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Original research article

Spatiotemporal patterns of vegetation phenology change and relationships with climate in the two transects of East China

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ABSTRACT

Changes in vegetation phenology due to global climate change directly impact the dynamic balance of terrestrial carbon and nutrients and the biodiversity pattern, and send feedbacks to climate system. It is crucial to understand spatiotemporal patterns and mechanisms of vegetation phenology change and their relationship with climatic change. In this paper, we quantified the spatiotemporal patterns of start and end of growing season for seven vegetation types in Northeast China Transect (NECT) and North–South Transect of East China (NSTEC) during 2001–2013 using MODIS Enhanced Vegetation Index (EVI). The integral of EVI during growing season was also calculated as an additional phenological index. We then proceeded to analyze the relationship between the three phenological metrics and climate variables including daytime and nighttime temperature and precipitation. To study the temporal phenological trend of deciduous broadleaved forest in northeast China, we identified stands of deciduous broadleaved forest without land cover changes during 2001–2013 and derived the slopes of temporal changes in phenological metrics. Regression was applied to quantify the relationship between phenological trends and trends of climate variables.

The vegetation types along the two transects in eastern China have distinctly different phenological characteristics and the strength of climate modulations on phenology varies among vegetation types. The study of temporal trend of phenological changes of the deciduous broadleaved forest in northeast China revealed that nighttime temperature is the most important driver. Increasing in nighttime temperature in spring tends to advance the start of growing season, while increasing in nighttime temperature during growing season tends to delay the growing season. Cold daytime prior to growing season also favors advanced start of growing season. On the other hand, summer nighttime temperature tends to bring down, whereas precipitation tends to enhance, the maximum EVI and hence the EVI integral as the latter is mostly determined by maximum EVI and to a less extent by length of growing season.

1. Introduction

Rapid climate change in the past half-century (IPCC, 2013) has significantly modified vegetation phenology (Edwards and Richardson, 2004; Jiang, 2012). Lengthening growing season and shift in plant development stages have been found in the globe (Myneni et al., 1997; Hoffmann et al., 2010; Linderholm, 2015). The extended growing season is mostly caused by

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the advance in start of growing season, and to a less extent by the delay of plant senescence (Gill et al., 2015; Linderholm, 2015). Shifts of vegetation phenology have profoundly modified the global carbon and nutrient cycles (Penuelas and Filella, 2001; Melillo, 2002; Turnbull et al., 2002; Davidson and Janssens, 2006; Menzel et al., 2006; Cleland et al., 2007; Piao et al., 2008) and biodiversity pattern (Berg et al., 2010), which sends feedbacks to climate by altering net greenhouse gas exchange as well as surface albedo and roughness (Bonan, 2008; Peng et al., 2013; Richardson et al., 2013). Therefore, it is crucial to understand the mechanisms of vegetation phenology in responses to changes in climate, e.g. temperature and precipitation (Polgar et al., 2013; Broich et al., 2014).

Start of growing season responds to temperature change in winter and spring. Sufficient winter chilling is required for plants to release bud dormancy (Murray et al., 1989; Morin et al., 2009). On the other hand, thermal time accumulation, i.e., the sum of daily mean temperature above a fixed threshold value, is needed for green-up (Cannell and Smith, 1983; Heide, 1993). Experiments for trees of different genera (*Alnus, Betula, Fagus, Larix, Picea*, and *Populus*) in Europe (Cannell and Smith, 1983; Rinne et al., 2011) and northeastern USA (Polgar et al., 2013; Xie et al., 2014) showed that chilling is required to break the dormancy and then warming temperature induces budburst and leafing-out of temperate woody plants. Thermal time, which is widely used to assess the effect of temperature on plant development (Chuine et al., 1998; Hanninen and Kramer, 2007; Fu et al., 2012), varies greatly among vegetation types (Fisher and Mustard, 2007; White et al., 2009; Melaas et al., 2013). Thermal time for green-up in temperate forest and grassland is greater than that in boreal vegetation due to variation in species composition and climate between the two regions (Fu et al., 2014). Thermal time also interacts with chilling (Heide, 1993), and the strength of the interaction depends on plant species. In general, thermal time requirement for leaf-out is decreased by stronger prior winter chilling. Thermal time requirement for onset of green-up is increased from 40°N southward in North America due to reduced winter chilling (Zhang et al., 2007). In summary, cold winter and warm spring tend to result in early initiation of plant growing season.

Plant phenology responds stronger to precipitation in semiarid and arid environments (Broich et al., 2014; Shen et al., 2015) as increase in precipitation enhances water availability in deep soil layers to alleviate water stress. Temperature sensitivity of the start of growing season is reduced for areas with less than 60-day preseason precipitation in temperate grasslands and deserts of China (Cong et al., 2013). Variation in winter and spring precipitation played a stronger role than temperature in inter-annual variability of vegetation greenness in dryland of the US Great Basin (Tang et al., 2015). On the other hand, too much winter precipitation may increase the thermal time requirement for vegetation green-up in the temperate and boreal regions (Fu et al., 2014). Winter precipitation in the form of snow packs rather than rainfall necessitates more heat energy to melt and to warm soil, thus may delay vegetation green up. Clouds associated with preseason precipitation may also reduce solar radiation and temperature (IPCC, 2013). Furthermore, discontinuous clear days will weaken the effect of high light intensity on spring leaf-out (Partanen et al., 2001).

Early experiments showed warming incurs earlier flowering and senescence thus leads to shorter growing season at individual species level (Post et al., 2008; Hoffmann et al., 2010). Earlier senescence is commonly observed for agricultural crops (Uprety and Reddy, 2016). On the other hand, many observational studies at temperate and polar regions indicate later autumn senescence. A coherent conclusion for temperate deciduous forest under warming climate is the progressively earlier spring phenology but later onset of autumn phenology (Khanduri et al., 2008). In addition to warming, precipitation in summer has been shown to delay the fall dormancy of deciduous broadleaved forest in northeastern United States (Xie et al., 2015). The contradiction between the experiments and the ecosystem level observation is reconciled with the difference in responses to warming among multiple species (Reyes-Fox et al., 2014): Some species may green up earlier, and others may senesce later, altogether resulting in the stretched apparent growing season at both ends. In addition, elevated CO_2 reduces stomatal conductance and conserves water in grassland, making most species active longer, hence further delays the growing season (Taylor et al., 2008; Reyes-Fox et al., 2014).

Several issues have not been well addressed in the past phenological research: (1) Rather than strong warming in winter and early spring in many other temperate regions (Bonsal et al., 2001; Robeson, 2004), the temperate China has cooler winter and early spring but warmer summer during the first decade of the new century. It is not clear how this cooling process would affect the vegetation phenology. (2) Recent studies of vegetation phenology using remote sensing tend to ignore the effects of land cover change, which may weaken their conclusions and obscure the mechanistic understandings of impact of climate change on plant phenology. (3) Other than changes in the length of growing season, the integral of vegetation index in the growing season is also important and needs to be addressed as it may be an indicator of ecosystem productivity.

In this paper, we intent to understand how start of growing season (SOS), end of growing season (EOS), and large seasonal integral of vegetation index in growing season (LSI) of seven major vegetation types change spatially with climate in the two transects of China: Northeast China Transect (NECT) and North–South Transect of Eastern China (NSTEC). The former is situated with nearly same latitude line of 42.5°N and features a strong precipitation gradient, and the latter is in parallel with latitudinal lines thus features a temperature gradient. As a second step to analyze the temporal changes during 2001–2013, we chose the sites of deciduous broadleaved forest during 2001–2013 in Lesser Khingan Mountains and Changbai Mountains to derive the temporal trend of phenological parameters and their relationship with climate variables. Sampling was guided by annual land cover maps to ensure that the sampled locations of deciduous broadleaved forest are free of land cover changes.