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Simulating Sub-daily Forest Backscatter to track Water, Carbon and Health in Forested Ecosystems

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The resilience of terrestrial ecosystems to drought and environmental stress is critical for the future of the terrestrial carbon balance. Vegetation water dynamics play a central role in these ecosystems, as they are closely coupled to carbon assimilation at the plant stomata. Sub-daily variations in plant water status are expected to reflect both abiotic and biotic stress responses. Improving our understanding of these short-term dynamics could enable us to detect early signs of vegetation health decline and provide new metrics to quantify ecosystem resilience and tipping points.

However, sub-daily vegetation water content (VWC) dynamics remain poorly understood and are weakly represented in terrestrial biosphere models. This knowledge gap is largely driven by the scarcity of sub-daily observations, as VWC is difficult to measure both in-situ and via satellite remote sensing. To address this observation gap, the SLAINTE mission concept was proposed as one of ESA's New Earth Observation Mission Ideas in response to the 12th Call for Earth Explorers. The goal of the mission was to capture sub-daily variations in vegetation water storage, including vegetation optical depth, VWC, plant water potential, and surface soil moisture.

A critical aspect of the continued development of this mission concept is consolidation of the observation and measurement requirements. Therefore, this study focuses on simulating sub-daily time series of forest radar backscatter using a radiative transfer (RT) model. The simulations are driven by continuous, non-destructive ground-based measurements of forest transmissivity collected at several forested sites across Europe. The resulting synthetic backscatter time series allows us to characterize and quantify the influence of sub-daily variations in plant water dynamics, vegetation structure, and biogeophysical properties on the radar backscattering coefficient.

We present initial results from simulations at two forest sites and discuss their implications for strengthening the science case of the SLAINTE mission. We also highlight key limitations encountered during the modeling effort. These include the high sensitivity of RT simulations to forest structural parameters and the limited availability of sub-daily validation data. Accurate model parameterization requires detailed information on forest geometry (such as foliage

density), which is difficult to obtain even by field measurements. We attempt to quantify forest architecture using terrestrial laser scanning. Validation remains challenging due to limited availability of sub-daily observations of VWC, vegetation dielectric properties, and radar backscatter, particularly when interpreting short-term fluctuations. Additionally, separating the effects of internal vegetation water dynamics from surface canopy water associated with interception and precipitation remains a significant challenge at sub-daily timescales. Addressing these issues will require continued interdisciplinary collaboration combining field observations, modeling and remote sensing.