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Short communication

Growth response of alpine treeline forests to a warmer and drier climate on the southeastern Tibetan Plateau

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ABSTRACT

Forest growth at high altitudes and latitudes is sensitive to climate warming. However, warming-induced drought stress has decreased forest growth and survival rates, and constitutes a key uncertainty in projections of forest ecosystem dynamics. A fast warming rate has occurred over the Tibetan Plateau (TP), and the response pattern of alpine forest growth on the TP to a warmer and possibly drier climate is still unknown. By compiling tree-ring width records from ten alpine treeline ecotones (ATEs), we developed an index of regional tree growth in ATEs (RTGA) on the southeastern TP, which is a major forested region of the TP. Our results showed a stable and clear coherence between RTGA and the regional summer (June-August) minimum temperature during the studied period (1950–2012, $R^2 = 0.59$, $P < 0.001$), despite a prominent drying trend since the 1990s. We conclude that warming-induced drought stress has not limited ATE forest growth on the moist southeastern TP.

1. Introduction

Warming rates that are faster than the global mean have been observed at high elevations and latitudes (Brohan et al., 2006; Pepin et al., 2015). Forest growth at the upper altitudinal and high latitudinal limits is generally limited by low temperatures; therefore, the growth of these forests has been considered to be particularly sensitive to climate warming (Korner and Paulsen, 2004; Rossi et al., 2007). However, growing evidence of decreased tree growth rates and increased drought sensitivity in the northern high latitudes has been reported (Briffa et al., 1998; Driscoll et al., 2005; Hellmann et al., 2016; Porter and Pisaric, 2011; Wilmking et al., 2004). This phenomenon, known as the divergence problem (DP), has been mainly attributed to drought stress aggravated by warming and has caused a high degree of uncertainty in tree-ring-based climate reconstructions and forest growth projections (D'Arrigo et al., 2008; Hellmann et al., 2016). The DP has mainly been observed in northern high latitudes; however, it has seldom been tested in regions with high elevations, such as the Tibetan Plateau (TP).

In recent decades, the rate of warming on the TP has been faster than that recorded across the Northern Hemisphere and that in other regions at the same latitude (Liu and Chen, 2000; Kang et al., 2010). In association with a fast rate of warming, precipitation has been reported to limit forest growth at the alpine treeline ecotone (ATE) in the dry regions of the TP, such as in the northeast (Liang et al., 2016a; Liu et al., 2006; Yang et al., 2013) and on the northern slope of the Himalayas (Liang et al., 2014), since the 1950s. Drought stress induced by fast warming is responsible for ATE forest growth limitation in both regions (Liang et al., 2016a; Schwab et al., 2018).

Nevertheless, forest growth has showed substantial spatial incoherence in different regions of the TP due to diverse hydrothermal conditions (Brauning and Mantwill, 2004). A comprehensive understanding of the climate response patterns of ATE tree growth is essential for predicting alpine forest growth on the TP. On the southeastern TP, where the highest alpine treeline in the world is located (Miehe et al., 2007), increased ATE forest growth has been reported in site-specific studies. However, whether the growth stimulation is due to increased CO_2 concentration or increased growing season temperature is still unclear (Huang et al., 2017; Li et al., 2017). Moreover, attribution of

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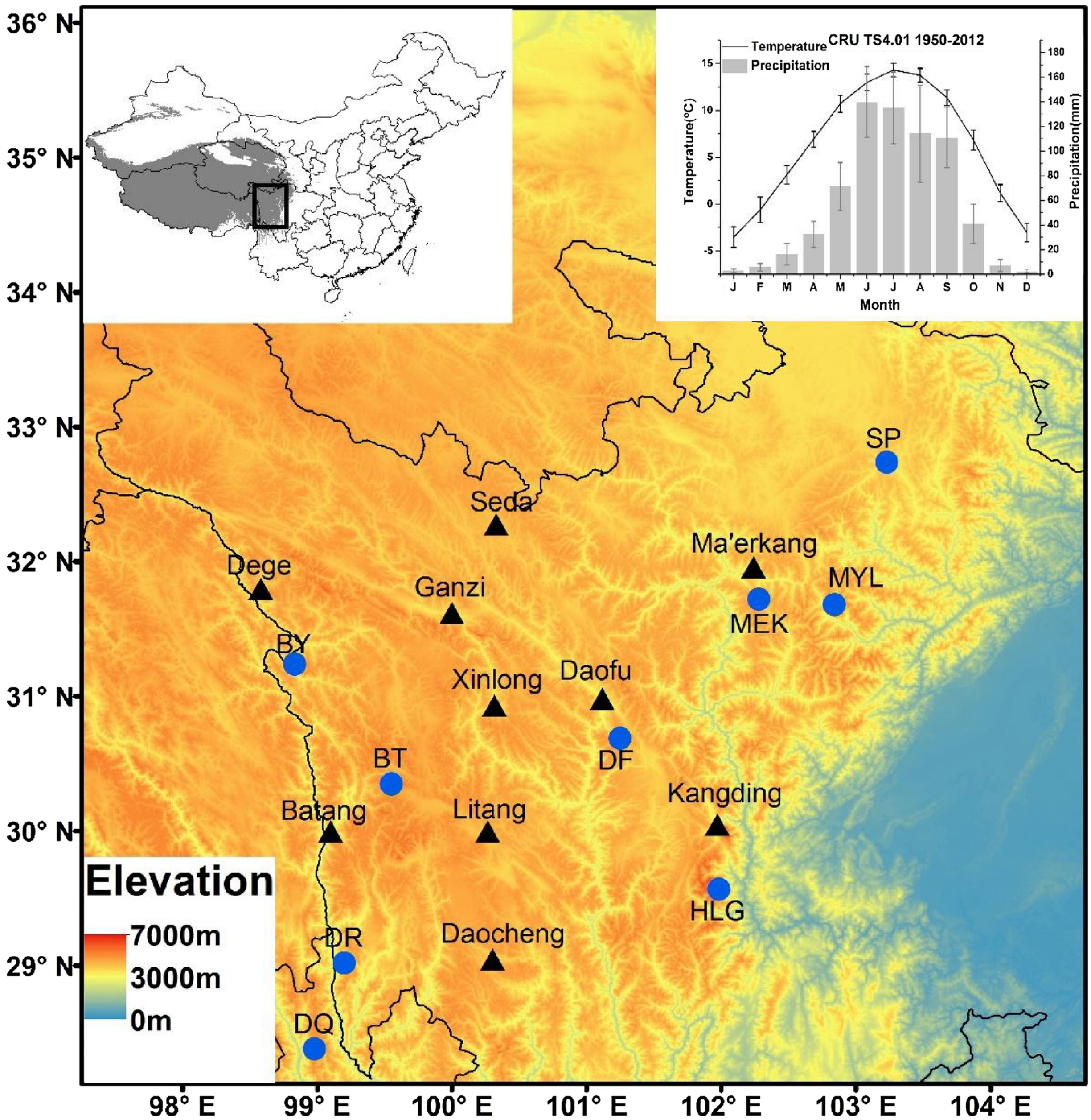

Fig. 1. Sampling sites (blue circles) and meteorological stations (black triangles). The top left insert shows the TP (grey shading depicting elevation 3000 m a.s.l.), with a black rectangle delimiting the region shown in the main figure. The top right insert is the 1950–2012 CRU TS4.01 dataset monthly mean temperature (black curve) and precipitation (grey bars) in the study region (28–33 °N, 98.5–103.5 °E). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Latitude (Lat.), longitude (Long.), mean elevation (Elev.) of trees, tree species, and number of trees (No. tree) sampled at each site and the time span of each TRW chronology with an expressed population signal (EPS) value greater than 0.85.

ID	Lat.	Long.	Elev.	Species	No. tree	Chrono. span
BT	30.35	99.55	4160	*Abies squamata*	36	1675-2011
DR	29.02	99.20	4221	*Abies squamata*	37	1752-2011
MEK	31.72	102.28	3967	*Abies faxoniana*	34	1774-2013
DF	30.67	101.25	4113	*Abies squamata*	38	1795-2012
BY	31.24	98.83	4012	*Abies squamata*	38	1796-2012
MYL	31.68	102.84	4150	*Abies faxoniana*	57	1826-2009
HLG	29.57	101.99	3750	*Abies squamata*	26	1869-2012
SP	32.74	103.23	3611	*Picea asperata*	32	1645-2014
DQ	28.38	98.98	4200	*Larix potaninii*	46	1696-2003
MYL	31.68	102.84	3750	*Sabina saltuaria*	37	1796-2009

alpine forest growth variability could be biased by non-climatic factors at the local scale, including inter- and intra-species competition (Liang et al., 2016b; Qi et al., 2015; Wang et al., 2016), soil nutrient availability (McNown and Sullivan, 2013; Sullivan et al., 2015), and topography (Liu et al., 2016; Salzer et al., 2014; Wang et al., 2017). Therefore, a better understanding of the climate response of ATE tree growth at the regional scale could improve our ability to predict regional alpine forest growth.

In this study, we addressed the question of whether the DP exists for forest growth in ATEs on the southeastern TP through a regional tree-ring chronology network and gridded climate data. Specifically, we aimed to understand the following: 1) the relative importance of different climate variables in controlling local and regional ATE forest growth and 2) the temporal stability of the climate response of regional ATE forest growth.