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A snow-free vegetation index for improved monitoring of vegetation spring green-up date in deciduous ecosystems

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ABSTRACT

Vegetative spring green-up date (GUD), an indicator of plants' sensitivity to climate change, exerts an important influence on biogeochemical cycles. Conventionally, large-scale monitoring of spring phenology is primarily detected by satellite-based vegetation indices (VIs), e.g. the Normalized Difference Vegetation Index (NDVI). However, these indices have long been criticized, as the derived GUD can be biased by snowmelt. To minimize the snowmelt effect in monitoring spring phenology, we developed a new index, Normalized Difference Phenology Index (NDPI), which is a 3-band VI, designed to best contrast vegetation from the background (i.e. soil and snow in this study) as well as to minimize the difference among the backgrounds. We examined the rigorousness of NDPI in three ways. First, we conducted mathematical simulations to show that NDPI is mathematically robust and performs superior to NDVI for differentiating vegetation from the background, theoretically justifying NDPI for spring phenology monitoring. Second, we applied NDPI using MODIS land surface reflectance products to real vegetative ecosystems of three in-situ PhenoCam sites. Our results show that, despite large snow cover in the winter and snowmelt process in the spring, the temporal trajectories of NDPI closely track the vegetation green-up events. Finally, we applied NDPI to 11 eddy-covariance tower sites, spanning large gradients in latitude and vegetation types in deciduous ecosystems, using the same MODIS products. Our results suggest that the GUD derived by using NDPI is consistent with daily gross primary production (GPP) derived GUD, with R (Spearman's correlation) = 0.93, Bias = 2.90 days, and RMSE (the root mean square error) = 7.75 days, which outcompetes the snow removed NDVI approach, with R = 0.90, Bias = 7.34 days, and RMSE = 10.91 days. We concluded that our newly-developed NDPI is robust to snowmelt effect and is a reliable approach for monitoring spring green-up in deciduous ecosystems.

1. Introduction

Vegetative spring green-up date (GUD) is a sensitive indicator of temperate and boreal ecosystems responding to global climate change (Wolkovich et al., 2012; Fu et al., 2016; Menzel and Fabian, 1999; Parmesan and Yohe, 2003; Wang et al., 2016). A number of studies have reported that the start of spring is occurring earlier in the recent decades in temperate and boreal ecosystems in the Northern Hemisphere (e.g. Buitenwerf et al., 2015; Myneni et al., 1997; Zhou et al., 2001). This shift in phenology exerts an important influence on large-scale biogeochemical cycles (Richardson et al., 2010; Xia et al., 2015). For example, Richardson et al. (2009) showed that earlier spring onset resulted in higher annual gross primary productivity (GPP) at two forest sites in the United States. However, a reliable approach for monitoring spring phenology in these ecosystems is still lacking.

For decades, satellite remote sensing has offered an attractive tool for large-scale motoring of vegetative status (Buitenwerf et al., 2015; Wang et al., 2015). The most widely used remote sensing product is the Normalized Difference Vegetation Index (NDVI). It uses two reflectance spectral bands and ratios them to provide an estimate of canopy greenness, a composite property of both leaf-level (leaf intercellular structure and biochemical compostion) and canopy-level (canopy leaf area and structure) properties. In general, NDVI is a good indicator of

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