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Latitudinal distribution of soil CO_2 efflux and temperature along the Dalton Highway, Alaska

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Abstract

In this paper, we investigate spatial variations in soil CO_2 efflux and carbon dynamics across five sites located between 65.5°N and 69.0°N in tundra and boreal forest biomes of Alaska. Growing and winter mean CO_2 effluxes for the period 2006–2010 were 261 ± 124 (Coefficients of Variation: 48%) and 71 ± 42 (CV: 59%) gCO_2/m^2, respectively. This indicates that winter CO_2 efflux contributed 24% of the annual CO_2 efflux over the period of measurement. In tundra and boreal biomes, tussock is an important source of carbon efflux to the atmosphere, and contributes 3.4 times more than other vegetation types. To ensure that representativeness of soil CO_2 efflux was determined, 36 sample points were used at each site during the growing season, so that the experimental mean fell within ±20% of the full sample mean at 80% and 90% confidence levels. We found that soil CO_2 efflux was directly proportional to the seasonal mean soil temperature, but inversely proportional to the seasonal mean soil moisture level, rather than to the elevation-corrected July air temperature. This suggests that the seasonal mean soil temperature is the dominant control on the latitudinal distribution of soil CO_2 efflux in the high-latitude ecosystems of Alaska.
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Keywords: Soil CO_2 efflux; Temperature; Moisture; Tundra; Boreal black spruce forest

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1. Introduction

Soil CO_2 efflux to the atmosphere comprises CO_2 generated by the respiration of microbial organisms and plants, and represents the second largest source of terrestrial carbon release to the atmosphere on a global scale (Bond-Lamberty and Thomson, 2010; Raich and Schlesinger, 1992; Schlesinger and Andrews, 2000). Global CO_2 flux, which is currently 98 ± 12 PgC (1 PgC = 10^{15} gC),

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increased by 0.1 PgC/yr between 1989 and 2008. This implies a global CO_2 flux response factor of 1.5 relative to air temperature (Q_{10}), and is consistent with an acceleration of the response of the terrestrial carbon cycle to global climate change (Bond-Lamberty and Thomson, 2010).

The carbon cycle in tundra and boreal forest ecosystems is vulnerable to Arctic climate change, as biological processes (e.g., decomposition and growth) are strongly affected by the degradation of permafrost and the duration of the snow-free season. These phenomena have contributed to tundra greening and boreal forest browning in Alaska (Alcaraz-Segura et al., 2010; Bhatt et al., 2010; Hudson and Henry, 2009; Parent and Verbyla, 2010; Verbyla, 2008). A shorter snow-covered period may contribute to a decrease in winter CO_2 efflux, and an increase in CO_2 efflux during the growing period in the Arctic (Sturm et al., 2005). Therefore, in a high-latitude terrestrial ecosystem, it is important to understand whether it is CO_2 uptake by vegetation, or CO_2 release from the soil, that controls the carbon balance and its response to a changing climate.

Soil temperature and moisture are important parameters in regulating soil CO_2 efflux in terrestrial ecosystems (Bond-Lamberty and Thomson, 2010; Bronson et al., 2008; Davidson and Jassens, 2006; Davidson et al., 1998; Gaumont-Guay et al., 2006a, b; 2008; Lavigne et al., 1997; Lloyd and Taylor, 1994; Rayment and Jarvis, 2000; Xu and Qi, 2001). Also, these parameters have been efficiently validated for ecosystem process-based models for the estimation of a regional carbon budget.

We selected five monitoring sites in the area between 65.5°N and 69.0°N, in the Arctic tundra and sub-Arctic boreal biomes, that we accessed via the Dalton Highway–Trans-Alaska Pipeline corridor in north–central Alaska. Estimated levels of soil CO_2 efflux can be affected by the measurement method used, due to factors such as the chamber size, measurement frequency (e.g., hourly, weekly, seasonal, or annual), and the type of flux measurement system (e.g., automated chamber system or manual system). The variability of soil CO_2 efflux within a constant area can be described by the coefficient of variation (CV), and the number of sampling points required for estimating a statistically significant mean soil CO_2 efflux can be obtained from this CV value. Manual chamber systems can more easily capture the spatial heterogeneity of a site throughout a year; on the other hand, the automated chamber system offers greater measurement frequency during snow-free periods. As this study intended to focus on the spatial heterogeneity of CO_2 efflux at each site, we used a manual chamber system.

-The aims of this research are to: 1) determine the environmental factors regulating the latitudinal distribution of soil CO_2 efflux; 2) evaluate the contribution of winter season CO_2 efflux through the snowpack to annual carbon emission; and 3) assess the spatial representativeness of soil CO_2 efflux within a plot at each site along the Dalton Highway during the growing season.

2. Material and methods

2.1. Site description

We measured soil CO_2 efflux (using the manual chamber system) within 25 × 25 m plots at five sites along the Dalton Highway–Trans-Alaska Pipeline corridor, which spans a distance of 650 km. Approximately 36 measurements (samples) per site were made during the growing season, and 6 to 15 measurements per site during winter. Specifically, we performed measurements in July 2006, August/September 2007, June and August/September 2008, September 2009, and August/September 2010 to represent the growing (snow-free) season, and in February/March 2007, March 2008, March 2009, and January/April 2010 to represent the winter season. The sites were located in biomes defined as upland tundra (UT, northernmost), subalpine tundra (SaT, north slope of Brooks Ranges), ecotone (TZ, a transition zone between the tundra and boreal forest), a younger black spruce forest near Coldfoot (BS1), and an older black spruce forest near Fairbanks (BS2, southernmost), and are shown in Fig. 1 and Table 1 on the description of the site.

Regarding the general pattern of vegetation in northern Alaska, Bliss and Matveyeva (1992) reported low-shrub–dwarf-shrub tundra and sedge–dwarf-shrub tundra as best representing the area. According to Raynolds et al. (2006), the northern foothills of the Brooks Ranges are covered by cotton-grass tussock tundra and dwarf-shrub moss communities. At higher elevations near the Atigan Pass, the vegetation of the subalpine tundra comprises prostrate dwarf-shrub graminoid communities, while the lowlands and uplands of the Tanana-Yukon flats are covered extensively by boreal forest and, in the valley bottoms and lowlands, by wetlands. Soil CO_2 efflux was measured on tussock tundra, non-tussock tundra (such as sphagnum and feather moss, and lichen) within the sample plot at each of the five sites.

The mean temperatures measured at each site in January and July between 2006 and 2010 are shown in Table 2. The temperatures recorded across the sites in January were similar, whereas those from July differed.