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NDVI-based vegetation dynamics and its response to climate changes at Amur-Heilongjiang River Basin from 1982 to 2015

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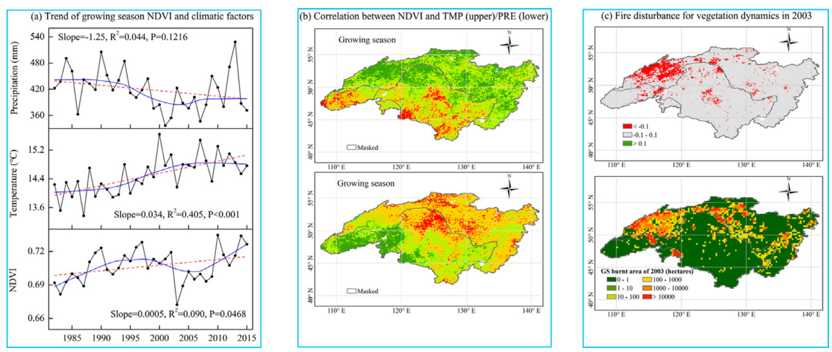
HIGHLIGHTS

- Growing season NDVI in AHRB initially increased to mid-1990s, and then declined to mid-2000s, finally rebounding to 2015.
- Forest types of AHRB showed positive correlation with growing season temperature and negative correlation with precipitation.
- Fires played an important role in vegetation dynamics in AHRB, especially in year 2003.

GRAPHICAL ABSTRACT



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ABSTRACT

Vegetation in Northern Hemisphere, being sensitive to climate change, plays an important role in the carbon cycles between land and the atmosphere. The response of vegetation to climate change was analyzed at pixel, biome and regional scale in Amur-Heilongjiang River Basin (AHRB) for growing season, spring, summer and autumn using Normalized Difference Vegetation Index and gridded climate data for the period 1982–2015. NDVI and climate variables trend detection methods and correlation analysis were applied. The potential impacts of human activities on growing season NDVI dynamics were investigated further using residual trend analysis. Results showed that at river basin scale, growing season vegetation experienced a discontinuous greening trend with two reversals, demonstrating that NDVI initially increased to mid-1990s, then declined to mid-2000s, and finally rebounded to 2015. This may be attributed to the shifting between drought and wet trends, indicating growing season NDVI was mainly regulated by precipitation. Temperature was the dominant factor on affecting spring vegetation growth while autumn NDVI showed negative correlation with precipitation due to the relation of precipitation with sunshine hours available for photosynthesis. The response of vegetation growth to climatic variations varied among vegetation types. Grassland NDVI exhibited positive correlation with precipitation in all time ranges. NDVI of needleleaved forest, broadleaved forest, mixed forest and woodland were positively correlated with temperature in all seasons, while showing significant negative correlation with autumn precipitation. Residual trend analysis revealed that human activities might lead to the vegetation degradation in China farming zone of AHRB. Fires also play an important role in regulating vegetation dynamics in the region. Results of our analysis can be used by national governments from three countries of AHRB in managing and negotiating vegetation resources of the region.

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1. Introduction

Vegetation dynamics has visible relationship to climate changes due to biophysical responses of plant respiration, photosynthesis and evapotranspiration (Guo et al., 2014; Hou et al., 2015; Wu et al., 2017; Zoran et al., 2016). Vegetation hugely impacts the terrestrial carbon cycles, energy exchange and water balance at variety of spatial scales starting from regional to global at seasonal, annual and decadal time periods (Cao and Woodward, 1998; Huang and Xu, 2016; Liu and Lei, 2015; Zhu and Southworth, 2013). Thus, over the recent decades, increasing attention is paid to the observed notable changes of global climate and their effects on vegetation growth (Chen et al., 2015; Jiapaer et al., 2015).

The contemporary long-time satellite remote sensing data provides an advanced way to monitor the surface vegetation dynamics in relation to climate variations at different spatiotemporal scales (Huete, 2016; Yang et al., 2013). With merits of long continuous time series, good data availability of products based on different remote sensors and indicator of photosynthetic capacity (Tucker et al., 2001), the Normalized Difference Vegetation Index (NDVI) is utilized most frequently to analyze the vegetation variations and its correlation with climatic and environmental factors in the Northern Hemisphere (Lamchin et al., 2017; Xu et al., 2017), such as Tibetan Plateau (Pang et al., 2017) and Central Asia (Kariyeva and van Leeuwen, 2011). Precipitation and temperature were considered as the two most important climatic factors on affecting vegetation dynamics (He et al., 2015). For example, previous study found that the decrease of summer NDVI in temperate and boreal Eurasia (>23.5°N) from 1997 to 2006 had relation to the remarkable decrease of summer precipitation (Piao et al., 2011). Rapid spring warming after 2002 enhanced the spring vegetation growth in Central Eurasia while growing season and summer vegetation growth were mainly driven by precipitation (Xu et al., 2017). As for methods, simple linear regression is typical method to analyze the trend of vegetation, though it may be affected by the outliers and the selection of start time (Eslamian et al., 2011). And nonlinear methods can provide sounded information about the trend changes of vegetation and climatic variables. Correlation analysis is usually applied to analyze the relationship between vegetation variations and climatic factors (Liu and Lei, 2015).

Analysis of contemporary vegetation dynamics with use of NDVI is especially effective for large transboundary geographical regions of the Northern Hemisphere with variable terrain and diverse vegetation with multiple types of land use (e.g. analysis of climate and human drivers of vegetation dynamics in Central Asia (Jiang et al., 2017), comprising five countries of the former Soviet Union).

Amur-Heilongjiang River Basin (AHRB, 107°31′–141°14′E, 41°42′–55°56′N) is located in the middle and high latitude parts of eastern Eurasia. This is a transboundary region, covered by various types of vegetation, having multiple land use and containing significant area with permafrost and frequent wildfires. AHRB consisted of three territories from Northeast of China (41%), Russian Far East (50%) and Northeast of Mongolia (9%). It covers an area of more than two million square kilometers and ranks the eleventh largest watershed in the world. The cold and dry monsoon from Siberia controls the AHRB in winter while in summer the basin is controlled by the wet and humid monsoon from the Sea of Okhotsk and Sea of Japan (Wang et al., 2017). It was found that global warming implied surface air warming around Lake Baikal to the west of AHRB and weakened the summer monsoon in recent decades (Zhu et al., 2012). Weakening of the monsoon highly influences seasonal distribution of temperature and precipitation, making the climate in the AHRB warmer and drier in general. Climate changes in the region are becoming more complicated due to variable terrain. Several mountain ranges are distributed across AHRB in a generally south-north direction (Yablonovyy, Borshchovochnyy and Greater Khingan in the upper reaches, Bureya, Changbai and Lesser Khingan in the middle reaches and Silkhote-Alin along the west ocean coast). Tukuringra-Dzhagdy and Stanovoy ranges stretch in the west-east direction at the northern border of AHRB. Songnen and Sanjiang Plain are located in the southern and eastern AHRB, respectively (see Fig. 1). Variable terrain and different socio-economic goals and traditions of China, Russia and Mongolia made the region an area with multiple land use types. Russian territory is mainly covered by natural vegetation and includes the country's major biosphere reserves. Mongolian part of AHRB is mainly pastureland and the Chinese one includes large areas of natural vegetation in mountains and agricultural lands in plains. Vegetation types of AHRB are spanning from coniferous forests (taiga) to grasslands (steppe). Variable vegetation and land use types should be considered in the study of relationship between vegetation dynamics and climate changes in AHRB, because both the phenology and physiology (photosynthesis and respiration) are controlled by seasonal variations in both temperature and precipitation by all vegetation types differentially.

Due to sensitive response of the local carbon pool to the climate change (Schuur et al., 2008), parts of AHRB turned to be in focus of the studies of terrestrial ecosystem and carbon balance. Existing work has analyzed the NDVI variations with climatic or environmental factors in Heilongjiang Province (Liu et al., 2011), Northeast China (Guo et al., 2017a; Guo et al., 2017b) or Northeast Asia (Matsumura et al., 2011). However, almost no studies investigate the vegetation dynamics of the entire AHRB and few studies make seasonal analysis of correlation between vegetation dynamics and climate change in the area. Additionally, the potential influences of human activities and natural disturbances on vegetation growth in AHRB were poorly understood in previous studies.

This study aims to analyze the spatiotemporal vegetation dynamics and its response to climate change in the Amur-Heilongjiang River Basin from 1982 to 2015. This paper focused mainly on the vegetation growing season (May to September) (Liu and Lei, 2015). Analysis for spring (April to May), summer (June to August) and autumn (September to October) was also conducted to achieve a better understanding of seasonal changes of NDVI and their responses to climatic variations. Objectives of this study are to: (1) investigate the NDVI inter-annual growing season and seasonal trend in relation to climate change in AHRB during the past 34 years and explore facts and reasons of the NDVI trend changes; (2) use NDVI to analyze impacts of climatic factors on vegetation growth at pixel scale among different vegetation types; (3) distinguish other potential drivers of NDVI changes including human activities and natural disturbances. Following hypotheses are taken for this study: (1) growing season NDVI trend is following the climatic changes during the study period; (2) response of growing season NDVI to climatic variations is different for different vegetation types in the study area; (3) Human activities and wildfires are affecting growing season NDVI in certain years and in some regions of AHRB.

2. Materials and methods

2.1. Data sources

The NDVI dataset used in this study was the latest updated version of the third generation Global Inventory Monitoring and Modeling System (GIMMS NDVI 3g.v1, available at https://ecocast.arc.nasa.gov/data/pub/gimms/3g.v1/ as nc4 files) (Zhou et al., 2018). The GIMMS NDVI 3g.v1 is generated from NOAA's Advanced Very High Resolution Radiometer (AVHRR) data, and the spatial resolution is 1/12°. Its temporal resolution is 15-day intervals with 34.5 years' time span. A maximum value composite (MVC) method was applied to get the monthly NDVI data by reducing the atmospheric effects about clouds and aerosol (Li et al., 2016; Li et al., 2017). The averaged NDVI for growing season, spring, summer and autumn was calculated for analysis. The pixels with an average of growing season NDVI <0.1 were masked as non-vegetated areas. Pixels location with NDVI value of certain month in growing season not greater than zero were also masked and excluded from the study to decrease the effects of snow cover and water. However, some