EGU26-21068, updated on 07 Nov 2026
https://doi.org/10.5194/egusphere-egu26-21068
EGU General Assembly 2026
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Sensitivity of C- and L-band SAR observations to water and carbon cycle variables in Mediterranean forests

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Synthetic Aperture Radar (SAR) satellites provide all-weather, day-night global Earth surface coverage, enabling continuous monitoring of ecosystems across multiple microwave bands. Over forested areas, SAR backscatter carries information on canopy water content, vegetation structure, and soil moisture. Microwave signals with shorter wavelengths interact with leaves and upper canopy layers, while longer wavelengths penetrate deeper and investigate branches, trunks, and soil. This makes SAR backscatter a proxy for retrieving ecosystem variables related to water and carbon cycles, such as soil moisture and biomass, which are critical inputs in data assimilation schemes for Earth system models.

However, SAR applications over forests are limited by backscatter saturation over dense canopies and by the limited penetration depth of shorter wavelengths through vegetation. Understanding how these constraints vary across different microwave bands, SAR variables, and forest types is thus essential before implementing data assimilation experiments.

This study explores the sensitivity of Sentinel-1 C-band (5.405 GHz, l ~ 5.55 cm) and SAOCOM L-band (1.275 GHz, l ~ 23.5 cm) SAR observations to soil moisture (SM), evaporation (ET), gross primary productivity (GPP), and Leaf Area Index (LAI), over Mediterranean forest sites. We analyze the sigma nought (σ0) backscattering coefficient in different polarizations (dual-pol for Sentinel-1, quad-pol for SAOCOM), along with its cross-ratio (σ0VH/ σ0VV), backscatter-incidence angle slope, and polarimetric decomposition parameters. We calculate the sensitivity of each parameter by computing linear regression against in-situ measurements of ecosystem variables. We also assess sensitivity changes across different acquisition geometries and timing (morning and evening overpasses), seasonality, and forest types.

We consider three study sites in central and northern Italy, namely IT-BFt, IT-Cp2, and IT-SR2, which belong to the ICOS/FLUXNET network and are equipped with soil moisture probes and eddy covariance towers for water and carbon fluxes measurements. The three sites comprise both deciduous (*Carpinus betulus*, *Quercus robur*) and evergreen (*Pinus pinea l.*, *Quercus ilex*) forests with diverse structural characteristics.

C-band backscatter from Sentinel-1 exhibits saturation at two out of three study sites, particularly where canopies are the densest. Conversely, L-band backscatter shows higher sensitivity to soil moisture and vegetation growth. By characterizing the sensitivity of SAR parameters to geophysical variables, this study contributes to a better understanding of the potential of SAR retrievals in data assimilation experiments to improve predictions of hydrological and carbon fluxes over forested regions.