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Spatial characteristics of ecosystem respiration in three tundra ecosystems of Alaska

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A B S T R A C T

Ecosystem respiration (ER) is a significant source in estimating terrestrial carbon budget under climate change. Here, we report on the assessment of spatial characteristics of ER, using manual chamber over three tundra ecosystems of Alaska. Annual simulated ER was 254–307 g CO_2 m^{-2} based on *in-situ* air temperature and 212–305 g CO_2 m^{-2} based on soil temperature, at Council, North Slope, and Arctic National Wildlife Refuge (ANWR) sites of Alaska. Growing-season ERs correspond to 79–92% (air temperature) and 81–86% (soil temperature) of simulated annual ER. Hence, soil temperature is a significant driver in modulating ER over tundra, suggesting soil temperature elucidates more than 80% of air temperature. At Council, between 31 and 84 sampling points during the growing season were required to attain spatial representativeness for ER, falling within ±10% of the full sample mean, with a 95% confidence level. At North Slope and ANWR sites, the number of sampling points was chosen to yield results within at least ±20%, with a 90% confidence level. These findings suggest that larger-size chamber and its measurement frequency can overcome logistical constraints and determine mean ER at tundra sites for the quantitative assessment of the tundra carbon budget in response to drastically changing Arctic environment and climate.

1. Introduction

Ecosystem respiration (ER)—the sum of soil microbe- and plant-respired carbon dioxide (CO_2) from the soil surface to the atmosphere—represents the second-largest source of carbon emissions between the atmosphere and the terrestrial ecosystem on a global scale (Schlesinger and Andrews, 2000; Bond-Lamberty and Thomson, 2010). Respiration in the tundra ecosystem depends on both the distribution of vegetation and the content of soil organic matter (SOM), with bioclimate and environmental gradients (Ping et al., 2008), all of which determine the spatial variability of respiration. Oechel et al. (1997) and Grogan and Chapin (2000) demonstrated that CO_2 exchange in tussock community was an order of magnitude greater than in wet sedge in the Arctic tundra ecosystem of Alaska. In other words, according to vegetation distribution, CO_2 production rate depends on different decomposition rates of SOM (Phillips et al., 2011), as well as on differences in environmental elements such as soil temperature and soil moisture. Further, it is widely observed that soil temperature and soil moisture play significant roles in determining respiration rates in the terrestrial ecosystem (Lloyd and Taylor, 1994; Davidson and Janssens, 2006; Bond-Lamberty and Thomson, 2010; Kim et al., 2013).

Tussock cotton grass (Eriophorum vaginatum) inhabits flat to moderate (up to about 27% (15°)) slopes underlain by permafrost (Wein, 1973; Alpert and Oechel, 1984; Kummerow et al., 1988). Tussock cotton grass communities occur in lowlands, coastal plains, patterned ground resulting from geomorphic and freeze–thaw processes (e.g., tops of high-centered polygons, rims of low-centered polygons, edges of frost boils), rolling uplands, gentle foothill slopes, flat summits, plateaus, and boreal zones (Hulten, 1968; Bliss et al., 1973; Chapin, 1974; Peterson and Billings, 1980; Kummerow et al., 1988). Gently sloping (<5%)

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areas of tussock cotton grass tundra cover wide expanses of northern Alaska, Canada, and Russia (Wein, 1973). Hence, tussock represents both widely distributed and typical vegetation in Arctic tundra and boreal forest ecosystems of the pan-Artic region (Miller et al., 1983; Oechel et al., 1997; Whalen and Reeburgh, 1988; Walker et al., 2008; Kim et al., 2013). Tussock tundra in Alaska is also a well-known source of carbon efflux to the atmosphere (Oechel et al., 1997; Kim et al., 2013). In two tundra sites across the North–South transect during the growing seasons of 2006–2010, Kim et al. (2013) noted that mean soil CO_2 effluxes from tussock and non-tussock (e.g., moss and lichen) regimes were 29.7 ± 6.8 and 8.8 ± 6.6 mgCO_2 m^{-2} min^{-1}, respectively. This suggests that soil-originated CO_2 emissions in tussock were much higher than in non-tussock vegetation, as well as a significant source of atmospheric CO_2 in the Alaska ecosystem. Further, Oechel et al. (1997) reported that even winter CO_2 efflux within tussock was a significant CO_2 source, and was much greater than in wet sedge on the Arctic coastal tundra plain of Barrow, Alaska. Our study provides understanding of spatial ecosystem respiration (ER) at three different tundra sites, generating evaluations of carbon budgets on local, regional, and Arctic scales.

Estimated levels of ER can be affected by the measurement methods used, due to factors such as chamber size (e.g., active cross-section), measurement frequency (e.g., hourly, weekly, seasonal, and annual), and efflux-measuring system type (e.g., manual or automated chamber). The spatial variability of ER within a constant area can be described by the coefficient of variance (CV, %), and the number of measuring points required for estimating a statistically significant mean ER can be obtained from this CV value. Manual chamber systems can more easily capture the spatial heterogeneity of a site; on the other hand, an automated chamber system offers greater measurement frequency during snow-free periods (Davidson et al., 2002; Hutchinson and Livingston, 2002; Savage and Davidson, 2003). As this study also intends to focus on the spatial heterogeneity of ER at each site, we used a manual chamber system to examine the spatial variability of ecosystem respiration, within three different tundra environments of Alaska. For example, Yim et al. (2003) calculated that the CV for spatial variability in soil respiration across 50 sampling points within a 30 × 30-m plot was 28%, using a small active area chamber (0.0125 m^2) within a larch plantation of Hokkaido, Japan in late August 2000. Average numbers for sampling points required for estimating soil respiration within 10% and 20% of its true mean, at the 95% confidence level, were estimated as 26 and 6, respectively. Therefore, the objectives of this study were to 1) evaluate the dependence of temperature on ecosystem respiration within different tundra ecosystems, and 2) assess the spatial characteristics of ecosystem respiration using a manual chamber system within a constant plot at three distinct environmental locations in Alaska (e.g., Council, North Slope, and ANWR), all of which are remote, extremely difficult to access, and require permitting for the investigation from the Alaska Department of Fish and Game and the Bureau of Land Management (BLM) of the Department of Interior.

2. Material and methods

2.1. Research site

The three research sites observed in Alaska are remotely isolated, managed, and protected by federal and/or state government, representing a relatively undisturbed tundra ecosystem. Council, the North Slope, and ANWR are located in western, northern, and northeastern Alaska, respectively (Fig. 1). Table 1 lists the geographical features of each site, showing distinct differences in weather patterns and dominant plant species among the sites,

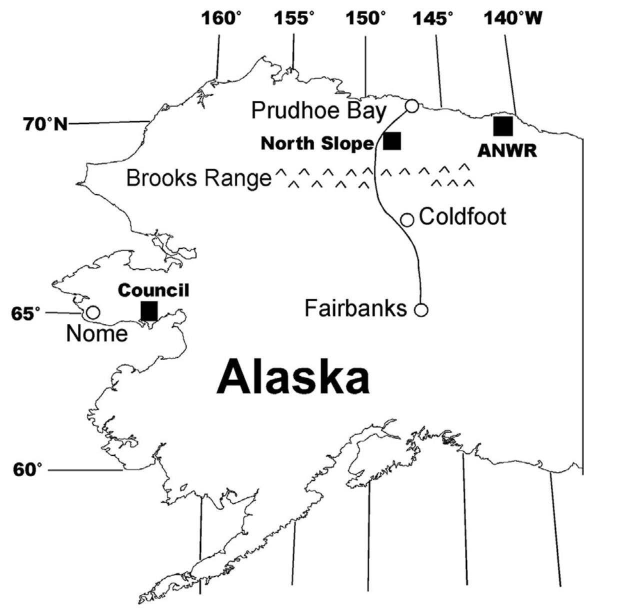

Fig. 1. Site locations: Council on the Seward Peninsula, the North Slope, and ANWR (Arctic National Wildlife Refuge), Alaska.

indicating differences in latitudinal and longitudinal distributions. Annual average air temperature and precipitation for these three sites were calculated from 6-, 25-, and 40-year measured data (National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA)). Fig. 2 shows daily mean soil temperature monitored at 5 cm depth below the soil surface at each site. Mean (and range) for observed soil temperatures at Council (2011), North Slope (2011), and ANWR (2008) were −0.6 (−15.4 to 15.7) °C, −6.4 (−21.0 to 13.8) °C, and −5.8 (−22.3 to 11.5) °C, respectively, while daily mean (and range) air temperatures were −2.8 (−33 to 16.7) °C, −13.7 (−46.6 to 27.2) °C, and −10.2 (−35.6 to 11.7) °C. Experimental plot size was 40 × 40 m (total 81 points; 5-m interval) at Council, 30 × 30 m (49 points; 5-m interval) at North Slope, and 40 × 100 m (55 points; 10-m interval) at ANWR. We performed ER observations at each point during the given growing season. At Council, I have measured two-time ERs for seven days a month at 81 points. Considering the constraints of accessibility and weather conditions, I conducted ER once for two days at 49 points at the North Slope site, and once for a week at 55 points at the ANWR site. Further, daytime (11am–6 pm) ER measurement was conducted at each Alaska site during summer. Summer in Alaska includes three months of sunlight throughout most of the day and night.

The thickness of organic matter layer is 22, 30, and 20 cm in Council, North Slope, and ANWR (Watanabe et al., 2012), respectively.

2.2. Ecosystem respiration (ER)

The system consisted of a chamber (24-cm diameter; 17-cm height), pump (flow rate: 1.0 L min^{-1}; CM-15-12, Enomoto Micro Pump Co., Japan), NDIR (non-dispersive infra-red) CO_2 analyzer (Licor-820, Licor Inc., USA), commercial 12-V battery, a Gelman filter and $Mg(ClO_4)_2$ column for removal of dust and water vapor, and a laptop computer running efflux calculation software (Savage and Davidson, 2003; Kim et al., 2013). After insertion of the stainless steel chamber base (24-cm diameter; 10-cm height; active cross section of 0.045 m^2) into the soil surface, we measured ER using the manual chamber system at each site after several days of