SATELLITE-BASED MONITORING OF ECOSYSTEM LEVEL DROUGHT USING VEGETATION OPTICAL DEPTH AND SUN-INDUCED CHLOROPHYLL FLUORESCENCE

S. De Cannière[1], F. Jonard[2]

[1]Earth and Life Institute, Université catholique de Louvain, 1348 Louvain-la-Neuve, Belgium
[2]Earth Observation and Ecosystem Modelling Laboratory, SPHERES Research Unit, Université de Liège (ULiège), Allée du Six Août 19, 4000 Liège, Belgium

Email: simon.decanniere@uclouvain.be; francois.jonard@uliege.be

IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium | 978-1-6654-2792-0/22/$31.00 ©2022 IEEE | DOI: 10.1109/IGARSS46834.2022.9883457

ABSTRACT

Climate change increases the severity and frequency of drought events. Over the globe, different ecosystems show different reactions to drought stress. By using two state of the art remote sensing techniques; vegetation optical depth and chlorophyll fluorescence, we can get a hand on reactions to drought stress at the ecosystem scale. The vegetation optical depth serves as a proxy for the total amount of water in the vegetation, while the sun-induced chlorophyll fluorescence serves as a proxy for the photosynthetic activity. Plant drought reactions break down into two strategies; isohydric behaviour and anisohydric behaviour. Isohydric plants tend to regulate their stomata, allowing them to reduce water losses during drought events. Anisohydric plants tend to be less strict in their stomatal regulation, allowing them to keep up their vegetation growth during drought events. In ecosystems dominated by isohydric plants, such as tropical rainforests, sun-induced chlorophyll fluorescence is a good indicator for the vegetation water status. In anisohydric regions, such as croplands, the vegetation optical depth provides better information on the vegetation water status, as these plants tend to show only little reactivity in their photosynthetic activity to drought stress. Combining the information of both metrics is expected to provide a more complete estimate of the plant water status.

Index Terms— *Solar-Induced chlorophyll fluorescence, drought stress, soil water availability, fluorescence yield, vegetation optical depth, stomatal closure*

1. INTRODUCTION

Climate change increases the severity and frequency of drought events. Remote sensing provides a great tool for monitoring vegetation status at a large scale. Reflectance-based remote sensing methods detect a stress by looking at the impeded vegetation growth, leading to smaller vegetation or to a less developed canopy. However, before the reduced growth occurs, the drought changes a plant in two ways; its water content reduces through transpiration and its photosynthesis slows down because of stomatal closure. These two early reactions to drought stress affect two different remote sensing metrics. The first metric is the vegetation optical depth (VOD), which serves a proxy for the total amount of water in the vegetation (Meyer et al., 2019). VOD consists of the total amount of biomass and the vegetation relative water content. The other variable is the sun-induced chlorophyll fluorescence (SIF) emission, which is mechanistically linked to the plant's photosynthetic activity. Thanks to this mechanistic link, the SIF reacts instantaneously to changing stress conditions (Jonard et al., 2020).

Depending on the plant's stomatal regulation, a water shortage will lower either the vegetation water content or its photosynthetic activity. This makes the VOD and SIF complementary signals for measuring the vegetation water status. This study evaluates the complementarity of these two signals and explains how they can be used to assess the ecosystem water status.

2. MATERIALS AND METHODS

This study combines data from three satellite data streams. First, the VOD is taken from the Soil Moisture Active Passive (SMAP) satellite with the MT dual-channel algorithm (Feldman et al., 2021). This algorithm provides VOD retrievals with a temporal resolution of 3 days and a spatial resolution of 36 km. The SMAP data come on an Equal Area Scalable Earth version 2 (EASE2) grid. SIF data were extracted from the TROPOMI sensor on the Sentinel 5P satellite (Köhler et al., 2018). The SIF data were reprojected to the SMAP EASE2 grid. The SIF signal is determined by both a structural and a biochemical component. Both components bear interesting information on the plant water status (Xu et al., 2021). In order to separate both components, the NIR_vP (Dechant et al., 2022) was calculated by multiplying the MODIS Normalized Difference Vegetation Index (NDVI) with the TROPOMI radiance in the near infrared Rad_{NIR} (equation 1). Normalizing the SIF with NIR_vP allows calculating the fluorescence yield φ_f, which is linked to photosynthesis (equation 2).

$$NIR_vP = NDVI \cdot Rad_{NIR} \quad \text{(equation 1)}$$

$$\varphi_f = \frac{SIF}{NIR_vP} \quad \text{(equation 2)}$$

To gain an effect of the drought conditions, we used the SMAP soil moisture (SM), from the MT-DCA algorithm and the vapour pressure deficit (VPD), form the ERA-5 climate reanalysis provided by the Copernicus Data Store air temperature and air humidity data sets (Hersbach et al., 2022). Special emphasis is centred on the different reactions of different ecosystems to drought stress, as they represent the different strategies of ecosystems to react to a drought. Very isohydric behaviour occurs in rainforests, while cornfields have a very anisohydric behaviour (Konings and Gentine, 2017). To get a hand on the regimes the temporal evolution of VOD and φ_F is evaluated over a dryland (13.1790S, 130.7945E), a eucalypt forest (35.6566S, 148.1517E) and a tropical rainforest

3. FIRST RESULTS

3.1. SOIL MOISTURE CONTROLS FLUORESCENCE YIELD AT DRYLAND SITE

In drylands, the SIF and soil moisture time series show a similar seasonal pattern, with a clear increase in φ_F during the beginning of the wet season. After January, in the second half of the wet season, the φ_F decreases back to the levels it had during the dry season, where it stabilizes around a minimal of 0.02. The short-term variability in soil moisture shows another temporal dynamic than the SIF emission. The NDVI and the VOD show their maxima after the soil moisture maximum (Figure 1).

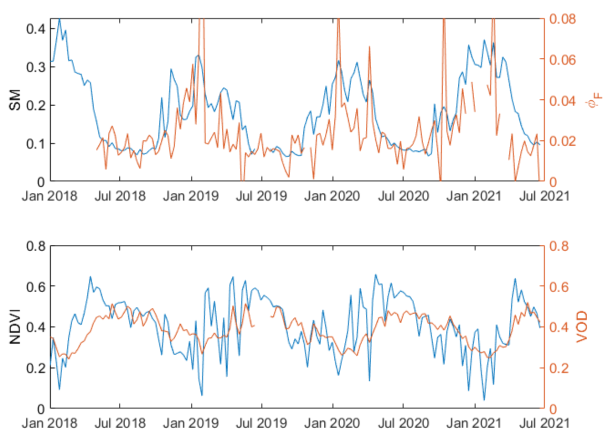

Figure 1: Temporal evolution of soil moisture, φ_F, NDVI and VOD during the study period over the Litchfield site

3.2. SOIL MOISTURE DOES NOT IMPACT FLUORESCENCE YIELD OVER EUCALYPT FOREST

Over the eucalypt site in Tumbarumba, the soil moisture does not affect the behaviour of φ_F, indicating ample water supply over the entire growing season. The VOD and SM show an opposing seasonal pattern, in which the VOD maximizes between November and January, while the SM maximizes between May and October. The NDVI does not show any seasonal pattern (Figure 2). The VOD is quicker to increase compared to the NDVI.

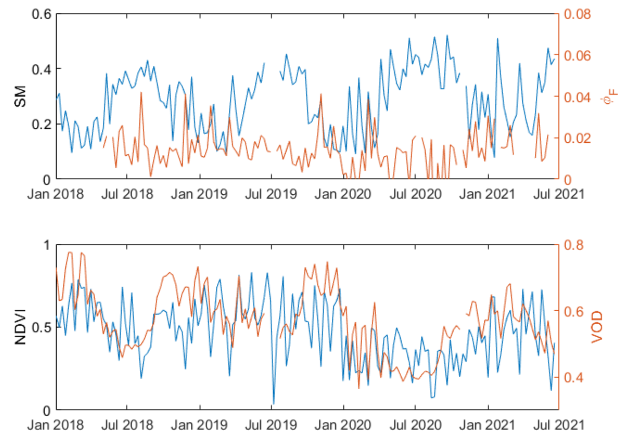

Figure 2: Temporal evolution of soil moisture, φ_F, NDVI and VOD during the study period over the Tumbarumba site

3.3. SOIL MOISTURE IMPACTS FLUORESCENCE OVER RAINFORESTS

The rainforest site shows an increase in φ_F between December 2018 and May 2019, but this behaviour is not repeated in 2020. This increase in φ_F is accompanied by a sharp increase in SM. The wet season of 2020 is less expressed, and it does not show a clear reaction in φ_F. Both the NDVI and the VOD show a seasonal cycle with minima in March. The VOD minima precede the NDVI minima.

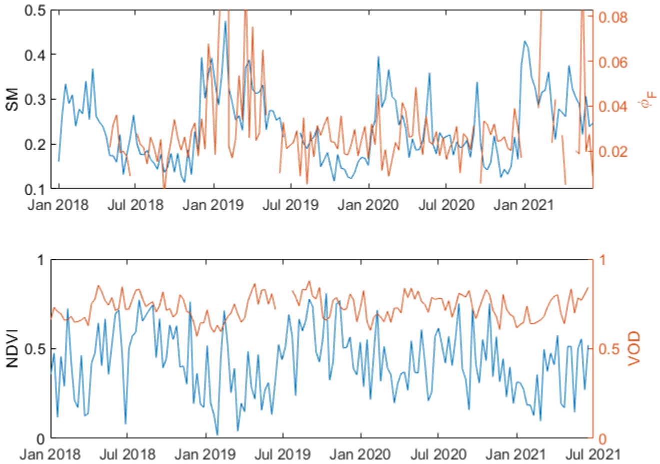

Figure 3: Temporal evolution of soil moisture, φ_F, NDVI and VOD during the study period over the Robson Creek site

4. DISCUSSION

The three study sites show a different behaviour of VOD and φ_f. The clearest link between SM and φ_F was found in the dryland. This suggests that water availability is the main constraint of the photosynthesis in that ecosystem. Similarly, we see that the temporal dynamics of NDVI and VOD agreed nicely. In the Tumbarumba eucalypt forest, the very low values of SM had some impact on VOD, but the φ_f remained unaffected, implying that the water availability has little effect on the photosynthesis. The VOD and NDVI show the same temporal pattern. In the rainforest, the sharp increase in soil moisture also lead to an increase in φ_F. This suggests that, even in wet environments, an increase in moisture content can lead to an increase in photosynthetic activity. This can be linked to the isohydric nature of rainforest ecosystem, which is quick to close stomata in case of a reduction in water content. This slows down photosynthesis, thus reducing φ_F, while allowing plants to maintain their water content, thus maintaining their VOD. Intercomparing the temporal dynamics of φ_F and VOD is expected to provide information on the ecosystem isohydricity.

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5. CONCLUSION

This study investigates the use of combining VOD and SIF to monitor drought stress at the ecosystem scale. The biochemical response is extracted from the SIF to form φ_f. Depending on the degree of isohydricity, either the VOD or the φ_f are quick to react to increasing drought conditions. Combining the information of these two variables should provide a more complete estimate of the plant water status.

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