remote sensing

Editorial

An Overview of Vegetation Dynamics Revealed by Remote Sensing and Its Feedback to Regional and Global Climate

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1. Introduction

Vegetation, as one of the crucial underlying land surfaces, plays an important role in terrestrial ecosystems and the Earth's climate system through the alternation of its phenology, type, structure, and function. Vegetation responds to climate warming quite differently, such as greening and browning across different regions, which have been reported by many remote sensing studies [1–3]. Vegetation is an important and sensitive indicator of climate and environment evolutions, underscoring the need to better understand vegetation physiological and phenological responses, detect mechanisms of how changes in land surface properties (e.g., surface albedo and roughness length) are associated with vegetation dynamics, and reveal climate and ecological feedbacks of vegetation changes. The recent advances of satellite remote sensing techniques and their derived products provide unique opportunities to study vegetation dynamics and its feedback to regional and global climate systems. Moreover, some of the new generation of climate models, such as CMIP6 Earth system models, which include dynamic vegetation, are state-of-the-art tools for investigating the interactions between vegetation and climate change.

After an open call to the community, we received some interesting works based on remote sensing data from which we summarize 10 papers that are already published, which focus on vegetation changes and the associated drivers, the effect of extreme climate events on vegetation, land surface albedo related to vegetation change, plant fingerprint, and vegetation dynamics in climate models. These articles well represent the focus of the Special Issue, which aims to investigate vegetation dynamics and its response to climate change.

2. Overview of Contribution and Future Perspectives

Identifying the influencing factors, so-called detection and attribution, for vegetation changes is an important subject of current research. Dong et al. [4] analyzed the spatial-temporal changes of vegetation NDVI in the Loess Plateau between 2000–2015 and used the geographical detector model (GDM) to quantify its dominant factors from climate, environment, and anthropogenic factors. They revealed that NDVI increases more rapidly in the semi-humid area than in the semi-arid area. For the former, anthropogenic factors, such as the GDP density, land-use type, and population density, have a great effect on the NDVI increase, while for the latter, the climate and environment factors, such as precipitation, soil type, and vegetation type, have a great effect. Meanwhile, the interactions between factors enhance the effects on vegetation change. A similar piece of work was done by Li et al. [5] in temperate drylands, specifically the Inner Mongolia grasslands. With an upward trend in NDVI in the growing season over the period 2000–2018, GDM suggests that both nature and human activities exert significant effects on the NDVI changes, accounting for more than 15% of the variability. Interactions between precipitation and air temperature dominate the NDVI change, accounting for 39%. Taken together, these articles include an attribution model to resolve the dominant contributors to vegetation change.

One of the most noticeable vegetation responses to the rapid warming in northern high latitudes is changes in the timing of thermal growing seasons and phenological cycles of plants [2]. These changes may induce direct and legacy effects on ecosystem gross primary production. Based on three widely-used remote sensing products of GPP (gross primary productivity) at a spatial resolution of 0.05° over 2001–2018, Marsh and Zhang [6] found that legacy effects from spring temperature are most pronounced in summer, where the Arctic ecosystem productivity has been stimulated. Spring warming likely lessens the harsh climatic constraints that govern the Arctic tundra and extends the growing season length. Further south, legacy effects are mainly negative. This strengthens the hypothesis that enhanced vegetation growth in spring will increase plant water demand and stress in summer and autumn. Soil moisture is the dominant control of summer GPP in temperate regions. However, the dominant meteorological variables controlling vegetation growth are different among the three GPP products. Different biomes show disparate (positive or negative, even lagged) impacts for the three GPP products. Overall, this work quantitatively assesses the direct and legacy effects of spring warming on seasonal GPP, and it also highlights the need to address uncertainties among different methods that are used to estimate GPP.

Net primary productivity (NPP) is a variable that reflects the efficiency of vegetation fixation and conversion of light energy, and thus it is often used to monitor vegetation dynamics, such as plant growth, development, reproduction, and senescence. Based on the MODIS NPP product and environmental factors (air temperature, solar radiation, and soil moisture) derived from the atmospheric reanalysis data (ERA5, MERRA2, and NCEP2), Wang et al. [7] found that nearly 60% of the global areas showed a higher NPP that is associated with an increased elevation. Soil moisture has the largest uncertainty to explain either the spatial pattern or inter-annual variation of NPP, while air temperature has the smallest uncertainty among the three environmental factors. NPP shows an obvious elevation differentiation with an elevation of 3060 m as the demarcation point, which divides the elevation into low and high. Mean annual air temperature is the main driving that affects the elevation distribution of NPP. Their work implies that elevation is a crucial factor when quantifying the carbon sequestration capability of vegetation globally.

When it comes to the world's Third Pole (Tibetan Plateau, TP), changes in vegetation dynamics also play a critical role in terrestrial ecosystems and environments. Similar to the Arctic, the TP has also experienced rapid and amplified warming during recent decades [8]. Therefore, vegetation dynamics in the TP have been attached increasing attention as it profoundly influences the terrestrial carbon cycle and climate change. Land surface albedo directly affects the energy balance on the land surface. Li et al. [9] examined the spatial-temporal changes of land surface albedo dynamics and its influencing factors (snow cover and vegetation) in the Qilian Mountains, Northeastern TP, using multi-source remote sensing data. Annual average albedo showed a weak increasing trend from 2001 to 2020. Surface albedo is closely associated with land surface cover, and vegetation is significantly negatively correlated with albedo. The improvement of vegetation condition reduces the surface albedo in the edge areas. Therefore, surface albedo can also be used for monitoring land surface conditions. Deng et al. [10] used remote sensing products and a dynamic global vegetation model to study the TP vegetation dynamics and the associated climatic drivers. They customized the Community Land Surface Biogeochemical Dynamic Vegetation Model to simulate the TP vegetation distribution and carbon flux and improved the model's phenology representation using seasonal–deciduous phenology parameterization. The newly developed processes substantially improve the model to reproduce in situ observations on the TP. In addition to better simulations of spatial-temporal patterns of GPP in the TP, their work also showed different indications of dominant drivers between the remote sensing product and the terrestrial ecosystem model.

Remote sensing is also used to monitor land and forest change footprint, facilitating the protection of the fragile environment. In combination with 8203 scenes of multi-source remote sensing data, Yan and Wang [11] use the LandTrendr spectral-temporal segmentation algorithm to explore forest change footprint in the upper Indus Valley. This work suggests that the area of forest recovery is 1% more than that of disturbance between 1990–2020, in which 70% of disturbance appears between 1990 and 2001 and 60% of recovery appears between 1999 and 2012. Although little difference exists in the overall trend of forest disturbance and recovery, the significant differences remain in forest management status across different regions because of grazing, fire, commercial tree planting, and afforestation policies. Li et al. [12] investigated the effects of time interpolation on phenology trend estimation in the mid-high latitudes of the northern hemisphere between 2001–2019, using a daily NDVI generated based on the moderate resolution imaging spectroradiometer (MODIS) MCD43A4 daily surface reflectance data over 120 selected sites. They found that there are nonignorable effects of the time interpolation on trend estimation, even though the effects are not significant. The effects of the time interpolation on trend estimation have shown significant differences among different vegetation types, with significant effects on vegetation types with apparent seasonal changes, such as deciduous broadleaf forests, and no significant effects among vegetation types with weak seasonal changes, such as evergreen needleleaf forests. In addition, the selection of extraction methods also affected trend estimation.

In recent years, climate extremes have been frequently reported by literature and media across the globe. Vegetation in response to climate extremes has been arousing general concern. For the response of vegetation to the heatwave, Dong et al. [13] examined the impact of heatwaves on vegetation growth rate on the TP from 2000 to 2020 using MODIS Nadir Bidirectional Reflectance Distribution Function Adjusted Reflectance (NBAR) based NDVI and EVI, microwave-based surface soil moisture, and long-term meteorological data. They found that the significant increase in the frequency of heatwaves only occurs in August during the last two decades. During heatwave periods, the soil moisture and precipitation are significantly lower than the corresponding multi-year average value. The temperature stress and water limitation caused by heatwave slow the vegetation growth on the TP but the sensitivity of alpine vegetation on heatwave is higher in June than in July and August. Wang et al. [14] investigated the effects of climate extremes on vegetation at multi-time scales using NDVI during 1982–2015 in Guangxi, China. They found that there are clear seasonal differences in the trend of NDVI in Guangxi, with the strongest greening in spring and February. On an annual scale, the NDVI is generally significantly correlated with extreme temperature indices, while there is no significant correlation between NDVI and most of the extreme precipitation indices used. On seasonal and monthly scales, the correlations between NDVI and extreme temperature and precipitation indices vary in months. Overall, these works are of great significance for the understanding of vegetation response to increasing extreme weather events under the background of rapid climate change.

The above studies advance the understanding of vegetation changes and their driving factors to a large extent. However, there is still some gap between our expectations and the currently collected papers. In addition to the response of vegetation to climate change, we also expect to look at some progress in the feedback of vegetation dynamics to ecosystems (e.g., carbon stocks, water, and soil conservation) and the climate systems. Therefore, we plan to reopen the Special Issue (named Specific Issue II: https://www.mdpi.com/journal/remotesensing/special_issues/6201BU8J59) to the community to collect recent progress involving this.

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