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Assessing C-band SAR-based VOD in forest ecosystems using physical scattering models

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The dynamics of water, biomass, and structure of forest ecosystems are challenging to assess on larger spatio-temporal scales with ground-based measurement techniques, particularly beyond individual tree stands. Here, satellite-based remote sensing provides solutions to enhance these assessments.

Vegetation optical depth (VOD) is a remote sensing variable that measures the attenuation of microwaves by vegetation. The VOD signal contains information on dry biomass, structure, and water content of vegetation. These signal components can be disentangled using microwave scattering or emission models, depending on active or passive acquisition modes. Short-term variations in VOD time series primarily reflect water dynamics, while seasonal changes are associated with biomass variations. VOD is operationally retrieved globally, with a temporal revisit of 1-to-3 days, from passive satellite sensors like AMSR-2, SMAP, and SMOS, acquiring at a relatively coarse spatial resolution (~40 km) with enhanced interpolations providing ~10 km gridding products. Thus, coarse resolution limits studying forest stands at local scales with passive microwave techniques.

This study aims to estimate spatially high-resolution Synthetic Aperture Radar (SAR)-based VOD in forest ecosystems based on Sentinel-1 C-band (5.504 GHz) backscatter data (10 m) from March to September 2023 in Germany. The focus is on two primary study sites, characterized by a deciduous broadleaf ("Leinefelde") and an evergreen needleleaf forest ("Wetzstein"), contrasting the most common forest types in Central Europe.

Regarding the methodology, we disentangle C-band VOD in its core components to derive the water content of the upper tree canopy, where the C-band is most sensitive due to microwave penetration capabilities. For this purpose, we employ a combination of physically-based soil and vegetation scattering models (radiative transfer theory). Moreover, we compare our resulting SAR-based VOD time series, among others, against VOD estimates derived from Global Navigation Satellite System-Transmissiometry (GNSS-T) at L-band (1.1-1.5 GHz), using in situ receivers, one at the top of the canopy and one on the ground. We further plan to validate our approach with in situ plant gravimetric moisture content (mg, $[\text{kg}_{\text{water}}/\text{kg}_{\text{wet biomass}}]$) measurements of the tree canopy for both forest sites. Finally, our approach paves the way for further application in agriculture. This will be explored in the new Land-Atmosphere Feedback Initiative (LAFI) in detail.

Retrieved satellite-based VOD at such high spatial resolution allows for small-scale up to stand-based analyses of forest water dynamics, biomass changes, and leaf water potential variations. Consequently, these SAR-based VOD dynamics hold potential for monitoring forest health, detecting drought and water stress as well as assessing plant phenology, biomass, and carbon storage.

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