Monitoring Vegetation Optical Depth (VOD) using GNSS-Transmissiometry at the Vielsalm ICOS site

Lecart Benjamin[1], Louis François[2] and François Jonard[1]

[1] Earth Observation and Ecosystem Modelling Laboratory, SPHERES, ULiège, Liège, Belgium
[2] Unité de Modélisation du Climat et des Cycles Biogéochimiques, SPHERES, ULiège, Liège, Belgium

Abstract

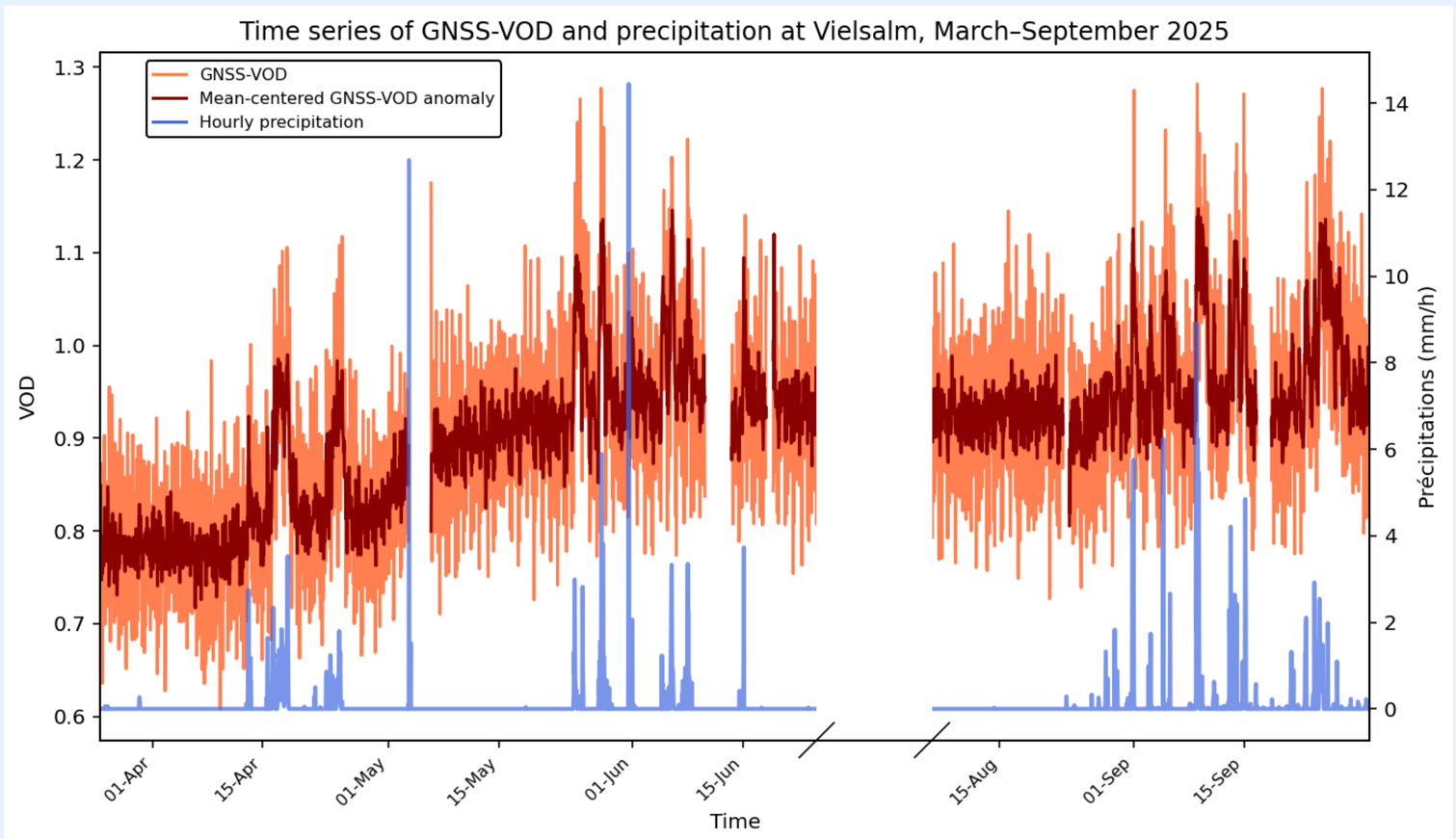
Monitoring vegetation water dynamics is essential to better understand ecosystem functioning and resilience under changing climate conditions**. Vegetation Optical Depth** (VOD), derived from microwave signals, has emerged as a **valuable proxy** for **vegetation water content and biomass** which are key parameters for fire risk assessment. Here, we present in situ measurements of VOD acquired using the **GNSS-Transmissometry** (GNSS-T) technique at the Integrated Carbon Observation System (ICOS) forest site of Vielsalm in Belgium (ES_BE-Vie). A dedicated station was installed on March 2025 to continuously record the attenuation of GNSS signals as they pass through the forest canopy, providing a direct estimate of VOD.

The station records data every 15 seconds, providing high temporal resolution observations that enable detailed monitoring of vegetation dynamics. The dataset allows tracking **short-term variations** like the impact of droughts and other environmental influences on vegetation and has the potential to capture **seasonal changes.** These ground-based VOD observations provide an independent reference for validating **satellite-derived VOD products** and improving **vegetation model parametrization.**

This work demonstrates the potential of GNSS-T for long-term vegetation monitoring in temperate forests and contributes to bridging the gap between ground measurements, remote sensing, and ecosystem modelling.

Experimental Setup

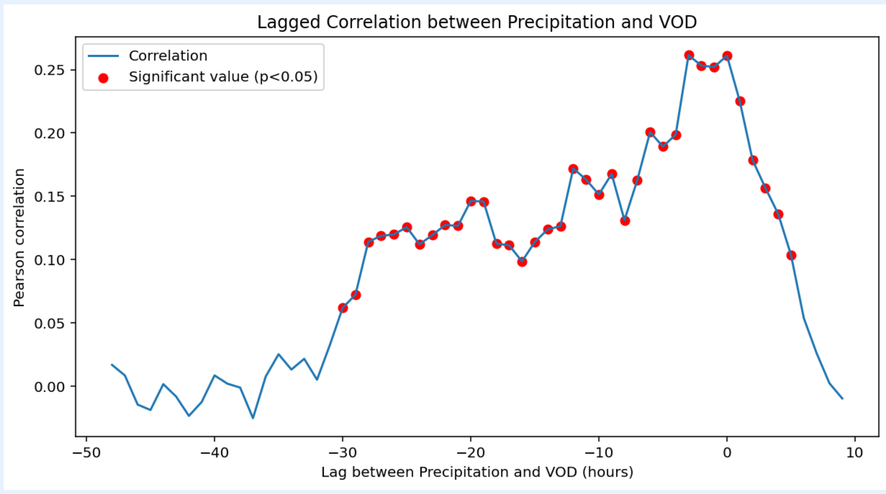
Temporal evolution of VOD



The time series of VOD is obtained by comparing the signal-to-noise ratio from a reference antenna located on a tower at the top of the canopy with the one from an antenna located under a beech canopy [1].

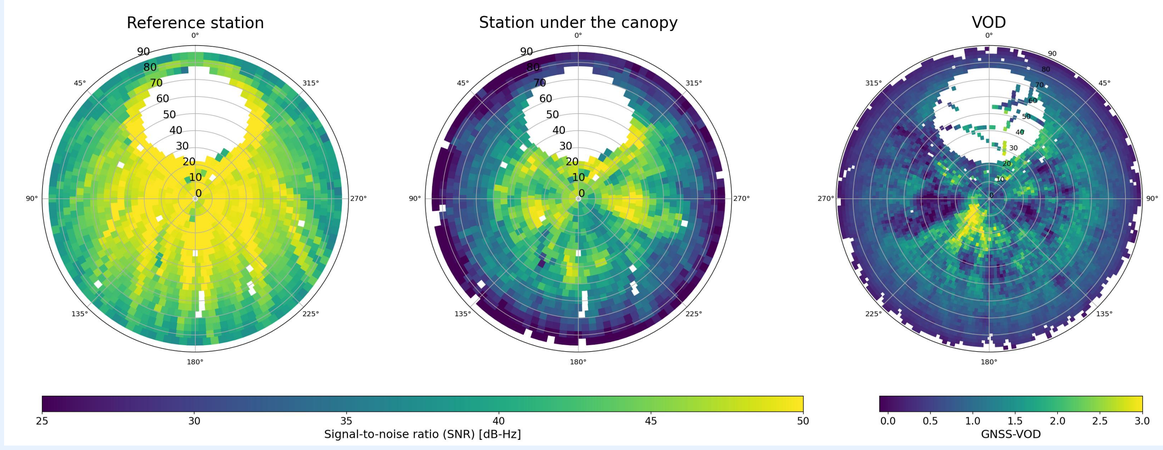
The data clearly show a seasonal increase in VOD between March and July, as well as more short-term increases during wetter periods with rainfall.

We observe an instantaneous correlation of 0.26 between the precipitation measured on-site and the VOD anomaly.



Sky plot of SNR and VOD

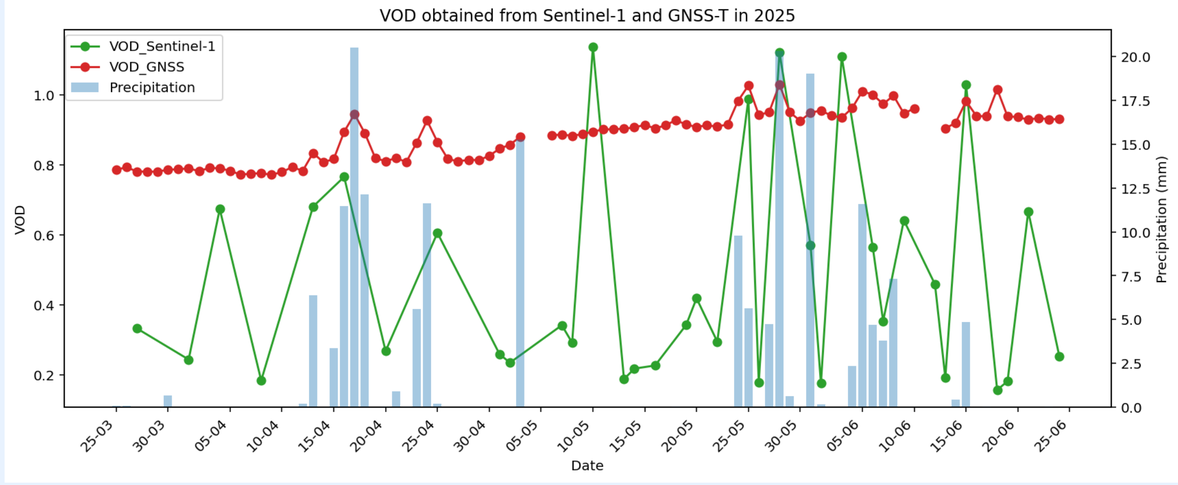
Hemispherical plot of the mean signal-to-noise ratio and VOD of August 2025



Hemispherical plots showing the spatial distribution of averaged signal-to-noise ratio (SNR) at L1/E1 frequency for a reference station (left) and a station under forest canopy (center), alongside the corresponding vegetation optical depth (VOD, right) derived from GNSS signal attenuation. The reference station exhibits higher SNR values across all azimuths and elevations, while the canopy station shows significant signal attenuation, particularly at lower elevation angles where the signal path through vegetation is longest. Spatial patterns reveal canopy structure, with darker VOD areas indicating gaps in the forest cover.

Future work

The next objective of this research is to use GNSS-derived VOD measurements to validate VOD satellite product at high spatial resolution (Sentinel-1).



VOD is directly proportional to the water content in vegetation making it a valuable indicator for estimating changes in vegetation water status over time [2].

This estimation can then be used to develop a wildfire risk index that considers the water stored in plants as a primary indicator, providing a physiologically-based assessment of fire susceptibility validated by GNSS-T. A vegetation-based wildfire risk index could be dynamically derived from VOD measurements provided by each new satellite acquisition, allowing near real-time monitoring of vegetation water status and fire susceptibility.

The estimation of vegetation water content by remote sensing will be integrated as an input variable into the dynamic vegetation model CARAIB to simulate current and future forest fire risks [3].

Two new ground stations have been added to the Vielsalm site: a second GNSS-T station beneath a beech canopy and one beneath a Douglas fir canopy.

[1] Humphrey, V., & Frankenberg, C. (2023). Continuous ground monitoring of vegetation optical depth and water content with GPS signals. *Biogeosciences, 20*(9), 1789–1811. https://doi.org/10.5194/bg-20-1789-2023

[2] Chaparro, D., Jagdhuber, T., Piles, M., Jonard, F., Fluhrer, A., Vall-llossera, M., Camps, A., López-Martínez, C., Fernández-Morán, R., Baur, M., Feldman, A. F., Fink, A., Entekhabi, D., & Konings, A. G. (2024). Vegetation moisture estimation in the Western United States using radiometer-radar-lidar synergy. Remote Sensing of Environment, 303, 113993. https://doi.org/10.1016/j.rse.2024.113993

[3] Warnant, P., François, L., Strivay, D., & Gérard, J.-C. (1994). CARAIB: A global model of terrestrial biological productivity. Global Biogeochemical Cycles, 8(3), 255–270. https://doi.org/10.1029/94GB00850

This publication is supported by the French Community of Belgium through the funding of a FRIA fellowship.

Team Contacts

- Benjamin.Lecart@uliege.be
- Louis.Francois@uliege.be
- Francois.Jonard@uliege.be