like lawns and flowerbeds. To address our objectives and test our hypothesis, we took direct field measurements of soil respiration using an automated soil CO_2 efflux system and used geographic information systems (GIS) and data from a landowner survey to model these fluxes along a transect originating in downtown Boston and extending 25 km west into suburban Concord, MA.

2. Methods

2.1. Site selection and measurements

The greater Boston area is the 10th largest metropolitan area in the United States (US Census Bureau, 2013) and has a temperate climate, with mean summer and winter temperatures of 21.7 °C and −0.1 °C, respectively, and approximately 110 cm of precipitation per year (National Climatic Data Center). To characterize variations in soil CO_2 efflux across this area, we sampled at 15 sites (Fig. 1) and within three potential cover types at each site: forest, lawn, and landscaped. Sites were chosen with varying amounts of surrounding development (Supplementary Fig. 1). All sites had hardwood tree canopies, no pets, and were in secured locations.

In early May 2014, 20.2 cm-diameter PVC collars were mounted into the soil at each site. After installation, collars were left to equilibrate in the soil for 2–3 weeks to avoid the pulse of CO_2 efflux associated with severed roots caused by installation. Sites that included lawn ($n = 13$), defined as an area whose dominant vegetation was grass at some point during the growing season, received four sample collars, with two collars in the lawn and two collars in

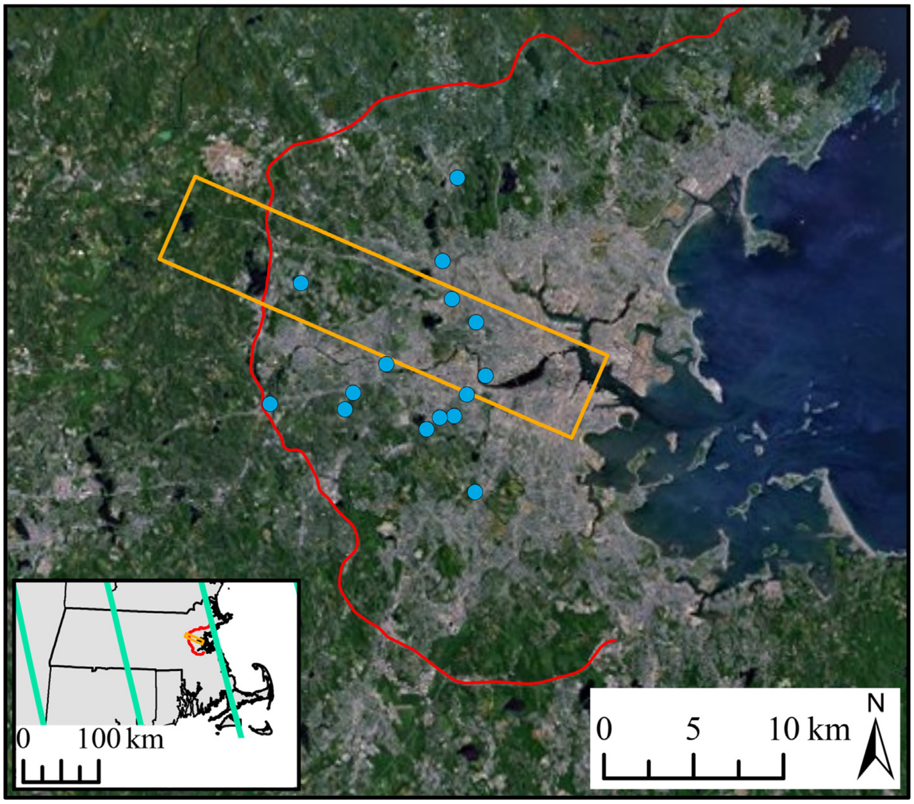

Fig. 1. Study area. Blue points represent soil respiration measurement sites. Orange box outlines 25 km transect from downtown urban Boston to suburban Concord, MA (Fig. 3). Interstate Highway 95 (I-95) is highlighted in red. In the inset, current OCO-2 summer nadir tracks are shown in green. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)