

Phenological characteristics of the main vegetation types on the Tibetan Plateau based on vegetation and water indices

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Abstract. Plant phenology is considered one of the most sensitive and easily observable natural indicators of climate change, though few studies have focused on the heterogeneities of phenology across the different vegetation types. In this study, we tried to find the phenological characteristics of the main vegetation types on the Tibetan Plateau. MCD12Q1 images over the Tibetan Plateau from 2001 to 2010 were used to extract the main vegetation types. The Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and Land Surface Water Index (LSWI) were calculated using surface reflectance values from the blue, red, near-infrared, short-wave infrared (SWIR) 6 (for LSWI6), and SWIR7 (for LSWI7) bands derived from MOD09A1 and used to explore the phenological characteristics of the main vegetation types on the Tibetan Plateau. The results showed that there were eight constant vegetation types on the Tibetan Plateau from 2001 to 2010 demonstrating multiple phenological characteristics. Evergreen needleleaf forest, evergreen broadleaf forest, and permanent wetland had the minimum NDVI values during the summer season, while open shrubland and grassland had the maximum NDVI/EVI values during this period. NDVI and EVI of cropland/natural vegetation had two peaks for their seasonal variations. EVI showed a more significant correlation with LSWI6/LSWI7 than NDVI. Compared to LSWI7, larger EVI values occurred in evergreen needleleaf forest, evergreen broadleaf forest, mixed forest, and permanent wetland, while smaller values occurred in shrubland and barren or sparsely vegetated cover, and nearly equal values occurred in grassland and cropland.

1. Introduction

For about a century, the Earth has been experiencing dramatic environmental changes. Global climate change has raised more and more concerns, and the warming trend has been accepted by many scientists and governments [1-7]. The Tibetan Plateau is the highest (>4000m) and largest (about 2,500,000km²) plateau in the world. It is known as a fragile ecosystem, widely covered by glaciers, snow, and barren or sparsely vegetated area [8]. Thus, the Tibetan Plateau is very sensitive to climate change and is considered an indicator region for climate change [9-11]. Plant phenology, with the patterns of vegetation bud burst, flowering, and senescence, is considered one of the most sensitive and easily observable natural indicators of climate change [12].

Several studies about the phenology of the Tibetan Plateau have been presented. Piao et al. studied spring vegetation green-up on the Tibetan Plateau over the period from 1982 to 2006 using



satellite-derived NDVI [13-14]. An increasing rate of 3.29 days/decade of growing season length was found during the last 50 years according to Dong et al. [15]. Liu and Chen found the Tibetan Plateau was experiencing substantial warming in recent decades, and this climate change was influencing the vegetation growth significantly [16]. Liu et al. [17] and You et al. [18] used meteorological data to check the length of the growing season within the context of climate change. Other studies have indicated that the response of plant phenology to the warming is heterogeneous due to geographical conditions [13, 19]. Shen et al. [19] found that the green-up onset paralleled the advance in thermal spring onset in many parts of the plateau, and indicated that the spatial heterogeneities in the key environment caused the different response of spring phenology [19].

However, few studies have focused on the heterogeneities of phenology across different vegetation types. In this study, we tried to find the phenological characteristics of the vegetation types on the Tibetan Plateau, which would be very useful for exploring patterns in plant phenologies' responses to climate change over the whole Tibetan Plateau.

2. Method

2.1. Main vegetation type definition

MCD12Q1 images, with a spatial resolution of 500m over the Tibetan Plateau from 2001 to 2010, were downloaded from <http://e4ftl01.cr.usgs.gov/MOTA/>. Land cover type 1 of the International Geosphere Biosphere Programme (IGBP) classification scheme was used. Areas with the same land cover over 10years (from 2001 to 2010) were extracted as a main vegetation type of the Tibetan Plateau, and eight constant vegetation types were found. Grassland and barren or sparsely vegetated land covered the most area of the Tibetan Plateau, and open shrubland, evergreen broadleaf forest, and mixed forest were distributed in the southwestern, southern, and eastern parts of the plateau, respectively. Other vegetation types including evergreen needleleaf forest, permanent wetland, and cropland/natural vegetation mosaic only occupied a small constant area.

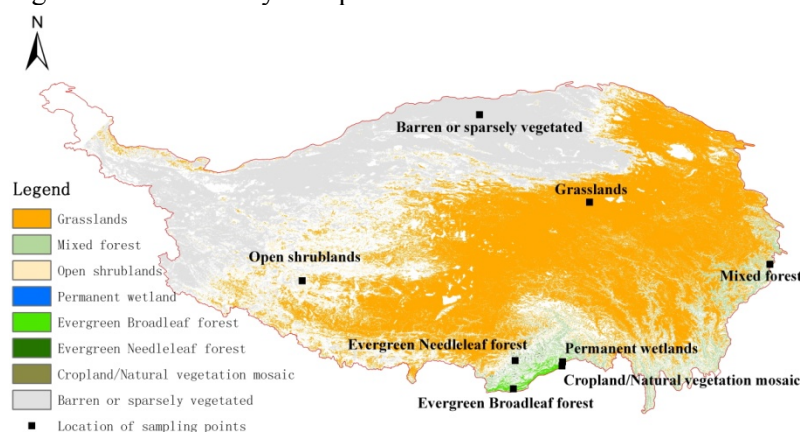


Figure 1. The distribution of the main vegetation types and their sampling points in the Tibetan Plateau. Land cover type 1 of the International Geosphere Biosphere Programme (IGBP) classification scheme was used with MCD12Q1 imagery, and areas with constant land cover from 2001 to 2010 were extracted as the main vegetation types.

2.2. Vegetation and water indices

The Normalized Difference Vegetation Index (NDVI) [20] and Enhanced Vegetation Index (EVI) [21-22] are sufficiently stable vegetation parameters to permit meaningful comparisons of seasonal and inter-annual changes in vegetation growth and activity [23]. The availability of an additional short-wave infrared (SWIR) spectral band provides an opportunity for developing and generating improved

vegetation indices that are sensitive to equivalent water thickness, such as the Land Surface Water Index (LSWI) [24-26].

The sampling points of the eight vegetation types (Fig. 1) with a size of 3×3 km were selected to analyze the phenologies. MOD09A1 eight-day composites with a spatial resolution of 500m from 2001 to 2010 for each point were downloaded from http://daac.ornl.gov/cgi-bin/MODIS/GLBVIZ_1_Glb/modis_subset_order_global_col5.pl. NDVI, EVI, LSWI6, and LSWI7 were calculated using surface reflectance of pure land cover types from the blue (459-479nm), red (620-670nm), near-infrared (NIR) (841-875 nm), SWIR6 (1628-1652 nm), and SWIR7 (2105-2155 nm) bands, according to:

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \quad (1)$$

$$EVI = 2.5 \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + 6\rho_{Red} - 7.5\rho_{Blue} + 1} \quad (2)$$

$$LSWI6 = \frac{\rho_{NIR} - \rho_{SWIR6}}{\rho_{NIR} + \rho_{SWIR6}} \quad (3)$$

$$LSWI7 = \frac{\rho_{NIR} - \rho_{SWIR7}}{\rho_{NIR} + \rho_{SWIR7}} \quad (4)$$

3. Results

The seasonal vegetation and water indices of the eight main vegetation types on the Tibetan Plateau were averaged over 10 years and mapped in Figure 2. It was found that the phenology of the eight vegetation types showed multiple characteristics. Evergreen needleleaf forest, evergreen broadleaf forest, and permanent wetland had minimum NDVI values during the summer season. The same was true for their EVI with the exception of evergreen needleleaf forest, which showed a weak seasonal variation in EVI and a decrease in the period of winter, contrasting with NDVI. For mixed forest, open shrubland, and grassland, the maximum NDVI and EVI values appeared during the summer season. The NDVI and EVI of cropland/natural vegetation had two peaks for their seasonal variations, maybe due to double cropping. Insignificant seasonal variations in NDVI and EVI were observed for barren or sparsely vegetated cover on the Tibetan Plateau. LSWI6 and LSWI7 had consistent seasonal patterns with NDVI / EVI for evergreen broadleaf forest, mixed forest, shrubland, and cropland. Two peaks of seasonal LSWI6 and LSWI7 appeared for grasslands.

For all vegetation types, NDVI was larger than EVI, and LSWI7 was larger than LSWI6, which indicated that the surface reflectance of SWIR7 bands was more sensitive to equivalent water thickness than that of SWIR6 bands. EVI showed a more significant correlation with LSWI6/LSWI7 than NDVI. Compared to LSWI7, larger EVI values occurred in evergreen needleleaf forest, evergreen broadleaf forest, mixed forest, and permanent wetland, while smaller values occurred in shrubland and barren or sparsely vegetated cover, and nearly equal values occurred in grassland and cropland.

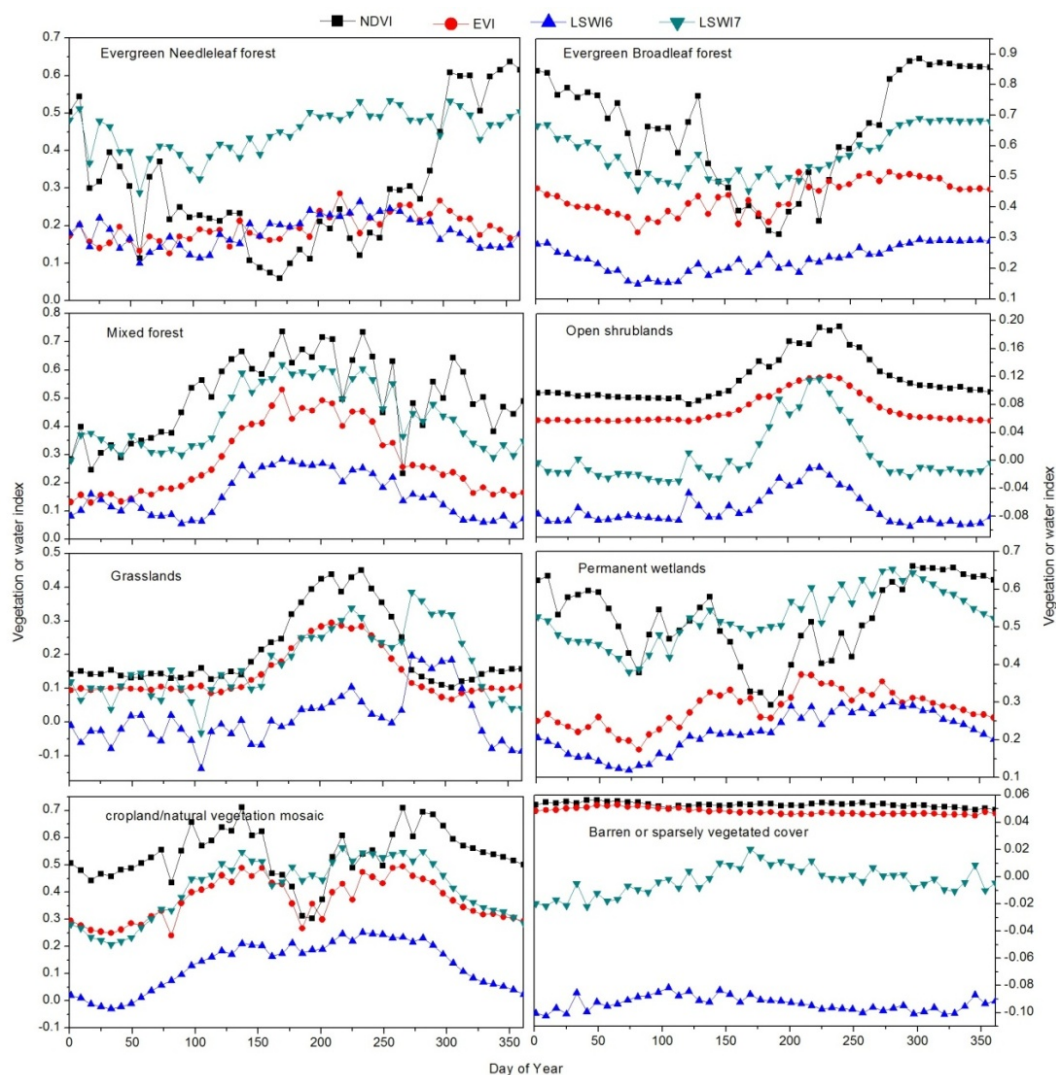


Figure 2. Seasonal variation of vegetation and water indices for the eight main vegetation types on the Tibetan Plateau

4. Conclusions and further studies

In this study, MCD12Q1 images from 2001 to 2010 with a spatial resolution of 500m over the Tibetan Plateau were used to extract the main vegetation types, with eight vegetation types found to have been constant over 10 years. Grassland and barren or sparsely vegetated land covered the most area of the Tibetan Plateau. NDVI, EVI, LSWI6, and LSWI7 were calculated using surface reflectance. It was found that the phenology of the eight main vegetation types showed multiple characteristics. Evergreen needleleaf forest, evergreen broadleaf forest, and permanent wetlands had their minimum NDVI values during the summer season and the same applies for EVI, except in evergreen needleleaf forest. Maximum NDVI and EVI values of mixed forest, open shrubland, and grassland appeared during the summer season. The NDVI and EVI of cropland/natural vegetation had two peak values for their seasonal variation. LSWI6 and LSWI7 had consistent seasonal patterns with NDVI and EVI for evergreen broadleaf forest, mixed forest, shrubland, and cropland. EVI showed a more significant correlation with LSWI6 and LSWI7 than NDVI; had a larger value than LSWI7 for evergreen needleleaf forest, evergreen broadleaf forest, mixed forest, and permanent wetlands; had values less

than LSWI7 for shrubland and barren or sparsely vegetated cover; and had similar values with LSWI7 for grasslands and croplands.

The results in this paper were based on the vegetation and water indices derived from the sampling points of eight vegetation types with a size of 3×3 km. Although we selected pure land cover samples in the MCD12Q1 imagery, the phenological characteristics may be different due to the local environment and climate conditions, even for the same vegetation cover types. We will map the phenological characteristics and provide their quantitative information in a future study involving other important vegetation parameters, such as leaf area index (LAI), clumping index (CI), and fraction of photosynthetically active radiation (FPAR).

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