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Onset of drying and dormancy in relation to water dynamics of semi-arid grasslands from MODIS NDWI

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ABSTRACT

Our knowledge of autumn phenology and its response to climate variability is currently limited. One way to improve our understanding of autumn phenology at the landscape scale is to investigate autumn vegetation dynamics based on multiple vegetation indices from remote sensing data. In this study, we derived two autumn phenological metrics (phenometrics), onset of drying and dormancy, for semi-arid grasslands from MODIS normalized difference water index (NDWI) time series. The onset of drying represents the start of decline in the vegetation's metabolism during autumn, and the onset of NDWI-based dormancy signifies the end of metabolic activity. These NDWI-based phenometrics were then compared with enhanced vegetation index (EVI)-based phenometrics in northeastern China from 2001 to 2013. Influences of climatic variability on autumn phenology were analyzed using partial correlation analysis. We found that, in general, the onset of drying was slightly later than the onset of EVI-based senescence. Both did not strongly correlate with precipitation and mean minimum temperature in August. The onset of NDWI-based dormancy had, on average, a time lag of seven days, relative to the onset of EVI-based dormancy during 2001–2013. Moreover, it showed a much stronger response to mean minimum temperature in September than EVI-based dormancy. A colder autumn generally advanced the onset of NDWI-based dormancy, while it had little effect on the onset of EVI-based dormancy in the study area. These results suggest that phenological studies using NDWI could expand our understanding of land surface phenology. Furthermore, considering the different responses of the onset of NDWI- and EVI-based dormancy to climate variability, a combination of these phenometrics could contribute to the study of the ecosystem processes (e.g., carbon cycle) in semi-arid grasslands.

1. Introduction

Phenology plays an important role in studying global change because phenological variability reflects the ecological response to climate variability, and affects the feedback of vegetation to the climate system (Penuelas et al., 2009; Richardson et al., 2013a; Schwartz, 1999; Walther et al., 2002). To date, the influence of environmental factors (e.g., temperature and precipitation) on spring phenology is better understood than that on autumn phenology (Dragoni and Rahman, 2012; Richardson et al., 2013a; Yang et al., 2014b). More attention needs to be paid to autumn phenology and its response to climate variability (Gallinat et al., 2015; Richardson et al., 2013a). Expanding observations of autumn phenology at different scales (e.g., species and landscape scales) is critical to improve our understanding of it (Gallinat et al., 2015; Garrity et al., 2011).

Satellite remote sensing serves as a powerful technique for detecting vegetation phenology (Justice et al., 1985; Reed et al., 1994; White et al., 1997). Vegetation phenology observed from satellite remote sensing is termed land surface phenology, which characterizes the seasonality of vegetation at the landscape scale (Friedl et al., 2006; Henebry, 2003). Remote sensing of autumn phenology typically focuses on deriving the onset of vegetation senescence, dormancy, or the end of growing season from vegetation indices time series (e.g., Dragoni et al., 2011; Ganguly et al., 2010; Gonsamo and Chen, 2016; Zhang and Goldberg, 2011).

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The normalized difference vegetation index (NDVI) and enhanced vegetation index (EVI) are the two most commonly used vegetation indices for autumn phenological studies (e.g., de Beurs and Henebry, 2010a; Garonna et al., 2014; Liu et al., 2015; Jeong et al., 2011; Zhang et al., 2012). However, using only greenness vegetation indices cannot comprehensively characterize autumn vegetation dynamics because vegetation senescence is accompanied by various biophysical and biochemical dynamics, for instance, changes in pigment content, water content, leaf area index, and canopy roughness. To expand our knowledge of vegetation dynamics in autumn at the landscape scale, it is essential to investigate autumn phenology derived from alternative vegetation indices or parameters (Henebry and de Beurs, 2013).

Satellite observations at longer wavelengths, for example from short-wave infrared or microwaves, could assist in better describing phenological changes related to the vegetation water content. In microwave region, vegetation optical depth, which is sensitive to biomass and water content, derived from the Advanced Microwave Scanning Radiometer for Earth Observation System (AMSR-E) has been used to monitor land surface phenology (e.g., Guan et al., 2014; Jones et al., 2011). Vegetation optical depth and NDVI were found to provide distinctive land surface phenology in several ecosystems (Guan et al., 2014; Jones et al., 2011). In short-wave infrared region, the potential of vegetation water indices, for instance, the normalized difference water index (NDWI, Gao, 1996), for tracking vegetation dynamics has been demonstrated in several ecosystems (e.g., Boles et al., 2004; de Beurs et al., 2009; de Beurs and Henebry, 2010b; Delbart et al., 2005; Xiao et al., 2002). However, efforts to detect phenology using vegetation water indices are still limited. They were commonly used as an alternative solution to reduce the influence of snow cover in boreal regions (Delbart et al., 2005, 2006; Thompson et al., 2015). The capabilities of vegetation water indices for characterizing vegetation dynamics may be under-utilized for some ecosystems (Wu et al., 2014). As water content is a sensitive indicator of the strength of plant metabolism (e.g., photosynthesis, respiration, and transpiration), vegetation water indices time series could provide new insight in land surface phenology.

The aims of this study are (1) to define two autumn phenological metrics (phenometrics) in semi-arid grasslands, onset of drying and dormancy, from MODIS NDWI time series, (2) to compare the NDWI- and EVI-based autumn phenometrics, and (3) to evaluate the sensitivity of these phenometrics to climate variability.

2. Materials and methods

2.1. Study area

The study area is situated in the Songnen Plain in northeastern China (Fig. 1). The mean altitude is about 150 m. This area has a semi-arid continental monsoon climate. The mean annual temperature ranges from 4.3 to 6.7 °C. The mean annual precipitation ranges from 300 to 460 mm, and most of the precipitation occurs from June to August. The area is snow-covered during late October to early April. The predominant land cover types are grasslands and croplands (Fig. 1(b)). The spatial distribution of grasslands in this area was obtained from the MODIS land cover type product (MCD12Q1). This product provides annual land cover type at a 500 m spatial resolution based on five land cover type classification schemes (Friedl et al., 2010). The MCD12Q1 data from 2001 to 2013, using the International Geosphere Biosphere Programme (IGBP) classification scheme, were selected. To reduce the influence of land cover change on the analysis of variability in land surface phenology, only grasslands that were consistently classified as such for all 13 years were retained.

2.2. MODIS surface reflectance product

We selected the MODIS MOD09A1 product, which provides 8-day composite surface reflectance data with a spatial resolution of 500 m, to obtain the NDWI and EVI time series. The effects of atmospheric gases and aerosols are corrected in this product. For each 8-day period, observations with the highest quality are selected based on cloud state, aerosol quantity, observation coverage, and view angle (Vermote et al., 2011). All available Terra MOD09A1 data for the study area (MODIS tile number: h26v04) from January 1, 2001 to December 31, 2013 were used. NDWI and EVI were calculated as follows:

$$NDWI = \frac{\rho_{b2} - \rho_{b6}}{\rho_{b2} + \rho_{b6}} \quad (1)$$

$$EVI = 2.5 \times \frac{\rho_{b2} - \rho_{b1}}{\rho_{b2} + 6 \times \rho_{b1} - 7.5 \times \rho_{b3} + 1} \quad (2)$$

where ρ_{b1}, ρ_{b2}, ρ_{b3}, and ρ_{b6} are the reflectance of band 1 (620–670 nm), band 2 (841–876 nm), band 3 (459–479 nm), and band 6 (1628–1652 nm) of MODIS, respectively. MODIS also contains another two water absorption bands: band 5 (1230–1250 nm) and 7 (2105–2155 nm). However, images of band 5 have obvious

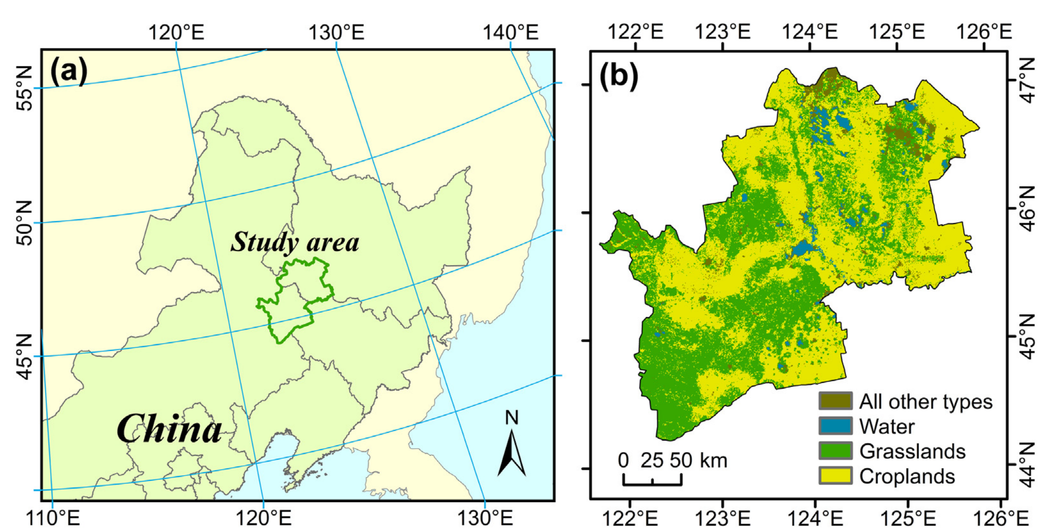

Fig. 1. Overview of the study area. (a) Location of the study area. (b) The land cover types in 2013 provided by the MODIS MCD12Q1 product.