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The temperature sensitivity of ecosystem respiration to climate change in an alpine meadow on the Tibet plateau: A reciprocal translocation experiment

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ABSTRACT

Information about the potential effects of climate change, especially cooling, on ecosystem respiration (Re) in alpine meadows is scarce. We determined the effects of warming and cooling on Re on the Tibetan Plateau using a 2-year reciprocal translocation experiment with 4 different vegetation types (3 alpine meadows and 1 alpine shrub differentiated by plant community composition) along an elevation gradient from 3200 to 3800 m (with vegetation types E2, E4, E6 and E8 at 3200, 3600, 3800 and 3800 m, respectively) during the growing seasons in 2008 and 2009. Mean growing seasonal Re decreased by 13.6, 30.3 and 40.7% per 200 m rise in elevation (cooling) for vegetation types E2, E4 and E6, but increased by 1.3, 35.9 and 58.8% per 200 m decrease in elevation (warming) for vegetation types E4, E6 and E8, respectively. Soil temperature explained 49.3–64.0% of daily Re variation and aboveground biomass explained 21.5–61.6% of average Re variation of the growing season for all vegetation types, but the effect of soil moisture on Re was small over 2-year. The values of Re temperature sensitivity increased with an increase in elevation for both warming (3.3, 24.3 and 53.5% $^{\circ}C^{-1}$ for vegetation types E4, E6 and E8) and cooling (8.0, 19.1 and 24.4% $^{\circ}C^{-1}$ for vegetation types E2, E4 and E6), suggesting that alpine meadow at higher elevation was more sensitive to both warming and cooling. Based on the values of Re temperature sensitivity for all pooled vegetation types (25.4, 5.6 and 19.6% $^{\circ}C^{-1}$ for warming, cooling and pooled warming and cooling), it could be over-estimated by 23% for warming alone compared with pooled warming and cooling. Therefore, asymmetrical responses of Re to warming and cooling should be taken into account when we evaluate the effect of temperature change on Re using models in the future.

1. Introduction

Ecosystem respiration (Re) accounts for a large proportion of gross fluxes in the annual carbon budget, and small changes in Re may cause significant variation in atmospheric CO_2 (Griffis et al., 2004; Grogan and Jonasson, 2005). The global average surface temperature increased by 0.74 °C in the 100 years from 1906 to 2005 and an additional increase of 1.8–4.0 °C is expected by the end of this century (IPCC, 2007). A large amount of carbon stored in soil

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in cold regions in arctic and alpine areas will probably be released into the atmosphere through respiration in a warmer future (Grulke et al., 1990; Oechel et al., 1993), providing positive feedback to global warming. Hence, many simulation experiments at the field scale have been established to investigate the potential responses of carbon (C) exchange between terrestrial ecosystems and the atmosphere to climate change (Bergner et al., 2004; Biasi et al., 2008; De Boeck et al., 2007; Grogan and Chapin III, 2000; Lin et al., 2011; Luo et al., 2001; Xia et al., 2009). Most previous climate change experiments have focused on warming but ignored cooling effects, which remain relevant as surface temperature tends to fluctuate (IPCC, 2007) and rapid cooling events have occurred during the Holocene (Link et al., 2003; Mayle and Cwynar, 1995) due to solar activity and El Niño strength (Sirocko et al., 2012). Thus, a lack of attention to ecosystem response to cooling may create uncertainty about the response of Re to temperature change in the future.

The Qinghai-Tibetan Plateau is the largest grassland unit on the Eurasian continent with an area of approximately 2.5 million km^2, most of which situated 3500 m or more above sea level (a.s.l.) (Zheng et al., 2009). The alpine meadow and alpine shrub are the two important vegetation types on the plateau, which cover 0.48 and 0.11 million km^2, respectively (Sun, 1996). On the mountainous Qinghai-Tibetan Plateau, plant community composition, soil properties and biomass production vary along the altitudinal gradient of mountains due to differences in environmental factors (Wang et al., 2007, 2008), which causes large variations in Re at different elevations along the mountain slopes (Hirota et al., 2009). The Tibetan Plateau is considered to be one of the most sensitive ecosystems to global climate change (Liu and Chen, 2000) and evidence indicates that the Qinghai-Tibetan Plateau is experiencing climate warming (Duan et al., 2006; Thompson et al., 1993) with “much greater increases than average” surface temperature (Giorgi et al., 2001; Hansen et al., 2006). However, according to data collected over 44 years from 1957 to 2000 at Haibei Alpine Meadow Ecosystem Research Station (Appendix A), the annual average surface temperature in 22 out of the 44 years was lower than average, while it was higher than average in 19 out of the 44 years, suggesting that warming and cooling spells have occurred in the past 44 years in this region (Li et al., 2004). Although the relationship between carbon exchange and environmental change in alpine meadows on the Tibetan Plateau has been widely studied (Hirota et al., 2010; Kato et al., 2004, 2006; Lin et al., 2011; Saito et al., 2009; Zhao et al., 2006), the responses of various vegetation types to climate change, especially to climate cooling, has rarely been studied and is very unclear.

The environmental gradient method, especially the reciprocal translocation method, which can simultaneously provide warming and cooling effects with a wide range of temperature differences in time and space, is widely used to study the responses of C processes to climate change (Hart, 2006; Kleja et al., 2008; Luo et al., 2010; Xu et al., 2010b). Aboveground biomass, an important contributor to Re, has been usually used as a proxy of Re (Flanagan and Johnson, 2005; Suyker and Verma, 2001) and is sensitive to warming (Lin et al., 2011; Wang et al., 2012). The responses of biomass to warming and cooling might be different due to differences in plant community composition and soil physicochemical properties along the slope of the mountain (Wang et al., 2008) affecting the variation of Re. Here, we studied the effects of warming and/or cooling on Re on the Qinghai-Tibetan Plateau using a 2-year reciprocal translocation experiment with 4 different alpine meadow vegetation types along an elevation gradient from 3200 to 3800 m during the growing seasons in 2008 and 2009. The objectives of this study were (1) to determine the effects of climate change (warming and cooling) on Re of different vegetation types at different timescales (daily, monthly and seasonal scales) during the growing seasons; (2) to evaluate the relationship between Re and environmental factors (soil temperature and moisture) and plant biomass; and (3) to assess Re temperature sensitivity of various vegetation types in the alpine meadow region.

2. Materials and methods

2.1. Study site

The experiment was performed at Haibei Alpine Meadow Ecosystem Research Station (HBAMERS) (37°37′ N, 101°12′ E), which is located in the northeast of the Qinghai-Tibetan Plateau. Mean elevation of this station is 3200 m. The station experiences a typical plateau continental climate, which is dominated by the southeast monsoon in summer and high pressure from Siberia in winter. Summer is short and cool, and winter is long and severely cold. Mean annual air temperature and precipitation from 1981 to 2000 were −1.7 °C and 561 mm, with maximum monthly mean temperature of 10 °C in July and a minimum of −15 °C in January. About 80% of annual precipitation falls during the growing season from May to September (Li et al., 2004) with a short growing season of approximately 134 days. Details about the site can have been reported by Zhao and Zhou (1999).

2.2. Experimental design

Details of the experimental design were reported by Wang et al. (2014a,b). Briefly, four 20-m long × 8-m wide plots were fenced at 3200 (37°36′42.3″ N, 101°18′47.9″ E), 3400 (37°39′55.1″ N, 101°19′52.7″ E), 3600 (37°41′46.0″ N, 101°21′33.4″ E) and 3800 m (37°42′17.7″ N, 101°22′09.2″ E) to avoid grazing from animals. The sites at each elevation had different alpine vegetation types (named vegetation type E2, E4, E6 and E8 at 3200, 3400, 3600 and 3800 m, respectively) (Fig. 1A). The soil depth is about 60–80 cm at 3200 and 3400 m and shallower (about 30–50 cm) at 3600 and 3800 m. Translocation of 30–40 cm intact soil depth caused only minimal damage to plant roots because 85% of total root biomass within a 40 cm soil depth is distributed above 10 cm (Wang and Shi, 1999). After the soils started to thaw in early May 2007, 12 intact soil blocks (length × width × depth = 1.0 × 1.0 × 0.3–0.4 m, with 30 cm depth at 3800 m due to a shallower soil layer) with attached vegetation from each elevation were cut off. Three of these 12 intact soil blocks reinstated at the same site (homesite) as control blocks that had been handled as similarly as possible to those blocks that were moved to other elevations. Another 9 intact soil blocks were transferred to the other 3 elevation site (translocated site). All intact soil blocks were fully randomized, transferred and surrounded by plastic to prevent any exchange with the ambient soil environment. Thus, this experiment consisted of 48 intact soil blocks (4 elevations, 4 vegetation types and 3 replicates for each vegetation type). Vegetation type E2 is dominated by *Kobresia humilis*, *Festucaovina, Elymus nutans*, *Poa spp.*, *Carex spp.*, *Scripus distigmaticus*, *Gentiana straminea*, *Gentiana farreri*, *Leontop odiumnanum*, and *Potentilla nivea* (Lin et al., 2009). Vegetation type E4 is dominated by alpine shrub *Potentilla fruticosa*, and jointly by *K. capillifolia*, *K. humilis*, *Saussurea superba*. Vegetation type E6 is dominated by *K. humilis*, *S. katochaete Maxim*, *P.nivea*, *Thalictrum alpinum*, *Carex spp.*, *Poa spp.*, and *P. fruticosa*, and vegetation type E8 is dominated *K. humilis*, *L. odiumnanum* and *Poa spp.* (Wang et al., 2014b).

In August of 2008 and 2009, plant aboveground biomass was estimated using a non-destructive sampling method (Klein et al., 2007; Wang et al., 2012). In brief, the mean height and coverage of the vegetation canopy were measured using a 1.0 m × 1.0 m quadrant divided into 100 0.1 m × 0.1 m squares each plot. The height of each plant was recorded for each species by means of 0.1 cm marks along a vertical ruler held behind the pin in a way that did not