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Temperature sensitivity of spring vegetation phenology correlates to within-spring warming speed over the Northern Hemisphere

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ABSTRACT

The inter-annual shift of spring vegetation phenology relative to per unit change of preseason temperature, referred to as temperature sensitivity (days °C^{-1}), quantifies the response of spring phenology to temperature change. Temperature sensitivity was found to differ greatly among vegetation from different environmental conditions. Understanding the large-scale spatial pattern of temperature sensitivity and its underlying determinant will greatly improve our ability to predict spring phenology. In this study, we investigated the temperature sensitivity for natural ecosystems over the North Hemisphere (north of 30°N), based on the vegetation phenological date estimated from NDVI time-series data provided by the Advanced Very High Resolution Radiometer (AVHRR) and the corresponding climate dataset. We found a notable longitudinal change pattern with considerable increases of temperature sensitivity from inlands to most coastal areas and a less obvious latitudinal pattern with larger sensitivity in low latitude area. This general spatial variation in temperature sensitivity is most strongly associated with the within-spring warming speed (WWS; $r = 0.35$, $p < 0.01$), a variable describing the increase speed of daily mean temperature during spring within a year, compared with other factors including the mean spring temperature, spring precipitation and mean winter temperature. These findings suggest that the same magnitude of warming will less affect spring vegetation phenology in regions with higher WWS, which might partially reflect plants' adaption to local climate that prevents plants from frost risk caused by the advance of spring phenology. WWS accounts for the spatial variation in temperature sensitivity and should be taken into account in forecasting spring phenology and in assessing carbon cycle under the projected climate warming.

1. Introduction

Spring vegetation phenology documents the onset of photosynthetic activity. The time shifts in spring vegetation phenology have strong influences on carbon cycle and energy balance in terrestrial ecosystems (Piao et al., 2007; Richardson et al., 2010; White et al., 1999), and in turn may show feedback to climate system by altering the land-atmosphere energy exchange (Jeong et al., 2009; Peñuelas et al., 2009; Schwartz and Crawford, 2001). Temperature is recognized as the main factor that controls spring phenology for temperate and boreal vegetation over the Northern Hemisphere (e.g., Zhang et al., 2004). A large number of studies reported that climate warming during recent decades has caused widely the time shift of spring vegetation phenology, albeit with different magnitude, over regional or global scales (Cleland et al., 2007; Myneni et al., 1997; Parmesan and Yohe, 2003; Peñuelas and Filella, 2001; Walther et al., 2002; Shen, 2011; Dragoni et al., 2011; Gonsamo et al., 2013; Shen et al., 2014b; Ge et al., 2014). To quantify the response of spring phenology to the change in thermal environment, it is becoming increasingly important to focus on the inter-annual change in spring phenology relative to per unit change in temperature, referred to as the temperature sensitivity (days °C^{-1}) (e.g., Matsumoto et al., 2003; Menzel et al., 2006; Wolkovich et al., 2012; Lapenis et al., 2013). Temperature sensitivity is considered to be one of the most sensitive indicators to characterize the response of terrestrial ecosystems to climate change, especially under the projected warming for the coming decades (Diez et al., 2012; Pau et al., 2011).

It is generally found that temperature sensitivity exhibits substantial variability in different regions for various vegetation types, either based on field observations (Menzel et al., 2006; Vitasse et al., 2009a; Wolkovich et al., 2012; Lapenis et al., 2013), remotely-sensed data (Cong et al., 2013; Shen et al., 2014a) or flux data (Wu et al., 2012). Some likely causes have been suggested to

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