Influence of wind speed on canopy Normalized Difference Vegetation Index (NDVI) measurements within forest ecosystem

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Abstract: Wind speed affects the observation of canopy vegetation index. When the wind blows, plants will swing, and the spatial structure of the canopy will undergo alterations. Such changes might have an influence on the measurements of the vegetation index. Although the existence of certain previous studies, there have been no studies on the scale of satellite remote sensing. Daily scale Normalized Difference Vegetation Index (NDVI) was chosen as the indicators to explore the influence of wind on canopy measurements within forest ecosystems. Our results show that in 558 sets of data, only 64 sets (11.5%) show a significant correlation ($p<0.05$) between NDVI and wind speed. This study provides a reference for the effect of wind speed on vegetation canopy structure measurements.

Keywords: Wind Speed, NDVI, Forest Ecosystem, Forest Types, MODIS

1. Introduction

The forest ecosystem is a huge carbon pool. As a key indicator that reflects the structure and function of the ecosystem (Litton, Raich, and Ryan 2007), the estimation of productivity got lots of attention (Shao et al. 2018; Soukhovolsky and Ivanova 2013; Skovsgaard and Vanclay 2013). Like the simplicity of canopy spectral reflectance, the vegetation index as a convenient quantitative representation is suitable for quantifying canopy structure and estimating productivity. On the other hand, the remote sensing model method is one of the most effective and accurate ways to estimate productivity, which is more suitable for large-scale investigation (Hilker et al. 2008). For these models, the vegetation index is pivotal input data, which can reflect eco-physiological processes of plants, estimate canopy structure and primary productivity. The Normalized Difference Vegetation Index (NDVI) is the most popular vegetation index, since the era of multispectral remote sensing (Huang et al. 2021). (Noda, Muraoka, and Nasahara 2021). These show that NDVI is becoming more and more important, and it is necessary for its accurate measurement.

Measuring NDVI accurately is a challenge. The measurements of NDVI are impressed by many external factors, like cloud cover(Leblon, Guerif, and La Rocque 2001; de Souza, Scharf, and Sudduth 2010), sun angle (de Souza, Scharf, and Sudduth 2010; Guan and Nutter 2001), sensor angle (Glick et al. 1982), canopy structure induced by wind (Leblon, Guerif, and La Rocque 2001; Rao, Brach, and Mack 1979). Those studies found that cloud cover and sun angle increased the coefficient of variation of the statistical results by about 30% to 50% (de Souza, Scharf, and Sudduth 2010); and the influence of cloud cover is hard to quantify (Leblon, Guerif, and La Rocque 2001). As the increase of sun angle, the incident radiation increase, while the percentage reflectance values decreased between 0.20 and 0.32% for each 100 watts m^{-2} (Guan and Nutter 2001). For vertical and oblique measurement angles of the sensor, the vertical angle is better (Glick et al. 1982). Most vegetation canopies are non-Lambertian reflectors, so view angle can influence spectral response (Wright 1986; Lunagaria and Patel 2017). The change of view angle can be the changes of sun angle, sensor angle, and canopy structure induced by wind.

Wind speed is an important factor in canopy NDVI measurement. The research of the influence of wind on vegetation spectrum measurements is mainly concentrated at the end of the last century. The earliest studies that can be retrieved are experiments for crops on the ground (Rao, Brach, and Mack 1979). It was found that radiance was more sensitive in the 450 to 650 nm to wind speed than in the 650 to 750 nm range. Due to the influence of the instrument at that time, the wavelength region of the field spectroradiometer was in the visible light region (350nm-750nm). As a result, the research on the near-infrared region is almost blank. In the later related research with the wavelength region of red light and near-infrared band, the near-infrared band is more sensitive (Lord, Desjardins, and Dube 1985). Both types of research found that wind had a negligible effect on the reflectance of the low crop (clipped). Later, more in-depth research found that wind was positively correlated to the variability of rice crop's reflectance ($r= 0.245$, $p>0.001$) in near-infrared, but not in red wavelengths (Leblon, Guerif, and La Rocque 2001). In the past related research, there are some characteristics: previous studies focused on crops, whose canopy reflectance is convenient to measure; these studies mainly small-scale in-situ measurement, lack of large-scale verification; the single band was used for correlation analysis with wind speed in data analysis, rather than vegetation index.

Therefore, we have several scientific problems want to explore: different from the previous research on the influence of wind speed on canopy reflectance from the ground measurement angle, what will happen from the angle of satellite? Compared with crops, how might tall forests behave? And as one of the most common vegetation indexes, how much Influence of wind speed on canopy NDVI measurements? Four main forest types all over the world were selected for this study. The major objective of this study was to discuss whether the change of wind will affect the estimation of NDVI from the angle of satellite, and if so, how much influence it will have and whether the impact on different forest types is different.

2. Materials and methods

2.1 Materials

2.1.1 Data sources

To ensure that the selected points have a stable underlying surface, the flux stations were selected in this study. Wind speed data over the canopy were extracted from flux data. FLUXNET2015 Dataset (fluxnet.org/, including more than 900 sites worldwide) and ChinaFLUX (chinaflux.org/, including more than 70 sites countrywide) are two observation flux networks. The min temporal resolution of flux data is 30 minutes. Among the sites covering different vegetation types, 62 forest sites were selected, including 4 forest types, Deciduous Broadleaf Forests, Evergreen Broadleaf Forests, Evergreen Needleleaf Forests, Mixed Forests. These 62 sites have different spatial scopes and time spans of flux data (Table 1).

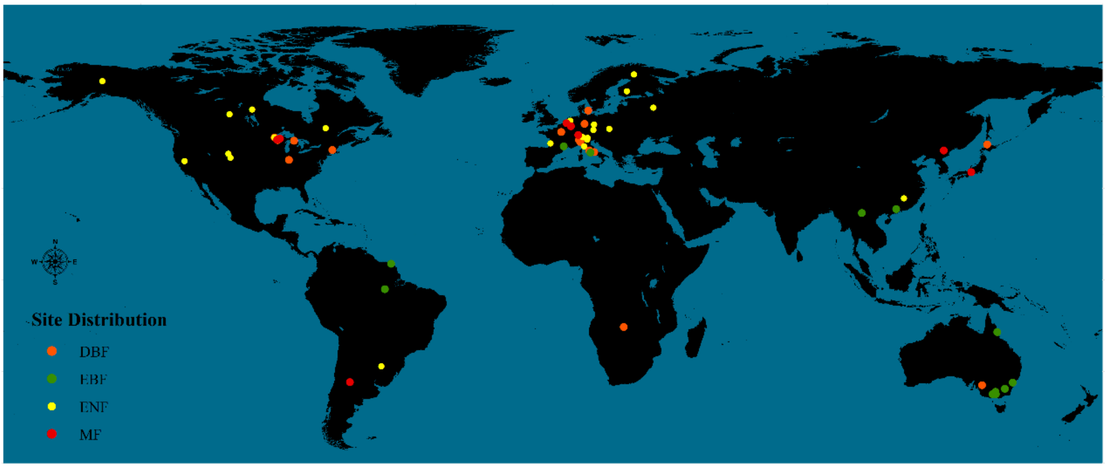

Figure 1. Sites distribution of our study. Including 19 Deciduous Broadleaf Forests (DBF), 13 Evergreen Broadleaf Forests (EBF), 22 Evergreen Needleleaf Forests (ENF), 8 Mixed Forests (MF).

NDVI data were obtained from Terra Moderate Resolution Imaging Spectroradiometer (MODIS). The MOD09GQ Version 6 (lpdaac.usgs.gov/products/mod09gqv006/) is one of the dozens of remote sensing data sets of MODIS, including 8 layers, Surface Reflectance Band 1, Surface Reflectance Band 2, etc. The temporal resolution is daily, and the pixel size is 250 m. Site data were extracted through Google Earth Engine (code.earthengine.google.com). Taking the pixel where the site is located as the center, the mean value of the central pixel and the surrounding 8 pixels is considered as the value of the site.

2.1.2 Data preprocessing

The transit time of the satellite is instantaneous, and the time must be included a certain half an hour. The average wind speed of this half an hour was found from the flux data without other processing. And there is a hypothesis that the wind speed with the temporal resolution of 30 minutes can match remote sensing data, whose acquisition is instantaneous. The corresponding NDVI data of these sites were gained by MOD09GQ and calculated by:

$$\mathrm{NDVI} = \frac{NIR - R}{NIR + R} \quad (1)$$

where NIR is the reflectivity in the near-infrared band, R is the reflectivity in the red band.

The choice of NDVI is based on three principles: the maximum time scope is two weeks to weaken the effects of natural growth; the fluctuation of NDVI is less than 0.1 to reduce the impact of cloud; the part with NDVI lower than 0.25 was discarded with the reason that few leaves in the canopy. Finally, 558 sets of data were screened out from 62 sites, including 192 Deciduous Broadleaf Forests (DBF), 98

Evergreen Broadleaf Forests (EBF), 177 Evergreen Needleleaf Forests (ENF), 91 Mixed Forests (MF). Each set of data contains a different amount of data.

One thing to note is that the time zone convention between flux data (local standard time) and remote sensing data (universal time) need to be converted according to the station location and satellite transit time.

2.2 Methods

Pearson correlation coefficient (r) and p value were used to evaluate the correlation between NDVI and wind speed.

3 Results

3.1 Distribution range of wind speed and NDVI of four forest types

The distribution range of wind speed and NDVI of four forest types was shown in Fig 2. The wind speed is mainly concentrated at 0-7.5 m/s. The wind speed distribution of each forest type is close to the pyramid. While for EBF, the difference is that when the wind speed is 0 m/s, the frequency is not close to 0. Compared with wind speed, the distribution of NDVI is more complex. There are many peaks in the frequency curve of NDVI. For DBF, EBF, MF, there is only one highest peak. And the corresponding NDVI of EBF’s peak is smaller than the other two. The curve of ENF is M-shaped. The sites we chose are all over the world, even for the same forest type, the NDVI of the growing season is different.

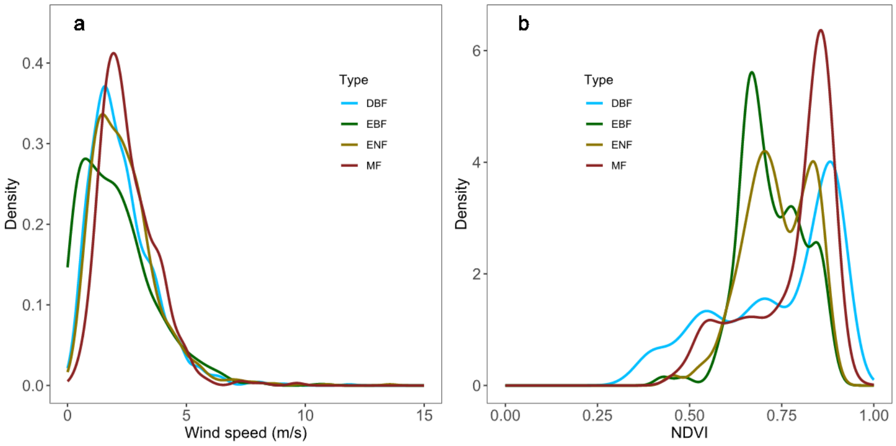

Figure 2. The probability density curve of wind speed (a) and NDVI (b) of four forest types, can represent their distribution.

3.2 The correlation between wind speed and NDVI

The results are discouraging. In 558 sets of data, only 64 sets (11.5%) show a significant correlation ($p<0.05$). That ratio seems so small that when I reviewed the data again two years later (2024-08-12), I couldn't think of a better way. I present the scatter plot (Figure 3) and look forward to reviewing this work in the future.

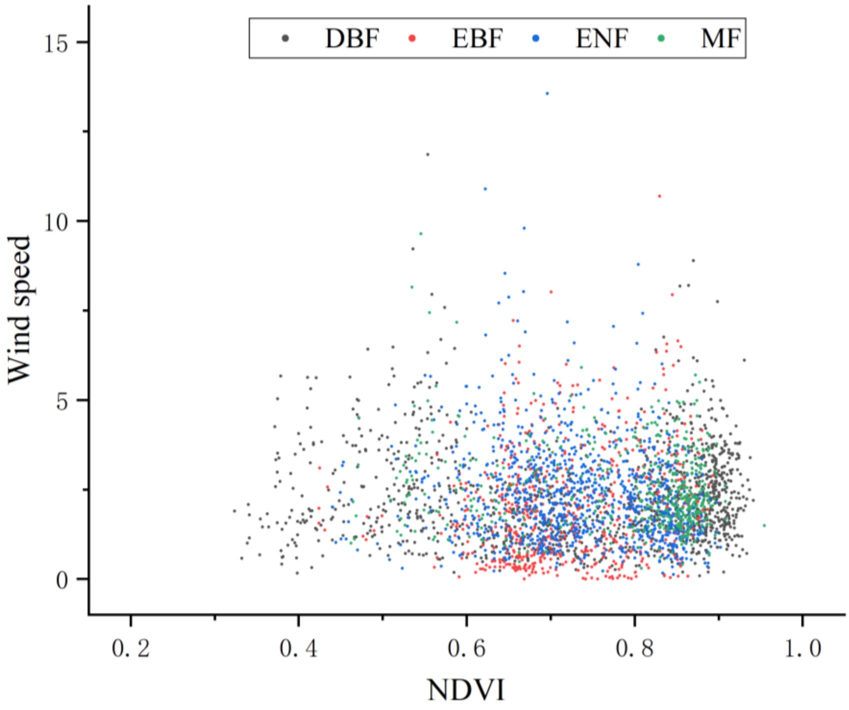

Figure 3. The scatter plot between NDVI and wind speed.

4 Discussion

We used satellite data to study the impact of wind speed on forest canopy NDVI measurements. Due to the influence of the atmosphere and solar angle, especially the spatial resolution of the image, the results of satellite remote sensing are usually worse than near-earth remote sensing. This means that it is difficult for us to get a better result than Guan, J. et al (Guan and Nutter 2001), who carry out their research on the ground. But this study is still an interesting attempt with more and more remote sensing products being used widely.

The results show that wind speed has a certain influence on the measurements of NDVI from the perspective of satellites. About 10% of the data have a statistically significant correlation. Even for different forest types, the results are similar. In the early ground study of Leblon et al. (Leblon, Guerif, and La Rocque 2001), the wind speed was positively correlated to the crop’s reflectance in near-infrared, which is consistent with our findings.

There are some limits to the research. One of the limits is that the time of wind and NDVI is not a perfect match. Satellite transit is often instantaneous; while for global multi-sites meteorological data, the highest time resolution is 30 minutes. On the other hand, the average of wind speed is 2.x m/s, which is too small.

5 Conclusions

Alternatively, the effect of wind speed on NDVI is weak, at least at the satellite scale.

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