Cold Regions Science and Technology 90–91 (2013) 1–8

Contents lists available at SciVerse ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Impact of experimental warming on soil temperature and moisture of the shallow active layer of wet meadows on the Qinghai-Tibet Plateau

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ARTICLE INFO

Article history:
Received 7 November 2012
Accepted 2 March 2013

Keywords:
Soil moisture
soil temperature
wet meadow
active layer
climatic change
Qinghai–Tibet Plateau

ABSTRACT

Climate change is now increasingly evident on the Qinghai–Tibet Plateau and has a strong impact on both the abiotic and biotic components of ecosystems, particularly on permafrost, active layer thickness, vegetation, and soil properties. Permafrost ecosystems are recognized to be sensitive to the influences of the changing climate, which may disturb the permafrost soil carbon (C) pool and lead to huge C emissions. To facilitate the assessment of warming effects on the temperature and moisture patterns in the shallow soil of the active layer of the wet meadows on the Qinghai–Tibet Plateau, near-surface air temperature was passively increased by using open-top chambers (OTCs) with two different temperature increments. Soil temperature and moisture were continuously monitored at depths of 5, 20, and 40 cm at hourly intervals in a wet meadow in the Beiluhe region on the Qinghai–Tibet Plateau from October 1, 2007 to June 24, 2009. When near-surface air temperature increased by 5.29 °C and 1.84 °C in the OTC2 and OTC1 plots, respectively, relative to the control plots, soil temperatures at depths of 5, 20, and 40 cm were seen to increase by 3.84°C, 2.23°C, and 1.42 °C, respectively, in the OTC2 plots and by 0.94°C, 0.27°C, and 0.25 °C, respectively, in the OTC1 plots. Soil moisture content at depths of 5, 20, and 40 cm declined by 8.04%, 1.79%, and 1.52%, respectively, in the OTC2 plots and by 5.33%, 0.69%, and 0.09%, respectively, in the OTC1 plots. Near-surface warming was found to extend the continuous thawing time of the shallow soil, delay the occurrence of the autumnal freezing process, and shorten the duration of continuous freezing. It was also seen to increase both the temperature of the shallow soil and the accumulated temperatures at different depths. Near-surface warming could be one of the main factors leading to the degradation of vegetation, thus threatening the stability of the soil C pool and the ecological safety of the Qinghai–Tibet Plateau.

1. Introduction

The climate is now clearly undergoing a warming trend and the active layer is thickening in permafrost regions (Hinzman et al., 2005; Osterkamp, 2005; Polyakov et al., 2002) and directly affect the terrestrial hydrological cycle, ecosystems, and climate feedback (Andrew et al., 2011; Guglielmin et al., 2011; Kimball et al., 2004; Zhang and Armstrong, 2001; Zhang et al., 2003a).

The Qinghai–Tibet Plateau is the only region in the world where permafrost is present at mid-latitudes, and it is considered to be more sensitive to climatic warming than the arctic region at high latitudes (Zhang et al., 2003b; Zhou et al., 2000). Scientists predict that the Qinghai–Tibet Plateau will experience "much greater than average" increases in surface temperatures in the future (IPCC, 2007). The temperature of the Qinghai–Tibet Plateau is currently rising at the rate of 0.01°C–0.03°C per year (Wei et al., 2003) and the temperature of the shallow soil is ever increasing (Zhang et al., 2008). This has resulted in the acceleration of permafrost degradation and the deepening of the active layer, and has seriously affected the surface energy balance and plant growth (Zhang et al., 2005). Studies in the arctic regions have shown that alpine ecosystems in the cryosphere are quite sensitive to global climatic changes that can cause dramatic changes in their soil properties, the form and quantity of the water they contain, and their soil CO_2 cycle, besides exerting a profound influence on all global ecosystems (Christensen et al., 2004; Jorgenson et al., 2001). As these cryosphere ecosystem responses may positively or negatively feed back to atmospheric CO_2 concentrations and thus affect future climates, they are critical for our understanding of these cryosphere ecosystems (Christensen et al., 2004). On the Qinghai–Tibet Plateau, 12.3 Pg of carbon (C) is stored in the shallow active layer in the permafrost region (Luo et al., 2000; Wang et al., 2002). Changes in soil moisture and temperature affect the decomposition of soil organic C (Nelson et al., 2002), leading to high levels of gaseous C entering the atmosphere and acting as positive feedback for global warming.

Wet meadows that constitute the main type of land in the permafrost regions on the Qinghai–Tibet Plateau are located in the source areas of several large rivers, including the Yangtze and Yellow Rivers, thereby playing an important role in regulating river flow and the

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http://dx.doi.org/10.1016/j.coldregions.2013.03.005

productivity of local grazing grasslands (Wang et al., 2001, 2002; Zhao et al., 2005; Zhou, 2001). To date, literature reports on the effects of increasing temperature on this high-cold ecosystem mainly focus on aspects such as grassland productivity, degradation of permafrost and vegetation, and soil respiration (Li et al., 2000; Wang and Cheng, 2001; Wang et al., 2005a, 2005b, 2007; Zhou et al., 2004). The effects of increasing temperature on the moisture and temperature patterns in the shallow active layer of the permafrost regions remain less studied. Therefore, our study seeks to examine the effects of warming on the patterns of temperature and moisture in the shallow active layer of the permafrost regions with widely distributed wet meadows on the Qinghai–Tibet Plateau. It will be helpful to understand the energy exchange process of the permafrost–soil–atmosphere vegetation and the change trend of soil temperature and moisture due to future climate changes, and also provide references for predicting the development of wet meadow ecosystems.

2. Materials and methods

2.1. Study site

This experimental study was undertaken in a wet meadow ecosystem, which represents a common type of (45% in area) vegetation in the Beiluhe region (34°51.26′N, 92°56.35′E and Fig. 1) in the hinterland of the Qinghai–Tibet Plateau, China. The study site represents an area of 85.6 km^2 at an altitude of approximately 4600–4800 m. The climate is cold and dry; the mean annual temperature is −3.60 °C (Sun et al., 2012), and the mean annual precipitation is 423.79 mm, 80% of which falls during the growing season (from May to September). The study site is usually underlain by permafrost and the type of vegetation found here is that of the wet meadow. The wet meadow ecosystem is populated by hardy perennial hygrophilous or hygromesophilic herbs under waterlogged or moist soil conditions. The primary vegetation consists *of Kobresia tibetica* Maximowicz, *Stipa aliena* Keng, and *Festuca* spp. (Wang et al., 2001; Zhou, 2001).

2.2. Experimental design

In this study, we followed the methods of the International Tundra Experiment and used open-top chambers (OTCs) as passive warming devices to generate an artificially warmed environment (Marion et al., 1997; Molau and Mølgaard, 1996). The experiment was conducted with a comparative trial design in a wet meadow with a vegetation coverage of above 85%. In September 2007, we installed six OTCs (three pairs of two heights) in the wet meadow. The OTCs are hexagonal in shape with 60° inwardly inclined sides and are made of 4 mm-thick, translucent synthetic glass having high solar transmittance at visible wavelengths (about 90%) and low transmittance in the infrared (heat) range (<5%) (Marion et al., 1997) (Fig. 2). The length of each side of the hexagonal openings of all OTCs was 34.6 cm, and the area covered by OTCs of 40 and 80 cm height was 0.98 and 2.01 m^2, respectively. A control plot (100 × 100 cm, 1 m^2) was also established in the vicinity of each OTC pair, thus three such control plots were set up. These OTCs were in use throughout the entire period of the experiment. To compare the warming effects of the OTCs, temperature and relative humidity were measured at 20 cm height with a shielded humicap in the center of OTC and control plots (Vaisala HMP45AC, Finland), and soil temperatures at depths of 5, 20, and 40 cm below the surface of the soil were taken with thermistor sensors, which were calibrated before using with an accuracy of ±0.05 °C and a resolution of 0.01 °C. These sensors were fabricated by the State Key Laboratory of Frozen Soil Engineering and have been applied in measuring soil temperature for nearly 20 years on the Qinghai–Tibet Plateau. Soil moisture was measured at depths of 5, 20, and 40 cm with calibrated soil moisture sensors with resolution of 0.1% (CS616, USA) in the OTC and control plots at the wet meadow study site. To minimize soil disturbance and reduce measurement errors, a suit of installation tool was used to help the

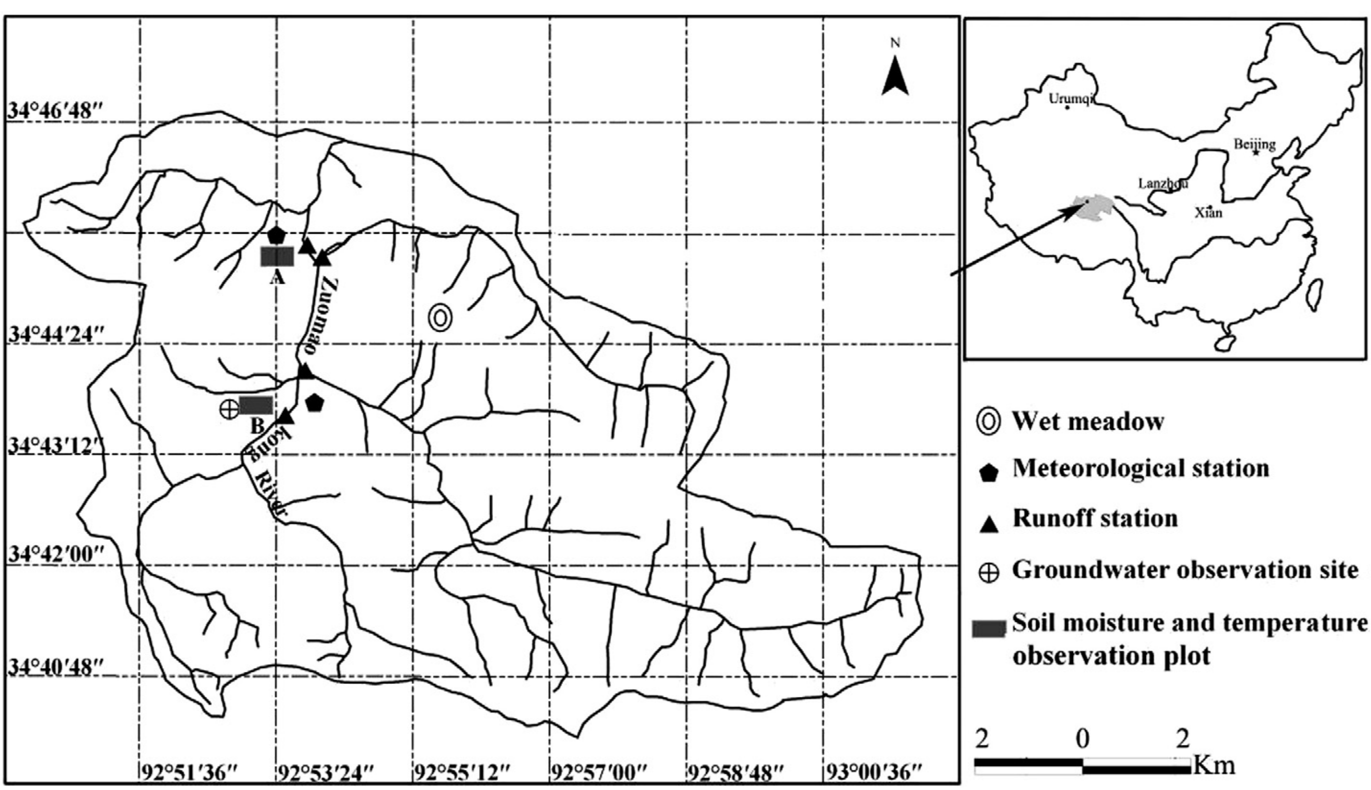

Fig. 1. Location of the study site in the Beiluhe region of the Qinghai–Tibet Plateau, China.