Program

18–20 Nov 2026

9th INTERNATIONAL WORKSHOP ON RETRIEVAL OF BIO- & GEO- PHYSICAL PARAMETERS FROM SAR DATA FOR LAND APPLICATIONS

Universitat Politecnica de Catalunya , Aula Master
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Table of contents

1 Wednesday 18 Nov

Welcome 1

Forest - Modelling and Retrieval I 1

Coffee Break 3

Forest - Modelling and Retrieval II 3

Lunch Break 6

Forest - Tomography I 6

Coffee Break 8

Forest - Tomography II 8

Round Table 10

Poster Session 10

Ice Break 10

11 Thursday 19 Nov

Soil and Hydrology I 11

Coffee Break 14

Soil and Hydrology II 15

Lunch Break 17

General Land Applications I 17

Coffee Break 19

General Land Applications II 19

Round Table 22

23 Friday 20 Nov

Agriculture 23

Coffee Break 26

Ice and Snow I 26

Round Table 30

Wednesday 18 November

09:00

Welcome

Session | **Conveners:**
Francesca Ticconi (ESA), Carlos López-Martínez (Universitat Politècnica de Catalunya), Francesco Torres Torres (Dean of UPC)

Description

welcome

09:30

09:30

Forest - Modelling and Retrieval I

Session

09:30–09:50

Forest Height Estimation From BIOMASS Data: Actual Status, Challenges, Potential and Ways Forward

Speaker
Roman Guliaev (German Aerospace Center (DLR))

Description

ESA’s BIOMASS, launched on April 29, 2025, able to acquire fully polarimetric, interferometric and tomographic information, enables for the first time large scale Pol-InSAR forest height inversion at P-band. The spatial baseline distribution of BIOMASS is optimized for tropical forest height retrieval and tomographic (reflectivity) profile reconstruction, while the satellite’s short revisit time of three days minimizes temporal decorrelation providing a unique opportunity to obtain high-quality forest height maps.

This contribution first provides an assessment of the actual performance of the BIOMASS forest height product at large and local scales, over a variety of forest types and terrain conditions, and discusses its main limitations. The validation is performed agains air- (ALS) and space-borne (GEDI) lidar measurements.

While the correlation between forest height and volumetric across-track interferometric coherence is well established, compensating for non-volumetric decorrelation contributions in the case of BIOMASS remains challenging due to ionospheric propagation effects and complex temporal decorrelation patterns, as well as the parameterisation of the vertical reflectivity profile.

In a second step, these challenges are addressed and possible data processing and algorithmic improvements required to achieve optimum performance are proposed. Different/possible model-based strategies for forest height inversion from BIOMASS acquisitions are discussed, including single-, dual-, and three-baseline scenarios. The different trade-offs are discussed and demonstrated by means of different BIOMASS test cases.

09:50–10:10

Monitoring the progress of afforestation projects with C- and L-band SAR backscatter

Speaker
Oliver Cartus (GAMMA Remote Sensing)

Description

Carbon markets, operating on the principles of emission trading and carbon offsetting, offer market-based incentives to reduce emissions and to adopt low-carbon practices. New rules from leading registries such as Verra, Gold Standard, and Isometric are advancing digital Measurement, Reporting, and Verification (dMRV) systems to enhance transparency and reduce monitoring costs in carbon offset projects by utilizing Earth Observation data to track carbon sequestration progress. Yet, the capabilities offered by remote sensing to support carbon markets have yet to be fully understood. Existing research data products are usually developed not considering the specific requirements of carbon markets. Not being tailored to the local site conditions, they are typically affected by inaccuracies, undermining their reliability.

The ESA-funded project CarbonEye aims at the development of transparent EO-based approaches for monitoring the progress of Verified Carbon Standard (VCS) projects by integrating information from localized ground data into an established and fully transparent above-ground biomass (AGB) mapping algorithm using decadal timeseries (years 2015 to 2025) of dual-polarization C- and L-band radar backscatter observations from the European Sentinel-1 and the Japanese ALOS-2 PALSAR-2 missions to deliver accurate time series of forest biomass maps. The CCI Biomass approach (Santoro et al., 2024) has been selected because of its physical model basis and the flexibility in adjusting its components to different forest structures while minimizing the need for contemporary, frequently updated in-situ data. Here, we discuss the performance of the modified CCI Biomass approach for seven VCS afforestation projects in Ghana, Sierra Leone, Uganda, Paraguay, Uruguay, and the Baltic states, which were selected because characterized by open datasets of carbon stocks in verification and validation reports in the Verra registry (the world’s largest carbon-offset registry).

A validation of AGB retrieval results obtained with the adapted CCI Biomass approach when using different combinations of multi-temporal C- and L-band co- and/or cross-polarization backscatter observations with plot- or stand-level AGB ground data indicated the reliability of the approach to map carbon stocks. Yet, the AGB mapping tends to require solutions that are somewhat tailored for each individual plantation site. Complicating factors were that i) projects participating in the carbon market often plant non-native, fast-growing tree species with structural properties that differ substantially from indigenous forests in the region, and ii) notable differences in the backscatter to AGB relationships could be observed also between species that are commonly planted (e.g., different types of Eucalyptus, Pine, Teak, or Acacia). Species related effects in the backscatter to AGB relationships did not affect all frequencies and polarizations equally. At several of the project sites, a combination of both frequencies and polarizations helped to overcome limitations (e.g., biased estimates) associated with a single frequency/polarization. At other project sites, instead, unbiased AGB estimates could only be achieved with a single frequency and polarization (e.g., L-band HV polarization). Different combinations of the available time series of C- and L-band backscatter observations therefore have to be considered when producing a decadal stack of AGB maps for each project area.

The trajectories of AGB and carbon stocks are to be compared to numbers released by the projects in verification and validation reports to assess the true potential of the suggested approach as an independent EO-based monitoring tool. First results of the map validation will be presented at the conference.

10:10–10:30

Physics-Informed Forest Aboveground Biomass Retrieval Using WCM and IWCM with Sentinel-1 and NISAR Data

Speaker

Wenyu Yang (University of Napoli Parthenope)

Description

Forest aboveground biomass (AGB) is an important indicator of forest carbon storage and plays a key role in carbon monitoring and forest management. The increasing availability of spaceborne synthetic aperture radar (SAR) observations from Sentinel-1 and NISAR provides new opportunities for large-scale AGB estimation. In this study, a physics-based AGB retrieval framework is developed using both the Water Cloud Model (WCM) and a zero-baseline formulation of the Interferometric Water Cloud Model (IWCM). The WCM is used to model the backscattering response, while the IWCM exploits interferometric coherence to characterize the contributions from the forest canopy and underlying ground. By neglecting the vertical decorrelation terms associated with the perpendicular baseline, the IWCM is simplified and the number of unknown parameters is reduced. Combined with polarimetric optimization, three IWCM formulations are investigated to represent ground-only, forest-only, and combined ground–forest contributions to interferometric coherence. Model parameters are estimated without using reference AGB, which is introduced only for independent validation.

Two parameter estimation strategies are explored: nonlinear least-squares optimization and a deep-learning-based framework. In the latter, a neural network predicts the unknown physical model parameters from SAR observations, which are then passed through the WCM/IWCM forward models to reconstruct the observed backscatter or coherence. The network is trained by minimizing the discrepancy between modeled and observed SAR measurements, while physical constraints are imposed to ensure physically meaningful solutions. The proposed framework combines the interpretability of physical models with the flexible parameter estimation capability of deep learning for forest AGB retrieval.

10:30–10:50

Ground topography effects in biomass estimation from P-band Biomass data

Speaker

Lars Ulander (Chalmers University of Technology)

Description

Biomass is the seventh Earth Explorer mission of the European Space Agency. Its primary objective is to reduce uncertainties in global carbon stocks of the terrestrial biosphere as well as the corresponding carbon fluxes caused by land use change (LULUCF, mainly deforestation) and land uptake (mainly forest regrowth). To achieve this goal, Biomass will generate yearly and near-global maps of above-ground dry biomass density (AGBD) from data collected by its polarimetric synthetic aperture radar (SAR) operating at P-band (432-438 MHz). Further innovative components of the Biomass mission are interferometry and tomography which will be used for reducing the disturbing effect of the scattering component originating from the ground level. The focus of Biomass is tropical forests where AGBD data is most urgently needed. Biomass will generate wall-to-wall maps of AGBD across South America, Africa, Asia and Australia on a 200-meter grid.

The baseline algorithm for AGBD from Biomass data is based on linear regression and a power-law model, relating AGBD to P-band radar backscatter at HH, VV and VH linear polarization [Soja et al. 2021]. This semi-empirical model has been developed based on airborne P-band SAR data collected prior to the mission over tropical and boreal forests. Further enhancements of the algorithm are expected based on experiences from the Biomass mission data. The baseline algorithm estimates AGBD by model inversion after training the model parameters on a global training data set using linear regression.

Analysis of Biomass level 1A/B/C and 2A data products have shown significant ground topography effects which cause errors in the AGBD estimates unless mitigated. Results from overlapping ascending and descending tracks clearly show this effect. Airborne SAR data collected prior to the mission launch also shows significant topographic effects [Bennet et al. 2024]. Results from analysis of the Biomass data will be shown at the conference, in particular comparing L2A ground-notched and tomographic data over tropical forested areas. Polarization differences are investigated and interpretations of the effects are provided. Prospects for mitigation will be proposed.

References:
Soja et al., Mapping above-ground biomass in tropical forests with ground-cancelled P-band SAR and limited reference data, Remote Sensing of Environment, vol. 253, 2021
Bennet et al., Sensitivity of P- and L-band SAR Tomography to Above-Ground Biomass in a Hilly Temperate Forest, IEEE Transactions on Geoscience and Remote Sensing, vol. 62, 2024.

10:50

10:50 **Coffee Break**
Break
11:10

11:10 **Forest - Modelling and Retrieval II**
Session

11:10–11:30

Paving the Way for Uncertainty-Aware Forestry Products Using TanDEM-X and AI

Speaker
Daniel Carcereri (German Aerospace Center (DLR))

Description

Accurate characterization and continuous monitoring of forest canopy height are essential to guide conservation efforts, evaluate temporal stability, and support climatological analyses under increasing anthropogenic pressures. While deep learning (DL) models applied to interferometric synthetic aperture radar (InSAR) data have been shown to achieve state-of-the-art performance, their operational utility has been hindered by a lack of uncertainty reporting, which is critical for error propagation and determining prediction reliability. This work introduces a novel Bayesian deep learning (BDL) framework for the uncertainty-aware estimation of forest canopy height using single-pass TanDEM-X InSAR data, marking its first application to SAR interferometry. The framework explicitly models aleatoric uncertainty through a heteroscedastic neural network and captures epistemic uncertainty by evaluating multiple intra- and inter-basin approximation strategies, including Stochastic Weight Averaging (SWAG), Deep Ensembles, and Multi-SWAG. The proposed approach was evaluated across a country-scale dataset in Norway with national airborne laser scanning (ALS) data as a reference, and demonstrated excellent in-distribution performance. All configurations yielded accurate forest height estimates, with the best achieving a bias of 0.01 m, a mean absolute error (MAE) of 2.38 m, a root mean squared error (RMSE) of 3.17 m, and a coefficient of determination (R2) of 0.76. Furthermore, all models provided well-calibrated and consistent uncertainty estimates under in-distribution conditions, with in particular the inter-basin approaches achieving a total predicted error (TPE) of 99% and an expected calibration error (ECE) of 0.047. However, when tested under out-of-distribution (OOD) conditions, which we emulated by systematically occluding products acquired with different height of ambiguity values, all Bayesian models were shown to significantly underestimate prediction errors. To resolve this, we coupled the BDL model with an ad hoc OOD detector, which successfully flagged domain-shifted samples, restoring uncertainty calibration and regression performance to in-distribution levels. This framework establishes a robust, reliable, and operational paradigm for generating the next generation of uncertainty-aware forest parameter maps from spaceborne InSAR data.

11:30–11:50

New Polarimetric Change Detectors: Application to Tropical Forest Monitoring Using BIOMASS SAR Data

Speaker

ayoub hamza

Description

Detecting changes between polarimetric radar observations is important for monitoring the temporal evolution of the biogeophysical properties of natural scenes. The long wavelength of BIOMASS's fully polarimetric P-band radar provides sensitivity to forest properties and their change over time.
Under the standard complex Gaussian model for single-look complex SAR data, polarimetric covariance matrices estimated by averaging independent samples redondant (complex Gaussian...) follow a scaled complex Wishart distribution. This model provides the basis for the generalised likelihood ratio test (GLRT) for change detection developed by Conradsen and al. Despite its optimal characteristics, this approach can be computationally expensive and does not explicitly distinguish changes in backscatter from changes in the polarimetric scattering mechanisms.
This paper proposes two new descriptors of polarimetric variations.
The first is based on a Log-Euclidean (LE) representation, which accounts for the geometry of positive-definite covariance matrices. while involving simple calculations of means and distances. This geometrically consistent representation may improve detection performance, while closed-form expressions may reduce computational cost, compared to Conradsen and al. Using an intrinsic Gaussian model on this space, a GLRT is developed to discriminate between the hypothesis of a common mean across both dates and that of distinct means for each date.
The second descriptor explicitly uses the eigenvalues decomposition of the covariance matrices. In contrast to the Log-Euclidean approach, this modelling approach aims to capture the geometry of both eigenvectors and eigenvalues through Lie group theory, thereby enabling a more accurate identification of scattering mechanisms and a more reliable estimation of their associated powers. Then, a GLRT detector is derived using a Gaussian model defined on the Lie-group of both eigenvectors and eigenvalues. It enables a deeper characterization of polarimetric changes by discriminating variations in backscattered power and changes in the underlying scattering mechanisms.
The proposed descriptors are evaluated using multitemporal BIOMASS data acquired over forested areas in the Brazilian Amazon. They are compared with the Wishart-based GLRT to assess their detection performance and their ability to characterise polarimetric variations associated with forest changes.

This work is funded by the Centre National d'Études Spatiales (CNES) and CESBIO.

11:50–12:10

Observation of Ground Surface and Dihedral Scattering Signatures from BIOMASS Pol-InSAR Data: From Local Dynamics to Large-Scale Mapping

Speaker

Noelia Romero-Puig (German Aerospace Center (DLR) / Hisdesat)

Description

Understanding forest structural dynamics is crucial for accurate forest biomass estimation, ecosystem monitoring, and carbon cycle modelling. The launch of the European Space Agency's (ESA) BIOMASS mission on April 29, 2025, opened a new era as the first spaceborne P-band synthetic aperture radar (SAR) continuously operating in quad-polarimetric, multi-baseline interferometric, and tomographic modes [1]. Thanks to its long wavelength (~70 cm), P-band SAR can penetrate dense forest canopies and reach the ground, resulting in complex scattering interactions. However, the physical interpretation of such P-band images, even in the context of polarimetric SAR time series, remains challenging due to the complexity of the scattering interaction that lifts the scattering entropy [2, 3, 4]. To resolve this the combination of polarimetric and interferometric (Pol-InSAR) information, sensitive to the vertical distribution of the scatters, can be exploited to decompose the total radar return into its round and volume components [5, 6].

In this contribution, we exploit 3-day repeat-pass Pol-InSAR BIOMASS acquisitions to isolate and interpret the polarimetric signature of the ground scattering component. The rapid environmental and weather changes (e.g., water level fluctuations and rain events) visible in the BIOMASS data induce complex temporal decorrelation patterns that vary spatially across consecutive 3-day interferograms making conventional multi-baseline ground-volume separation techniques suboptimum [7]. To overcome this, a single-baseline, model-based approach based on the Random Volume over Ground (RVoG) formulation [8] is employed, tailored to the BIOMASS revisit cycle. Following the ground and volume separation, the recovered ground scattering matrix is decomposed into direct surface and ground-trunk dihedral interaction components. The relative weight between these signatures yields direct physical insight into horizontal (ground) and vertical (canopy) forest structure.

The proposed methodology was validated during the BIOMASS In Orbit Commissioning phase over vegetated coastal and riverine ecosystems, such as the Congo River Delta. In these environments, conventional PolSAR images failed to reflect rapid hydrological dynamics, and interferometric coherence maps alone presented ambiguous interpretations. By isolating the ground signature, the recovered polarimetric change mechanisms successfully disentangled and explained the underlying decorrelation patterns, explicitly recovering tide-induced scattering dynamics beneath dense mangrove and forest canopies [9]. Building on these results, a first large scale analysis is performed and presented, including country wide tropical forest regions, such as Gabon and the Amazonian forest. The structural signature of different forest types and disturbance regimes is analysed and discussed.

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[9] N. Romero-Puig, M. Pardini, R. Guliaev and K. P. Papathanassiou, "Initial P-band BIOMASS Pol-InSAR Observations for Forest Structure Mapping," in Proc. EUSAR 2026, Jun. 2026.

12:10–12:30

Forest Height Estimation Based on Sentinel-1 Interferometric Coherence and Meteorological Data

Speaker

Marc Herrera-Giménez

Description

This work analyses the possibility of estimating forest tree height (TH) at high and low spatial resolution using Machine Learning (ML) models and multi-source Earth Observation (EO) data. Estimating forest biophysical parameters is a must to quantify climate change effects, and the challenge with EO is the complexity and volume of data. Building on the observation that a direct relation exists between the SAR interferometric coherence, especially the temporal decorrelation component, and the biophysical parameters of forests, this work studies the possibility and the effects of combining interferometric coherence with artificial intelligence models, AI4EO, to estimate forest tree height. The interferometric coherence along a digital elevation model (DEM) and a land cover map (LC) is combined with meteorological data in a Random Forest model to estimate tree height in three different test sites: the Pyrenees region between southern France and Catalonia in Spain, the central part of Finland and an area close to Yellowknife, Canada, in the Northwest Territories. The three areas expand across 200km × 50km, and for each of them, 20 Sentinel-1A and Sentinel-1B acquisitions separated 6 days apart are used, obtained from December to March for different years depending on the site, with only VV polarization processed for the 6-day complex interferometric coherence computation. The ground-reference data consist of a DEM from Copernicus 30m Global DEM, an LC map and a tree height ground reference, at a high spatial resolution of 10m–30m. The meteorological data are obtained through ERA5 and include rain, snow, wind and temperature at a lower spatial resolution of 10km as a consequence of the model; in total, 8 different variables are used. The study consists of two parts. First, the estimation of tree height at the low 10km×10km resolution by downscaling the high-resolution variables, aggregating the pixels at 10km × 10km subareas, assessing the contribution that the InSAR coherence at 10km may bring when combined with the native ERA5 meteorological data, DEM and LC. Second, a high-resolution study at 10m × 10m, to study if the weather conditions add complementary information to the native Sentinel-1 resolution data; to reduce computational complexity, this analysis is limited to a 10km × 10km subset and only a single 6-day coherence pair is employed. The model employed is Random Forest, as it outperformed other tested models, such as Support Vector Machines and K-Nearest Neighbours. In the low-resolution analysis the model is trained and tested using each individual 6-day coherence acquisition, and the mean of the results defines the validation metrics: the mean Root-Mean-Square-Error (RMSE) is 2.098m, 1.231m and 2.009m and the mean determination coefficient (R2) is 0.702, 0.211 and 0.690 for the Pyrenees, Finland and Yellowknife, respectively. The 10m analysis uses just the first 6-day coherence acquisition of each site; hence no mean is required; the RMSE is 4.442m, 3.053m and 1.698m and the R2 is 0.672, 0.549 and 0.837, respectively. Relatively low RMSE and R2 are achieved for both analyses, although the errors for the Pyrenees and Finnish sites double when moving from the low-resolution to the high-resolution analysis, primarily due to the homogeneity introduced in the low-resolution data, while for the Canadian site the error decreases by approximately 20 %. These errors must be interpreted in the context of their spatial resolutions, thus in the low resolution, the variability in heights is eliminated. The results show how the combined information from these multiple sources complements each other to estimate the tree height with a relatively low error in an operational way, highlighting the potential of combining multi-source data and machine learning techniques and opening the possibility of further data fusion for improved results.

12:30

12:30

Lunch Break

Break

14:00

14:00

Forest - Tomography I

Session

14:00–14:20

3D Forest Structure Mapping Using BIOMASS Tomography: Challenges, Potentials and Ways Forward

Speaker

Matteo Pardini (German Aerospace Center (DLR))

Description

Since November 2025 the ESA BIOMASS Synthetic Aperture Radar (SAR) mission is acquiring multi-baseline full-pol P-band data in a 3 day repeat pass mode enabling the reconstruction of the full 3D distribution of the backscattered radar power (reflectivity) by means of tomographic (TomoSAR) techniques. In this context, BIOMASS TomoSAR reconstructions provide for the first time the unique possibility of characterizing 3D forest structure (linked to the 3D size, location and arrangement of trees, trunks and branches in a stand) at global scales.
The interpretation of TomoSAR reconstructions in terms of 3D forest structure has been addressed so far only at airborne spatial / temporal resolution and coverage in correspondence of lidar and ground measurements [1]. However, real data experiments have shown that the BIOMASS instrument and mission implementation make conventional multi-baseline TomoSAR reconstructions different from airborne ones. In particular, two factors become critical: the coarse BIOMASS range resolution and the 3-day repeat-pass interferometric implementation. Both of them limit the lateral (> 50 m) and vertical resolution (in the order of 20 m) of the TomoSAR reconstructions, and in turn of structure indices (> 4 ha). At the same time, the 3-day revisit-time introduces a non-stationary change of the underlying reflectivity profile due to changes of water content in the vegetation on ground. While experiments so far show that the separation of scattering contributions seems achievable within the resolution limits, their reconstructed reflectivity may lose significance.
In this context, this work addresses the challenges and discusses the potentials for 3D forest structure mapping using BIOMASS measurements, based on experimental analyses performed in a variety of forest sites / types. The ecological significance of currently available structure metrics [1] at the BIOMASS resolution will be discussed over relevant (known) large scale structure gradients. In this, the use of single-baseline reflectivity reconstruction algorithms (as Polarization Coherence Tomography, PCT) will be considered not only for limiting the effects of a changing reflectivity profile in the TomoSAR reconstruction, but also to characterize temporal change. Finally, possible directions for increasing the significance and resolution of structure mapping will be addressed and discussed.

References:

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14:20–14:40

Identification and measurements of individual trees with tower-based L-band 3D radar tomography in a boreal forest

Speaker

Theresa Leistner (Department of Environmental and Energy Sciences, Chalmers University of Technology, Gothenburg, Sweden)

Description

Understanding temporal variations in L-band forest backscatter remains challenging because the conventional SAR observations represent a mixture of canopy, branch, trunk and ground scattering contributions from multiple trees within a single resolution cell. High-resolution radar tomography provides an opportunity to separate these contributions and investigate forest dynamics at the scale of individual trees.
In this study, we explore the capability of tower-based L-band SAR tomography at all polarization combinations to identify and monitor individual trees in a boreal forest. Measurements were acquired by the BorealScat-2 radar tower located in the Svartberget Experimental Forest in northern Sweden. The tower features a horizontally moving antenna array that enables coherent SAR processing and reconstruction of 3D forest backscatter tomograms. Measurements are acquired every 30 minutes during the growing season. Due to acquisition times of several minutes, tree motion causes temporal decorrelation during windy periods, and focused tomographic reconstructions are therefore only obtained under low-wind conditions.
L-band tomographic observations from two growing seasons are analyzed together with meteorological data and stem water content measurement acquired at three heights of a few trees. The high spatial resolution of the tomograms enables extraction of vertical reflectivity profiles for selected trees and the assessment of their temporal variability across polarization channels.
Results show that observations acquired during calm conditions allow clear identification of individual trees within the tomogram and reveal temporal variations in their vertical reflectivity profiles. Diurnal backscatter variations as well as longer-term responses to changing environmental conditions are observed. Differences in the temporal behavior between trees are further investigated using LiDAR-derived structural information to assess the influence of local canopy structures and line-of-sight conditions.
The results demonstrate the potential of tower-based L-band SAR tomography to resolve and monitor individual trees within a dense boreal forest and provide new insight into the processes governing temporal L-band backscatter variations and their relation to stem water content variations.

14:40–15:00

Parametric 3-D imaging of forests using an improved PolTomoSAR approach and BIOMASS data

Speaker

Laurent Ferro Famil (ISAE-SUPAERO & CESBIO)

Description

SAR tomography (TomoSAR) is a powerful technique for characterizing natural volumes over large areas, as it enables three-dimensional mapping of reflectivity by coherently combining two-dimensional SAR images acquired along slightly shifted trajectories. SAR systems operating at low frequencies can be efficiently used in tomographic mode to characterize the vertical structure of densely forested environments. In practice, quantitative tomographic imaging is often achieved through non-parametric spectral analysis, but the resulting vertical resolution may be insufficient to precisely characterize forest structure. In such cases, parametric TomoSAR, which incorporates prior knowledge of the composition and shape of the vertical reflectivity profile of the imaged medium, provides a means of estimating relevant forest descriptors. Recent studies have shown that low-order models based on simple reflectivity templates can be effectively employed to accurately image forests at P-band.
Polarimetric diversity significantly enhances the capabilities of TomoSAR for three-dimensional characterization of complex scattering mechanisms, as well as for separating ground and volume contributions. This decomposition is usually performed using singular value decomposition (SVD), which expresses the covariance structure as a sum of two Kronecker products. Among the infinite number of possible solutions, a particular solution can then be selected to represent the polarimetric and tomographic responses of the ground and overlying volume. Despite being optimal in the least-squares sense, the SVD-based solution presents several limitations, including the lack of positive semi-definiteness (PSD) of the retrieved components, which may occur for a small number of samples, and a loss of separation performance when the vertical resolution is low. Applying parametric TomoSAR independently to each decomposition term is not fully satisfactory, as it neither improves the polarimetric characterization nor prevents leakage between the two components identified during the decomposition.
This paper proposes an alternative to SVD based on joint diagonalization using special unitary operators, followed by parametric TomoSAR focusing directly in the optimized polarimetric space. The main features of the proposed approach are:
- guaranteed estimation of PSD components, owing to the use of unitary transformations, regardless of the number of available samples;
- preservation of the mutual dependence between spatial and polarimetric estimates during the focusing process, by which different spatial solutions lead to different polarimetric features.
The validity of the proposed technique is demonstrated through selected examples, while its relevance and performance are quantitatively assessed using BIOMASS PolTomoSAR data acquired over tropical forests.

15:00

15:00

Coffee Break

Break

15:20

15:20

Forest - Tomography II

Session

15:20–15:40

Model-free and high-resolution 3D imaging of forests using moment-based SAR tomography

Speaker

Laurent Ferro-Famil (ISAE-SUAPERO & CESBIO, University of Toulouse, France)

Description

Forest SAR tomography is a key tool for monitoring biomass. It involves processing a stack of coherent SAR images to extract various observables related to biomass. One challenge of forest SAR tomography is that the shape of the forest's reflectivity profile is unknown. Typically, a prior is introduced; for example, the reflectivity profile is assumed to be Gaussian or an exponential. However, the choice of this prior affects estimation performance, because an incorrect model introduces estimation biases.

This communication focuses on characterizing both the forest and the ground backscattered responses using a recently introduced estimation method, called MoMET. The method is based on a characterization of the unknown reflectivity profile by its central moments. It is robust to uncertainty in the reflectivity profile, and is numerically efficient, allowing its application to large areas. It allows the estimation of the total backscattered power and the center of phase of the ground response, and the total backscattered power, the center of phase, and the spread of the forest response. The algorithm is applied to real tomography SAR data.

First, the use of central moments, which is the basis of the MoMET algorithm, is justified by a short discussion on the observability of the forest SAR tomography problem. The key idea is that the spread of the scatterers is small with respect to the system ambiguity, typically 5 meters vs. 90 meters. Therefore, the spectrum of the reflectivity density is smooth and can be approximated by the first terms of its Taylor expansion, which involves the moments of the distribution. The MoMET estimation algorithm is then presented, with a discussion on the choice of its hyperparameter, the maximal order estimated.
\medbreak
The algorithm is then applied to: (i) TropiSAR campaign data and (ii) Biomass mission data. To assess the performances, tomograms are computed, and MoMET estimates are compared to the LIDAR data available for the TropiSAR campaign and with the usual $L2$ parametric fits for both data sets. The results suggest that MoMET presents better robustness, better stability, and better numerical complexity than the usual parametric models.

Thanks to its robustness and its low complexity, MoMET algorithm is particularly suited for forest SAR tomography, where it can efficiently process wide areas.

15:40–16:00

Single-Baseline P-band PolInSAR Tomography with the Two-Layer Model: Application to ESA BIOMASS Data

Speaker

Alberto Alonso-Gonzalez (Universitat Politecnica de Catalunya (UPC))

Description

Polarimetric SAR Interferometry (PolInSAR) merges polarimetric SAR, offering the ability to distinguish between different scattering types within individual resolution cells, and interferometric SAR, which provides sensitivity to the vertical distribution of scatterers.

The PolInSAR two-layer model represents the signal as a combination of ground and volume contributions and has proven especially useful for modelling the signal over vegetation. Because these two components have different polarimetric and interferometric characteristics, physical parameters such as the ground phase or forest height can be extracted [1]. More recently, the model has also been used to separate and extract fully polarimetric signatures of the ground and volume as a polarimetric decomposition [2].

When several baselines are available, the vertical reflectivity profile of the vegetation can be estimated, which is equivalent to forming a synthetic aperture in the across-track dimension as in SAR tomography, converting the problem into a spectral estimation. Under the two-layer model, the vertical reflectivity of the ground and volume define their interferometric coherences, linking the polarimetric and interferometric dimensions of the data [3]. In this work we exploit the spatial variability of the volume-layer height across the image to estimate the volume reflectivity profile from a single baseline, assuming the volume profile of spatially close stands equals the same normalized profile scaled in height. The ground and volume components, together with the coherences modelled from the inverted profile, are then combined through the two-layer forward model to synthesize the full multipolarization multibaseline (MPMB) covariance matrix for an arbitrary baseline distribution. Classical tomography applied to this modelled stack then yields per-pixel tomograms.

The technique was first evaluated with airborne F-SAR data from DLR over the AfriSAR campaign at P-band. In this contribution we extend the validation to real spaceborne ESA BIOMASS data. Although a quantitative assessment against external reference profiles remains future work, the retrieved profiles reproduce known structural contrasts within the imaged area: deforestation scars are clearly separated from intact forest, and denser stands appear both taller and more polarimetrically diverse. These results demonstrate the feasibility of single-baseline tomographic reconstruction under the operational constraints of the BIOMASS interferometric phase, supporting the monitoring of forest vertical structure and its temporal evolution.

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16:00–16:20

Multi-Source Fusion for Near-Real-Time Forest Loss Monitoring Using Sentinel-1 and Sentinel-2 Time Series with an Unsupervised Bayesian Method

Speaker

Marta Bottani (CESBIO (Université de Toulouse))

Description

Timely and accurate monitoring of deforestation is critical for managing tropical forests, yet individual Earth observation sensors have inherent limitations. Multispectral imagery provides rich spectral information on vegetation properties but is often hindered by cloud cover and limited canopy penetration. Synthetic Aperture Radar (SAR) complements optical data by being largely insensitive to atmospheric conditions and by providing insights into vegetation structure, but SAR-based monitoring can be affected by moisture variability, reduced contrast when residual vegetation remains after clearing, and the fading of deforestation signatures over time. The complementary nature of multispectral and SAR data has led to growing interest in multi-source fusion approaches. However, most existing methods rely on offline processing or decision-level fusion strategies, which do not fully exploit the temporal and spectral synergies between the two sources. Consequently, no operational forest loss monitoring system currently integrates both modalities within a unified framework.

In this context, the Bayesian Online Change Point Detection (BOCD) algorithm has been generalized to handle asynchronous, irregularly sampled, multi-source time series by incorporating a dynamically weighted fusion scheme. Specifically, a source's relevance depends on how recently it was observed, gradually diminishing as the time since its last observation increases, following a physical decay model. The resulting method, named ms-BOCD, enables sensor-agnostic, interpretable, and Near Real-Time (NRT) detection of deforestation.

The method is applied to Sentinel-1 SAR and Sentinel-2 multispectral time series and evaluated for deforestation detection over sampled areas in the Brazilian Amazon, covering a total of 8,000 hectares. The reference data for validation are provided by MapBiomas Alerta and include clearings of various sizes, i.e., 0.1–1, 1–5, 5–20, and >20 hectares. Additionally, the method is compared against existing approaches, including VH-BOCD (BOCD using only Sentinel-1 cross-polarization), RADD, and GFW (Global Forest Watch), which aggregates alerts from multiple independent operational systems.

Results highlight an overall 26% improvement in detection performance of ms-BOCD compared to VH-BOCD and RADD, along with near-zero false alarms. Gains are particularly pronounced for larger deforested areas (+27% for >20 ha vs. +7% for 0.1–1 ha), which often correspond to parcels with residual vegetation remaining after clearing. This pattern is due to the slash-and-burn deforestation practice typical of the Amazon, where cut trees are left to dry before being burned at the end of the dry season, as removing large quantities of biomass is difficult in densely forested areas. Particularly, residual vegetation poses challenges for C-band SAR data, as it can cause volume scattering saturation, especially in cross-polarization channels, making multispectral data especially useful in these cases. Compared to ms-BOCD, GFW shows a 13% increase in false alarms, likely due to the aggregation of errors from independent alerting systems. Finally, temporal analysis indicates that ms-BOCD achieves faster detection than RADD while maintaining performance comparable to GFW.

Overall, ms-BOCD provides accurate, interpretable, and NRT detection of deforestation, demonstrating the potential of multi-source Bayesian fusion for operational tropical forest monitoring.

16:20

16:20

Round Table

Session

17:00

17:00

Poster Session

Session

18:00

18:00

Ice Break

Break

19:00

Thursday 19 November

09:30

Soil and Hydrology I

Session

09:30–09:50

Ground--Latent Interferometric Model for Soil Moisture Anomaly Retrieval

Speaker

Giovanni Costa (RIDE Lab - Politecnico di Milano)

Description

This work introduces the Ground--Latent Interferometric Model (GLIM), a physics-based representation of the interferometric response to soil moisture variations building upon the formulation in [2]. GLIM represents the observed response as the superposition of two physically distinct scattering mechanisms: a temporally stable Ground contribution, providing a common interferometric phase reference, and a moisture-dependent Latent contribution associated with subsurface dielectric variations. Their separation is achieved through a Temporal Sum of Kronecker Products (T-SKP) decomposition, extending the SKP formulation [1] to the multi-temporal PolInSAR domain. The Ground contribution is used for phase calibration, while the isolated Latent response is inverted to retrieve Soil Moisture Anomalies (SMA) without requiring in-situ calibration or site-specific tuning.

GLIM and its inversion are experimentally assessed using the HydroSoil campaign [3], comprising more than 31,000 C-band acquisitions collected every 10 minutes over complete Barley and Corn phenological cycles. The inversion is assessed throughout the crop cycles, showing that retrieval performance is primarily controlled by the observability of the Latent contribution as vegetation develops. The evolution of the Latent-to-Ground Ratio (LGR) further provides a physical interpretation of the transition from soil- to vegetation-dominated scattering and of the recovery of soil observability during senescence.

09:50–10:10

High-resolution surface soil moisture retrieval: A hybrid machine learning framework integrating change detection and downscaling for precision water management

Speaker

zihao wang (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC))

Description

Soil moisture (SM) is a critical variable in hydrological, ecological, and agricultural domains, playing a pivotal role in irrigation management, drought monitoring, and crop yield prediction. While in-situ measurements provide highly accurate SM data, they are costly and spatially limited. Remote sensing techniques enable large-area monitoring, but current satellite SM products, with spatial resolutions of 1 km or coarser, struggle to capture the rapid SM variations required at the agricultural field scale. Synthetic aperture radar (SAR) offers the spatial detail needed for such applications, but its backscatter is strongly influenced by surface roughness and vegetation, which complicates direct SM retrieval.
To address these challenges, this study proposes a high-resolution surface soil moisture (SSM) retrieval framework that integrates SAR and other data into a change detection-based downscaling (CD-DS) method. The framework integrates Sentinel-1 C-band SAR (VV and VH polarization), Sentinel-2 normalized difference vegetation indices (NDVI), and the 1 km Disaggregation based on Physical And Theoretical scale Change (DISPATCH) SSM product as background information, and is applied over Catalonia, a Mediterranean agricultural region with frequent droughts and a dense network of soil measurement stations. The key SAR variable is the backscatter difference derived from the CD approach: for each 30 m cell, and within discrete NDVI classes, the backscatter of each acquisition is referenced to the minimum backscatter observed under similar vegetation conditions, which represents the driest state. By comparing radar signals acquired over the same cell under approximately constant NDVI, the contributions of surface roughness and vegetation structure are largely removed and the remaining signal is dominated by SM changes. Sentinel-1 and Sentinel-2 data from 2017 to 2024 were used, and in-situ SSM measurements (5 cm depth) from 18 stations of the Soil Measurement Network of the Institut Car tografic i Geologic de Catalunya (ICGC) soil monitoring network served as labels: 13 stations for training (2017–2021) and all 18 stations for independent validation (2022–2024).
Four ML algorithms—Support Vector Regression, Random Forest, XGBoost, and LSTM—were evaluated. XGBoost outperformed the other models, achieving an R^2 of 0.933 and an RMSE of 0.023 cm^3/cm^3 on the test set. Validation across the 18 stations, which cover forest, vineyard, grassland, shrubland, and fruit-tree land cover, gave an average correlation coefficient (R) of 0.63, a ubRMSE of 0.045 cm^3/cm^3, and a bias of 0.024 cm^3/cm^3. A comparison with 54 sampling points from a field campaign carried out in the Urgell irrigated area in 2015 gave an R of 0.82 and an RMSE of 0.06 cm^3/cm^3. Feature importance analysis based on SHAP values showed that the backscatter difference is the second most influential variable after the background SSM, confirming the contribution of the CD variable to the retrieval accuracy. The retrieved SSM time series follow the in-situ observations across the years, and capture the abrupt increases in SM following precipitation and irrigation events. In terms of spatial distribution, the 30 m SSM maps closely match the SIGPAC irrigation type maps, with higher SSM values in irrigated parcels and lower values in rainfed farmland.
The results show that introducing a change detection variable into an ML-based downscaling scheme is an effective way to obtain field-scale SSM from Sentinel-1 SAR data. The proposed framework delivers high-resolution SSM estimates that can support precision irrigation, drought monitoring, and local water resource management.
Keywords: surface soil moisture; Sentinel-1; change detection; downscaling; machine learning; XGBoost; Catalonia

10:10–10:30

Assessing mire breathing patterns across Mecklenburg Vorpommern, Germany using a Sentinel-1 SBAS approach

Speaker
Luc Pienkoß (Deutschland/ Universität Rostock)

Description

Peatland condition is a key indicator of ecosystem integrity and carbon storage potential, making reliable monitoring of degradation processes essential at regional to national scales. Mire breathing—the cyclic surface motion driven by hydrological dynamics—serves as an important proxy for peatland degradation. Drained or degraded peatlands typically exhibit weak oscillatory behaviour combined with persistent subsidence trends, whereas near-natural peatlands show pronounced seasonal surface dynamics. Quantifying peatland subsidence therefore provides a structural indicator for assessing peatland condition and its implications for carbon storage dynamics and greenhouse gas emissions.

In this study, interferometric time-series analysis based on Sentinel-1 Synthetic Aperture Radar (SAR) data was applied to monitor large-scale peatland subsidence using a Small Baseline Subset (SBAS) approach implemented in MintPy. Ascending and descending stacks were processed and decomposed into a vertical-dominant and an east-west component. Additionally, hourly Radolan precipitation data were integrated to relate subsidence dynamics to hydrological forcing, and first in-situ measurements from extensometers were used to capture actual ground motion. The analysis covers peatlands across the federal state of Mecklenburg-Vorpommern (north-eastern Germany) for the period 2016–2025 and demonstrates a scalable monitoring framework applicable to national peatland inventories.

The results reveal pronounced spatiotemporal subsidence patterns across the study region. Across the coherent peatland network the median vertical-dominant displacement rate is -1.6 cm yr^{-1}, bracketed by -1.1 and -2.1 cm yr^{-1} from the two orbit geometries. At three representative sites the rates span almost the full regional distribution, from -3.1 cm yr^{-1} at the most strongly degraded site to $+0.2$ cm yr^{-1} at a near-stable valley-fen site. In addition, distinct site-specific mire breathing signals were identified, with seasonal amplitudes between 4.6 and 10.1 cm at these sites and a regional median of 1.9 cm. The time series show enhanced subsidence during summer months and partial surface recovery during wetter periods, highlighting the strong control of hydrological conditions on peatland surface dynamics.

Overall, the findings demonstrate the capability of SBAS-based InSAR time-series analysis to capture both long-term subsidence trends and short-term oscillatory responses in peatlands. Comparison with in-situ extensometer measurements supports the seasonal scale and timing of the remote-sensing-derived deformation signals, and continuous GNSS stations agree to within 1.1 mm yr^{-1}. This supports large-scale peatland mapping and monitoring efforts and provides a remote-sensing-based component relevant for greenhouse gas accounting and monitoring. Future work will focus on improving methodological robustness and validating the InSAR-derived deformation signals using in-situ subsidence measurements.

This research was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Project-ID 531801029 (TRR 410).

10:30–10:50

Deep Learning-Based Soil Moisture Retrieval from Short Sentinel-1 Time Series

Speaker

Jose Luis Bueso

Description

Soil moisture is the amount of water contained in the unsaturated soil zone and is a key variable controlling plant water uptake, crop yields, groundwater recharge, and land–atmosphere exchanges of heat and carbon. Accurate knowledge of its spatial and temporal distribution is therefore important for applications such as precision agriculture, drought monitoring, and flood forecasting.

Remote sensing enables frequent, non-invasive soil moisture monitoring over large areas. Microwave radiometer missions such as NASA's Soil Moisture Active Passive (SMAP) and ESA's Soil Moisture and Ocean Salinity (SMOS) provide near-daily global observations at kilometer-scale resolution. More recently, Synthetic Aperture Radar (SAR), particularly the Sentinel-1 constellation, has attracted considerable interest because it provides observations at resolutions down to 10 m and offers the potential for higher-resolution soil moisture products.

In this study, we investigate a deep learning (DL) approach for time-tagged soil moisture retrieval by combining, for the first time, backscatter and repeat-pass interferometric information from multi-temporal Sentinel-1 data. Because high-quality reference measurements are scarce, we adopt a two-step training strategy. First, the model is weakly supervised using a large dataset of lower-accuracy soil moisture estimates. It is then fully supervised and fine-tuned using reliable in-situ measurements at 0–5 cm depth.

As initial DL architecture, we rely on a state-of-the-art fully convolutional neural network (CNN), chosen for its proven ability to extract multi-scale spatial features from radar data for regression tasks [1]. The architecture comprises approximately 760,000 trainable hyperparameters, ensuring sufficient model capacity to learn complex nonlinear relationships between radar observables and soil moisture dynamics while maintaining computational efficiency.

The experimental setup is based on distinct Regions of Interest (ROIs) selected to represent diverse environmental and climatic conditions across the study area in central and west Europe. For each ROI, a three-year time span (2018–2020) of Sentinel-1 acquisitions is considered, providing a consistent temporal coverage for soil moisture retrieval and model evaluation. Each ROI comprises approximately 180 time-series samples, capturing seasonal variations and a wide range of soil and vegetation states. This multi-regional, multi-temporal configuration ensures that the model is trained and validated under heterogeneous conditions, thereby enhancing its robustness and generalization capability across different land cover types and climatic regimes. A geographic subdivision of the ROIs is performed for splitting the dataset into independent training, validation, and testing regions.

For the weakly supervised stage, the Copernicus Global Land Operations Surface Soil Moisture (CGLS-SSM) product is used as reference [2]. The DL model receives several Sentinel-1-derived inputs: SAR backscatter intensity, InSAR coherence at different temporal baselines, interferometric phase triplets, and local incidence angle (LIA). Together, these features capture surface scattering properties, acquisition geometry, and structural changes related to soil moisture. The initial target resolution is 1 km, consistent with existing products, while the framework is designed to scale toward 100–200 m resolution.

As first results on the testing dataset, we have obtained peak performance by combining both SAR, InSAR and geometry-related features as input to the network, achieving a Mean Error (ME) of 0.96%, a Mean Absolute Error (MAE) of 7.25%, a Root Mean Squared Error (RMSE) of 9.65% and a coefficient of determination (R2) of 0.87. These preliminary results show in general a promising performance for the pretext, weakly-supervised task. The results indicate that InSAR information from short Sentinel-1 time series provides complementary information that enhances the model's ability to characterize soil moisture dynamics.

Subsequently, for regressing absolute soil moisture values, we fine-tuned the pretrained model using in-situ measurements from the International Soil Moisture Network (ISMN) stations, located in Denmark, the Netherlands, the United Kingdom, and Spain at a depth of 5 cm. The selected ISMN stations are divided into training, validation, and test sets while maintaining a similar distribution across the datasets. Starting from the model weights obtained through the weakly supervised pre-training, the fine-tuning process adapts the proposed DL model to the characteristics of the in-situ observations. Specifically, it learns to map each short Sentinel-1 time series to the corresponding absolute soil moisture measurement, thereby refining the model to capture the finer-scale relationships present in the reference dataset. The best performing model evaluated against 700 ISMN stations measurements achieves a ME of 0.0243 m3/m3, a MAE of 0.0614 m3/m3, and a RMSE of 0.072 m3/m3.

The proposed DL approach demonstrates promising performance in exploiting both SAR and InSAR features from the Sentinel-1 mission to retrieve absolute soil moisture estimates that closely agree with in situ measurements. The scalability of the proposed model will be further exploited to improve retrieval performance and enable the generation of large-scale soil moisture maps across Europe at a spatial resolution of 100–200 m.

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10:50

10:50

Coffee Break

Break

11:10

11:10

Soil and Hydrology II

Session

11:10–11:30

Large-Scale Soil Moisture Retrieval in Complex Terrain: A Physics-Informed Deep Learning Approach

Speaker

Chiara Telli

Description

Monitoring soil moisture in Alpine regions is essential for understanding hydrological dynamics, drought events, and the impacts of climate change in mountain environments. However, reliable monitoring remains challenging due to strong spatial heterogeneity, complex topography, sparse in situ observations, and rapidly changing land-surface conditions. While spaceborne Synthetic Aperture Radar (SAR) offers a valuable opportunity for large-scale soil moisture monitoring, the influence of vegetation, surface roughness, local incidence angle, and land-cover variability makes the direct soil moisture retrieval particularly challenging, especially in complex mountain regions where the SAR signal is also affected by geometric and radiometric distortions. As a result, current SAR-based algorithms for soil moisture estimation often have limited accuracy or are not readily applicable in mountain regions.

In this study, we present HydroSAR, a physics-informed deep-learning framework for large-scale soil moisture retrieval tailored to heterogeneous and topographically complex terrain. The framework integrates three complementary components: spatially aware deep-learning methods to exploit spatial context and dependencies in SAR and ancillary observations; hydrological-model information to provide physically meaningful soil moisture patterns; and semi-empirical SAR backscatter modelling to explicitly represent interactions among the radar signal and soil and vegetation.

HydroSAR consists of two interconnected branches: a hybrid forward-modelling framework for SAR backscatter simulation, and a physics-based inversion framework for soil moisture retrieval from individual SAR acquisitions. In the forward branch, a deep-learning network estimates spatially distributed, physically constrained static model coefficients, while temporally varying soil moisture and vegetation information are provided by the WFLOW hydrological model and an LAI climatology. The semi-empirical backscatter model is embedded within the training framework, and its parameters are calibrated by minimizing the discrepancy between simulated and observed Sentinel-1 VV backscatter time series.

The calibrated coefficient maps are then used in the inverse physics-based retrieval branch, where the semi-empirical model is analytically inverted to estimate soil moisture from individual Sentinel-1 VV acquisitions and the corresponding vegetation information. This two-stage configuration separates the computationally intensive calibration step from the lightweight retrieval step, enabling soil moisture estimation from single SAR acquisitions.

The framework is developed using ascending and descending Sentinel-1 OPERA RTC time series over the Alpine arc (5.6-12.7°lon, 44.0-48.0°lat), covering approximately 147612.70 km2. WFLOW simulations at 6-hour temporal resolution are matched to the SAR acquisition times, while ancillary information on topography, acquisition geometry, land cover, vegetation, soil properties, and Sentinel-1 VH backscatter is incorporated to support parameters estimation. Preliminary results show a RMSE = 1.6 dB and a correlation coefficient r = 0.7 for VV backscatter reconstruction at 100 m spatial resolution. For soil moisture retrieval, RMSE = 0.07 $m^3\ m^{-3}$, ubRMSE = 0.06 $m^3\ m^{-3}$, and r = 0.4 are obtained when evaluated against in situ measurements at 0–2 cm depth from stations located at the Long-Term Socio-Ecological Research site in Val Mazia, South Tyrol.

The HydroSAR framework was developed within the ESA-funded “SMEM: Soil Moisture Ensemble Method” project.

11:30–11:50

Using Quad-Pol ALOS PolSAR for Monitoring Wetland Dynamics

Speaker

Sebastiano Pignato (University Of Stirling)

Description

Continuous water-level monitoring in shallow coastal lagoons and wetlands is essential for ecological protection and water resource management. In extensive wetland systems such as the Danube Delta, ground gauges are sparse and often difficult to install and maintain. While satellite altimetry provides only limited coverage because its measurements are restricted to narrow ground tracks, SAR provides much denser spatial coverage, but retrieving centimetre-scale water-level variations from SAR is challenging in these environments. Small changes in water level produce only small horizontal shifts in the shoreline, which can be difficult to detect at the spatial resolution of freely available SAR data.
We introduce a method for estimating water-level changes by measuring sub-pixel shoreline movements along transects perpendicular to the shoreline. The approach uses multi-temporal ALOS-2 PALSAR-2 L-band quad-polarimetric SAR data and projects intensity profiles onto a fixed shoreline reference frame. The method was evaluated against continuous in-situ pressure loggers in two independent lagoons of the Danube Delta: Lake Sinoie at Histria and Lake Razim at Dolosman, using fixed transects per site.
Across a 34 cm seasonal drawdown, the in-sample retrieval shows strong agreement with observed water levels ($r = -0.88$, $R^2 = 0.78$, RMSE ≈ 5.85 cm). A linear regression between the observed water-level changes and the corresponding SAR-derived sub-pixel shoreline displacements was used to estimate the local shoreline slope, yielding 0.76 m/cm for Dolosman and 1.10 m/cm for Histria. Under leave-one-date-out cross-validation, the method achieves an RMSE of 6.53 cm, compared with 14.11 cm for a mean-level baseline, corresponding to a 53.7% reduction in prediction error.
These results demonstrate that sub-pixel L-band SAR shoreline tracking can provide a practical approach for monitoring centimetre-scale water-level dynamics in wetlands.

11:50–12:10

Did the 2026 summer drought leave a SAR signature? Backscatter and polarimetric response of the Brasschaat ICOS forest compared to 2025

Speaker

Paulina Swiatek (TU Delft)

Description

The summer of 2026 was exceptionally dry and warm across Europe, and its ecological impact is now becoming measurable. At the ICOS ecosystem station in Brasschaat, Belgium (ICOS code Be-Bra), eddy-covariance measurements from the 40 m tower indicate that canopy photosynthesis fell roughly 19% below the long-term average. (https://www.vrt.be/vrtnws/nl/2026/08/24/brasschaatse-bossen-kreunden-deze-zomer-onder-de-droogte-laatst/) It is the lowest carbon uptake recorded since observations began at the site in 1997. What is missing is the link to spaceborne observation: it is not yet established whether this anomaly is detectable from space, nor how representative the tower footprint is of the surrounding forest - tower measurements integrate over only a few hundred metres around the mast. Whether drought impacts of this magnitude leave a detectable signature in spaceborne observations, and how far across the landscape they extend, remains untested for this site.

Drought alters canopy water content, dielectric properties and structure through stomatal closure, foliage loss and reduced water storage. SAR is sensitive to all these quantities, especially in C- and L-band. As droughts cause water deficits in trees and eventually lead to early foliage loss, the S-1 radiometric signal and polarimetric signatures are tested regarding their sensitivities to these effects.

This contribution presents an initial assessment of how spaceborne SAR observations captured the 2026 drought anomaly at Brasschaat using summer 2025 as a contrasting reference period under more typical meteorological conditions. Ground-based GNSS sensors at this site, installed as part of the TU Delft GNSS-T network provides continuous information on vegetation water dynamics. Combined with ICOS data, these provide continuous, non-destructive proxies for vegetation and soil water dynamics at temporal resolutions far exceeding the satellite revisit, and offer an independent reference against which SAR observables can be interpreted. We explore how these datasets can be combined with SAR signatures to attribute observed radar anomalies to plant water status.

Here we present preliminary results based on Sentinel-1 imagery. Ongoing analysis may incorporate additional SAR observables, sensors or in-situ variables pending availability. We will discuss the interpretability and limitations of the observed signals and what they imply for the design of future missions including Sentinel-1 Next Generation, ROSE-L and potential sub-daily SAR concepts.

12:10–12:30

High Resolution mapping of Soil Moisture and Vegetation Biomass in the framework of ESA SMEM project

Speaker

Giuliano Ramat (IFAC CNR)

Description

The **Soil Moisture Ensemble Method (SMEM)** is a project funded by the European Space Agency (ESA) aimed at enhancing both the accuracy and spatial detail of soil moisture (SM) and vegetation water content (VWC) retrievals derived from multi-frequency Synthetic Aperture Radar (SAR) observations. The initiative addresses some of the major limitations affecting current retrieval approaches, particularly in areas characterized by complex topography, dense vegetation cover, or arid environmental conditions.
The SMEM framework relies on an ensemble methodology that integrates information from multiple SAR frequencies and sensors together with optical multispectral observations. This integration is achieved through advanced Artificial Intelligence (AI) techniques coupled with physically based models, enabling a more robust exploitation of the complementary information provided by different remote sensing systems.
A major component of the research focuses on the development of machine learning methods for estimating soil moisture (m^3/m^3) and vegetation biomass, expressed as Plant Water Content (PWC, kg/m^2), in agricultural environments. The approach exploits the combined use of microwave observations collected by both satellite radiometers and SAR systems. The dataset includes radiometric measurements from NASA's SMAP mission and JAXA's AMSR2/3 sensors, together with L-, C-, and X-band SAR acquisitions provided by ALOS-2, SAOCOM, Sentinel-1, and COSMO-SkyMed.
Multi-temporal observations have been gathered over agricultural sites located in Tuscany, Central Italy, where the dominant land covers include wheat, maize, sorghum, sunflower, vineyards, and pasturelands. Additional information has been obtained from Sentinel-2 multispectral imagery. To support satellite data analysis and validation, dedicated field campaigns have been conducted during satellite overpasses, collecting key soil and vegetation parameters such as soil moisture, surface roughness, crop structural characteristics, and fresh and dry biomass.
The initial phase of the study investigated the sensitivity of microwave signals to soil and vegetation properties across different frequencies. These analyses were aimed at quantifying the relative contributions of soil and vegetation to the overall radar backscatter response. Building upon these results, crop and vegetation classes were identified through Deep Learning techniques applied to COSMO-SkyMed and Sentinel-2 data [1].
Subsequently, high-resolution soil moisture maps were generated through the disaggregation of low-resolution soil moisture products obtained from radiometric observations using the HydroAlgo algorithm [2]. Artificial Neural Networks (ANNs), following the methodology proposed in [3], were employed by combining high-resolution Sentinel-1 C-band data with L-band observations from ALOS-2 and SAOCOM. The inclusion of L-band measurements was intended to exploit their higher sensitivity to soil moisture variations.
Finally, high-resolution PWC estimation was achieved through the integration of COSMO-SkyMed X-band SAR data, crop classification outputs, and the derived high-resolution soil moisture products.
The outcomes obtained to date demonstrate the potential of the proposed methodology. Future activities will extend the analysis in both space and time, with the objective of assessing the robustness and transferability of the approach and performing a more comprehensive validation of the generated products
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12:30

12:30

Lunch Break

Break

14:00

14:00

General Land Applications I

Session

14:00–14:20 **BIOMASS overview**

Speaker
Bjorn Rommen

Description

Overview

14:20–14:40 **BIOMASS P-band coherence investigation**

Speaker
Urs Wegmüller (Gamma Remote Sensing AG)

Description

The coherence is a parameter that characterizes the noise of the interferometric phase, as well as the SNR improvement achieved with multi-image filtering or averaging of backscatter images. Our main interest relates to the fact that the coherence depends on specific characteristics of the imaged scatterers, so that it can support applications as land-use classification and bio- and geo-physical parameter retrieval.

During the tomographic phase the BIOMASS P-band SAR acquires tomographic stacks of seven images. All acquisitions are using quad polarization. The intervals between the subsequent acquisitions are 3 days, the perpendicular baselines around 700m. A tomographic set provides multi-temporal backscatter, as well as interferometric coherence values for 3, 6, 9, 12, 15, and 18 day intervals, all at hh, hv, vh, and vv polarization. Polarimetry (e.g. polarimetric decompositions) is therefore also supported and can be done independently for the seven acquisitions, supporting on one hand the investigation of temporal change and on the other hand the calculation of temporal averages and other statistical parameters.

We selected data sets over different biomes and investigated the dependences of the coherence on relevant factors. Pairs with different time intervals, baselines, polarizations and backscatter levels were used to characterize temporal decorrelation, volume decorrelation effects, polarization characteristics, and noise effects. Polarimetric decompositions, cross-channel coherence calculations, and noise equivalent sigma zero (NESZ) estimates were used to support the interpretation.

Over most surfaces several factors are relevant for the resulting coherence. The signal noise is very relevant for all areas with a low backscatter. For relatively smooth surfaces, e.g. water surfaces, agricultural fields, and flood plains, the backscatter is often at or even below the NESZ level, resulting in very low coherence values almost independently of the actual presence of temporal change, especially at cross-polarization. A useful test is to calculate the hv to vh polarization coherence for an individual date. Apart from the noise decorrelation a coherence of 1.0 is expected in this case for almost all scatter types. So, the observed coherence directly indicates the level of the signal noise related decorrelation. For a signal to noise ratio of 1 (same level of signal and noise, total scattering observed is twice the NESZ) the noise coherence factor becomes 0.5.

At co-polarization the backscatter over low vegetation (e.g. grassland) and agricultural fields the backscatter level is often sufficiently higher than the NESZ. Consequently, temporal change can be identified through lower coherence levels. Multi-temporal coherence composites can be used to show change occurring in different intervals in different colors.

Over forest the backscatter at co- and cross-polarization is much larger than the NESZ, noise decorrelation becomes irrelevant. Using the tomographic stacks, it is difficult to separate gradual temporal decorrelation and volume decorrelation effects because of the linear dependence of the available time intervals and perpendicular baselines. The coherence slightly decreases with increasing baseline and time interval. Observing very similar coherence levels for different 3-day intervals, we rather think that the volume effect is the more relevant cause for the decorrelation. This is observed at co- and cross-polarization. At cross-polarization dihedral effects are not the dominant scattering mechanism, so scattering from stronger branches is thought to explain the relatively high cross-polarization coherence values over forest. Based on these early results we expect that the baseline dependence of the P-band coherence over forest, determined for BIOMASS tomographic stacks, is of interest for the retrieval of forest parameters as the above ground biomass.

14:40–15:00

Looking Through the Forest: Interferometric SAR Notching at P-Band for Below-Canopy Mapping with BIOMASS

Speaker

Youssra EL BENNIOUI (ISAE-SUPAERO)

Description

Mapping features lying beneath a forest cover using SAR measurements represents a major challenge, due to the response of the overlying vegetation volume, wave attenuation caused by propagation through the forest canopy, and high-intensity scattering mechanisms occurring at the ground level, which mask ground contributions and prevent direct interpretation of conventional SAR imagery. Interferometric notching, a processing technique that exploits the spatial diversity of multi-baseline SAR acquisitions, represents an appealing solution to address these limitations, as it enables the selective suppression of specific scattering contributions by an appropriate choice of the interferometric baseline. Canopy notching suppresses the vegetation volume response, isolating the residual ground-level scattering mechanisms that would otherwise remain hidden beneath the forest cover. The resulting filtered image provides a representation of the ground reflectivity, whose polarimetric and radiometric features can then be analyzed to characterize the underlying scene.

This work investigates the application of canopy notching to the mapping of sub-canopy features in dense tropical environments, using P-band SAR data acquired by the ESA BIOMASS mission. The suppression of canopy contributions enables the identification of ground-level scattering mechanisms associated with natural and anthropogenic features, including surface water bodies, ancient settlement structures, and other landscape elements that would otherwise remain undetectable beneath the forest cover. Further characterization of the revealed ground-level features is then carried out through a polarimetric analysis, exploiting the full polarimetric diversity of the acquisitions. Classical decomposition techniques, such as the Van Zyl decomposition, along with polarimetric parameters including entropy and indicators of single and double-bounce scattering, allow discrimination between different types of ground cover.

The proposed approach is applied to fully polarimetric P-band Biomass data acquired over three tropical study sites: Manaus (Brazil), used as an urban/forest interface reference site; Amacayacu (Colombia), a partially flooded environment where ground scattering retrieval is investigated; and São Paulo (Brazil), a mixed environment featuring complex topography. Results show the ability of interferometric canopy notching to reveal sub-canopy features of both natural and anthropogenic origin, highlighting the potential of the ESA Biomass mission for below-canopy mapping in dense tropical environments.

15:00–15:20

Diverging post-fire SAR-derived trends of ground deformation and backscatter across permafrost gradients

Speaker

Barbara Widhalm (b.geos)

Description

Arctic wildfires can trigger long-lasting changes in permafrost landscapes, but the magnitude and persistence of these responses depend strongly on local environmental conditions. Here, we investigate post-fire landscape dynamics across North American Arctic tundra using a space-for-time approach, comparing fire scars of different ages along a gradient of permafrost conditions and ground temperatures derived from the ESA CCI Permafrost dataset. We used L- and C-band SAR data to investigate InSAR-derived annual and thaw-season deformation rates. In addition, C-band backscatter was analysed to characterize post-fire changes in surface conditions over time. Deformation and backscatter responses were evaluated relative to adjacent undisturbed areas, reducing the influence of year-to-year fluctuations.
We observed enhanced thaw-season subsidence following fire, with the response varying across regions. While annual deformation generally approached those of the surrounding undisturbed areas within approximately 10 years, the thaw-season deformation signal remained elevated for approximately 50 years on average, with recovery taking slightly longer in colder environments. The direction of deformation trends was generally consistent across regions, with initially increased subsidence, radar backscatter showed a much stronger regional dependence, with contrasting trend directions across ground-temperature conditions. Warmer permafrost environments generally showed enhanced summer backscatter after fire events, by about 1 dB, whereas colder regions predominantly exhibited initial reductions of approximately 0.5 dB or less. These contrasting responses likely reflect differences in the relative contributions of soil moisture, vegetation recovery, and changes in surface structure and roughness.
Comparing regions across a range of permafrost conditions revealed distinct regional differences in fire-scar characteristics, highlighting the need to consider multiple environmental factors when assessing post-fire recovery.

15:20

15:20

Coffee Break

Break

15:40

15:40

General Land Applications II

Session

15:40–16:00

Digital Terrain Model Retrieval from BIOMASS P-Band Tomographic Data: Processing and Validation

Speaker

NAOMI PETRUSHEVSKY

Description

The launch of the European Space Agency’s BIOMASS mission, the first spaceborne P- band SAR mission, opens new opportunities for characterizing forest ecosystems from a low-frequency radar perspective. The long wavelength of P-band signals enables significant penetration through the forest canopy, providing information on the vertical distribution of above-ground biomass and on the underlying terrain. In particular, the retrieval of the ground scattering contribution enables the generation of Digital Terrain Models (DTMs), a product traditionally derived from airborne LiDAR measurements, which provide high accuracy but are limited in spatial and temporal coverage.

This work presents a complete processing chain for the generation of forest DTMs from BIOMASS tomographic data. The proposed approach addresses the main challenges associated with exploiting interferometric phase information in forested environments. These include the calibration of the interferometric phase to mitigate ionospheric disturbances, the estimation and removal of unknown phase offsets between acquisitions due to residual atmospheric effects, and the identification of an equivalent phase center for vertically distributed scattering that preserves the geometric consistency required for phase triangulation. A dedicated separation of ground and volume scattering contributions is then performed to isolate the phase associated with the terrain surface and retrieve the underlying topography. Finally, a quality index is computed to quantify the ability of the algorithm to explain the observed phase in terms of the underlying model.

The resulting DTM is validated against airborne laser scanning (ALS) measurements provided through the GEO-TREES initiative, which offers high-resolution DTMs and biomass reference data. The comparison demonstrates good agreement between the BIOMASS- derived terrain elevations and the ALS ground reference, highlighting the potential of P- band tomographic observations for terrain retrieval beneath forest canopies. These results demonstrate the feasibility of deriving accurate DTMs from BIOMASS data and represent an important step toward exploiting the mission’s unique capability for simultaneous characterization of forest structure and underlying terrain at continental and global scales.

16:00–16:20

Quad-Polarimetric SAR Reconstruction from Reduced-Polarimetric Observations under L- & P band dataset

Speaker

Jiachen Li (Universitat Politecnica de Catalunya)

Description

Quad-polarimetric (QP) SAR reconstruction from reduced-polarimetric observations can extend the usability of compact- and dual-polarimetric (CP/DP) data while preserving key polarimetric information for scattering analysis and downstream applications. This presentation evaluate QP reconstruction through AI in different aspects, including input modes, output parameterizations, and loss functions, rather than focusing on a specific network architecture. Reconstruction performance is assessed in terms of accuracy, positive definiteness, numerical stability, and the preservation of polarimetric characteristics, including entropy H, anisotropy A, and the alpha angle. The analysis is conducted on three datasets acquired by RADARSAT-2, and BIOMASS with L and P bands, respectively. In addition, a comprehensive evaluation framework is established to assess reconstruction performance from covariance-level, channel-wise, and polarimetric-feature perspectives.

16:20–16:40

Estimation of the Polarimetric Orientation Angle in Dense Tropical Forest using BIOMASS Data

Speaker

Titouan Tyack (CESBIO)

Description

Azimuth terrain slopes induce a rotation of the polarimetric SAR (PolSAR) response of environements, which may significantly affect the retrieval of bio- and geo-physical properties through polarimetric approaches that do not compensate for this effect. Besides its obvious use for polarimetric data compensation, the Polarization Orientation Angle (POA) may be employed to characterize the topography of bare soils, as shown in [Schuler 1996].

Several studies [Lee 2003] have reported that the POA can be measured accurately over bare soil, whereas its estimation is, in general, markedly affected by the presence of volume scattering. Strong volume contributions, whose polarimetric structure remains invariant under rotation around the radar line of sight, mask out the orientation-sensitive part of the signal and make the overall POA estimation process less reliable.

In this context, the BIOMASS mission represents an opportunity to acquire information on the topography of terrain lying beneath forest cover. P-band SAR signals penetrate deeply into dense forests and generate strong returns from the ground. Reliable POA estimates could be used as prior information for DTM retrieval in dense forests, and could help mitigate artefacts related to complex phase screen compensation.

This study explores the potential of the BIOMASS mission for POA estimation through the following three steps:
- Evaluating the quality of POA maps computed from BIOMASS data for various land cover classes and terrain slope conditions. This analysis is carried out by comparing estimates obtained using the circular polarization algorithm [Lee 2003] with reference data derived from airborne laser scanning.
- Establishing a theoretical framework to forecast POA estimation reliability from the acquired PolSAR data. This step builds on elements of estimation theory, as well as on the identification and analysis of polarimetric scattering mechanisms.
- Evaluating mitigation strategies based on single and multi-baseline InSAR volume cancellation techniques.

This study is conducted using BIOMASS acquisitions over several test sites, in South America and Africa, together with reference lidar data.

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16:40–17:00

Mapping inundation dynamics in forested wetlands by PALSAR-2 ScanSAR

Speaker

Jessica Rosenqvist (solo Earth Observation)

Description

Wetlands are multi-function ecosystems which store surface water and regulate water flows, they drive evatransporation and precipitation, and purify and replenish groundwater aquifers. Wetlands moreover constitute biodiversity hotspots for terrestrial, avian and aquatic life, and consequently for the livelihood of people. – Where there are wetlands, there is life.

Wetlands are characterised by their inundation dynamics, where inundation maximum and minimum extent and duration are key parameters that define their composition. Information on forested wetlands, where inundation occurs partly or fully under a closed forest canopy is however scarce and recognised as an information gap by the Ramsar Wetlands Convention. In the Amazon Basin, forest wetlands constitute around 15% of the basin.

JAXA's L-band SAR missions (JERS-1, ALOS, ALOS-2) have a long track record of mapping and monitoring wetland inundation on a large scale, with the long L-band wavelength being particularly effective due to its ability to operate under cloud cover and penetrate vegetation canopies. Under JAXA's systematic observation strategy, PALSAR-2 ScanSAR data have been acquired over the pan-tropical belt on a regular (6-week) basis from launch in 2014 until present.

In a collaboration between JAXA, soloEO, Aberystwyth University and Wetlands International, we have used the complete archive of PALSAR-2 ScanSAR data over the northern part of South America, including the Amazon and Orinoco basins, and Central Africa, to create time-series maps of inundation extent on a 6-week basis from late 2014 to present (September 2026) at 50 m pixel spacing.

The ALOS-2 data used have been processed by JAXA to radiometrically terrain corrected (RTC) datasets according to CEOS Analysis Ready Data Normalised Radar Backscatter (CEOS-ARD NRB) format standards. The workflow was implemented on the CEOS Analytics Lab cloud server and includes the following steps:

- Reprojection and speckle filtering
- Residual antenna pattern calibration
- Corrections for incidence angle dependency and scene bias
- Decision tree image classification
- Mosaicking
- Gap-filling and temporal filtering
- Generation of inundation duration maps
- Uncertainty assessment

For each of northern South America and Central Africa, 9 inundation extent maps have been generated for every year, resulting in some 200 maps for the period 2015-2025 for the two regions. Each map consists of two bands – band 1 is the wetland map (6 classes: inundated vegetation, seasonally submerged vegetation, open water, mud banks, other land cover, and masked areas). Band 2 is a metadata layer which shows the classification provenance, such as whether a pixel was derived from one or two SAR observations, through gap-filling or temporal filtering.

Additionally, annual maps of inundation duration, which indicate how many times a pixel has been classified as Inundated Vegetation in the time-series for each year were generated. With nine wall-to-wall PALSAR-2 coverages per year, pixel values range between 0-9, where DN=0 thus indicates classified as non-flooded and DN=9 indicates classified as flooded during all acquisitions during the year in question. 11 inundation duration maps were generated for each of northern South America and Central Africa.

The data are being made available under a CC BY 4.0 license from JAXA EORC and on Zenodo.

17:00

17:00

Round Table

Session

17:40

Friday 20 November

09:00

Agriculture

Session

09:00–09:20

ASSESSMENT OF FULLY POLARIMETRIC BIOMASS DATA FOR SOIL MOISTURE RETRIEVAL

Speaker

Irena Hajnsek (German Aerospace Center / ETH Zurich)

Description

Water management for irrigation is an essential activity especially in agricultural areas or where water is scarce. Water storage in the soil affects the vapour transpiration but also its heat storage capacity, its thermal conductivity and the energy separation between latent and sensible heat fluxes. From a hydrological perspective, soil moisture links the partitioning of rainfall into runoff and infiltration and therefore it has an important role in several ecological applications as flood forecasting, crop yield expectation, meteorological prediction, erosion and slope failure forecasting, water reservoir management, etc.
Most of the soil moisture models describe only the bare soil response. In a real scenario, the presence of bare soil is not common as most of the time some kind of vegetation may be found on top. In order to reduce the amount of vegetation responses in addition to the soil moisture estimation longer wavelength can be used. In this study we like to explore the polarimetric and interferometric response of the BIOMASS mission, which operates in P band wavelength.
Polarimetry can be used to define the scattering mechanisms and is able, when using decomposition methods to separate the ground and vegetation contribution. To perform this separation a physical model is employed and fully polarimetric data is needed in order to invert for the different involved parameters. It is worth mentioning that for extracting the ground response and the corresponding soil moisture, a significant degree of penetration into vegetation is required. For this reason, SAR soil moisture inversion has traditionally been investigated with L-band. In this study we use quad polarimetry in P band to investigate the sensitivity to bare soil and vegetated soil for soil moisture estimation [R1].
Differential SAR interferometry, a popular technique for measuring displacements of the Earth's surface, is potentially influenced by changes in soil moisture. Different mechanisms for this impact have been proposed, but its magnitude, sign and even presence remain poorly understood. In this study the dependence of the phase, the coherence magnitude as well as the phase triplets at different polarisation on soil moisture is investigated. In addition, the impact of vegetation is analysed [R2].
The main test site is located in Argentina, where massive ground measurements exists and a comparison with the SAOCOM derived soil moisture can be performed.
[R1] Hajnsek, I., Pottier, E., & Cloude, S. R. (2003). Inversion of surface parameters from polarimetric SAR. IEEE Transactions on Geoscience and Remote Sensing, 41(4), 727-744.
[R2] Zwieback, S., Hensley, S., & Hajnsek, I. (2015). Assessment of soil moisture effects on L-band radar interferometry. Remote Sensing of Environment, 164, 77-89.

09:20–09:40

Retrieval of Vegetation Water Content from C- and L-band SAR data: Methodology and Initial Assessment

Speaker

Sofia Rossi (Consiglio Nazionale delle Ricerche (CNR) – Istituto per il Rilevamento Elettromagnetico dell'Ambiente (IREA), Bari, Italy)

Description

Monitoring crop conditions is essential for forecasting agricultural production and supporting food security. Two key variables for this purpose are Surface Soil Moisture (SSM) and Vegetation Water Content (VWC). VWC quantifies the amount of water stored in the above-ground biomass per unit area and is commonly measured through destructive field sampling. While accurate, this approach is labor-intensive and unsuitable for operational monitoring over large agricultural regions.
Earth Observation (EO) technologies offer an effective alternative for systematic, large-scale VWC monitoring. Optical remote sensing has been extensively used for this purpose but is often hindered by cloud cover and atmospheric effects. Microwave observations, in contrast, provide all-weather and day-and-night monitoring capabilities. VWC can be inferred from microwave measurements through the retrieval of Vegetation Optical Depth (VOD), a variable that describes microwave attenuation within the vegetation canopy. However, VOD products derived from radiometers and scatterometers are currently available only at coarse spatial resolutions (typically 10-50 km), limiting their applicability at the field scale. Synthetic Aperture Radar (SAR) observations are therefore a key resource for downscaling VOD- and VWC-related information to agricultural plot resolutions [1].
Despite this potential, the retrieval of VWC from SAR data remains challenging because of the complex interactions between soil, vegetation, and surface roughness contributions to the radar backscatter signal. The increasing availability of C-band observations from Sentinel-1 and L-band observations from missions such as NISAR, SAOCOM, and ALOS-4, together with the future ROSE-L mission, creates unprecedented opportunities for synergistic multi-frequency retrieval approaches.
Within this context, the ESA SARWATER project aims to retrieve SSM and VWC at approximately 250 m spatial resolution across a wide range of crop and soil conditions through the combined use of C- and L-band SAR observations [2]. The proposed framework relies on two pillars: first, the distinct temporal dynamics of soil moisture, VWC, and surface roughness, which allow their individual contributions to SAR measurements to be decoupled; and second, the complementary sensitivities of C- and L-band responses to soil and vegetation properties, which guide the overall retrieval strategy. The methodology was initially developed and tested using airborne C- and L-band SAR data acquired during the AGRISAR 2006 campaign over the Görmin test site in northern Germany, together with concurrent in situ measurements [3].
This work also presents the retrieval methodology and its initial assessment over two contrasting agricultural regions: the Tavoliere plain in southern Italy and the Rur Catchment in Germany. The analysis is based on multi-year Sentinel-1, ALOS, and SAOCOM observations combined with extensive in situ VWC measurements collected during dedicated field campaigns, including ESA SARSENSE [4] and SARSimNG-HT [5], as well as SSM observations from long-term hydrological monitoring networks. The retrieved VWC estimates are further evaluated through comparison with independent optical-based [6] and model-derived [7] VWC products.
References:
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Acknowledgment: This research was supported by the project SAR retrieval of soil and vegetation WATER content (SARWATER), funded by the European Space Agency (ESA) under Contract No. 4000148119/25/I-EB-bgh. (Website: https://sarwater.irea.cnr.it/)

09:40–10:00

Towards physically informed Sentinel-1 above-ground biomass retrievals over Alpine permanent meadows

Speaker

Giulia Graldi (Eurac Research)

Description

Reliable estimates of above-ground biomass in mountain grasslands are crucial for assessing production losses and supporting index-based insurance schemes, particularly as climate change causes more frequent drought events increasingly threatening alpine agriculture. However, biomass retrieval from SAR imagery remains challenging in mountainous regions because complex terrain introduces severe geometric distortions and radiometric variability into radar observations. These effects complicate the interpretation of radar signals and can reduce the reliability of retrieval methods.
Over permanent meadows of South Tyrol, in Italy, we previously investigated machine learning (Göhner, 2024) and deep learning (Singh et al., 2025) model architectures combining Sentinel-1 observations and ancillary variables to fill gaps in Sentinel-2 Leaf Area Index (LAI) time series, using LAI as a proxy for permanent meadow biomass (Castelli et al., 2023). However, their predictions were predominantly driven by meteorological and temporal features rather than by the EO signal itself. This limited the models' capacity to exploit the information conveyed by Sentinel-1 backscatter and motivated a shift towards the direct estimation of above-ground biomass. Achieving this objective first requires a better understanding of how radar backscatter responds to grassland biophysical properties and how this response is influenced by terrain, vegetation development, and agricultural practices such as mowing events.
Accordingly, this study moves towards a physically informed analysis of Sentinel-1 observations, starting from a sensitivity analysis of amplitude-based SAR features to in situ measurements of vegetation water content, above-ground biomass, sward height, and LAI, as well as to agricultural practices, using observations collected over two years across eight permanent meadows in South Tyrol (Castelli et al., 2026). Particular attention is given to the role of acquisition geometry, as the interaction between the radar signal and the complex alpine terrain produces substantial spatial variability in the local viewing geometry. We therefore analyse the Projected Local Incidence Angle to determine whether this topographic variability can provide a proxy for multi-angular observations and support the identification of dominant scattering mechanisms and their seasonal evolution. This sensitivity analysis provides the physical boundary conditions for a subsequent biomass retrieval using inversion frameworks such as the Water Cloud Model, thereby supporting more robust and interpretable above-ground biomass estimation in managed alpine grasslands.
Preliminary results confirmed the feasibility of exploiting the topographic complexity of South Tyrol to construct a multi-angular time series from Sentinel-1 SAR observations over permanent grasslands. Specifically, more than 85% of permanent meadow pixels in the study area exhibited a PLIA variation range exceeding 8°, meeting the threshold established in the literature from Hahn et al. (2017) for reliable angular characterization. Furthermore, the temporal window required to compose this multi-angular time series ranged between 5 and 11 days during 2023–2024 (operating with Sentinel-1A only), when in situ data are available. Further analyses will evaluate the feasibility of leveraging this temporal density for dynamic time-series smoothing, aiming to isolate seasonal phenological trends from rapid environmental noise without compromising the detection of abrupt biomass changes caused by mowing events.

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10:00–10:20

HydroDrone: a UAV-InSAR Campaign for Short-Term Temporal Decorrelation - Processing and Preliminary Results

Speaker

Pietro Grassi (Politecnico di Milano)

Description

HydroDrone is an ESA-funded UAV-based C-band SAR campaign designed to investigate short-term temporal decorrelation over vegetated scenes across timescales ranging from tens of seconds to minutes and several hours. Characterizing the temporal evolution of vegetation coherence at these timescales is important for understanding the dynamics of vegetated scatterers and their impact on interferometric observations. This is particularly relevant for SAR systems characterized by long coherent integration times, for which scene changes occurring during image formation may result in significant coherence loss. Future geosynchronous SAR concepts represent a notable example, as their coherent integration times may be comparable to the short-term temporal decorrelation timescales investigated here, making the characterization of these dynamics critical for reliable image formation.
Previous experimental campaigns have investigated radar backscatter variability and temporal decorrelation over vegetation using ground-based SAR, airborne SAR, and tower-mounted radar systems. However, these experiments have generally been characterized either by limited spatial coverage and imaging capability or by revisit intervals on the order of several minutes, leaving the intermediate temporal regime between tens of seconds and a few minutes poorly characterized through high-resolution SAR observations. HydroDrone was conceived to address this gap by exploiting the flexibility of a UAV platform together with a repeated circular external-looking acquisition geometry. This configuration enables a wide surrounding area to be repeatedly observed while maintaining a very short revisit interval. In the configuration considered here, approximately 1 km^2 is imaged with a circular pass duration of about 20 s. Consecutive passes are designed to reproduce the same viewing geometry, thereby minimizing spatial decorrelation and facilitating the isolation of temporal effects.
The circular external-looking geometry requires a dedicated SAR processing formulation. In contrast to conventional linear trajectories, the tangential wavenumber support depends on both the target position and the radius of the circular trajectory. Using the full antenna beamwidth, the reference tangential resolution can be expressed as:
$ρ_{t}=λ/[4 \ \sin(α_{ant}/2)] r_p/r_s $
where r_p is the target radial distance from the trajectory center and r_s is the trajectory radius. SAR images are focused using time-domain back-projection while adapting the processed wavenumber support to enforce a spatially uniform tangential resolution across the scene.
For interferometric applications, residual UAV trajectory inaccuracies represent an additional critical issue, since navigation uncertainties introduce phase errors that may severely degrade the interferometric products. HydroDrone therefore employs a multi-aperture InSAR trajectory refinement strategy based on short overlapping sub-apertures. For each sub-aperture, the residual interferometric phase is modeled in the local tangential-radial-vertical coordinate system as
$\phi_{err}=K_t \ dS_t+K_r \ dS_r+K_z \ dS_z $.
The residual three-dimensional displacement of the phase center is estimated through an iterative coarse-to-fine search. The corrections retrieved over the individual sub-apertures are subsequently interpolated along the complete trajectory, and the SAR data are refocused using the refined platform trajectory.
The HydroDrone project encompasses eight campaign days distributed throughout the year to capture seasonal variations in vegetation and soil conditions, with two campaigns performed in each season approximately 45~days apart. Each campaign day consists of three UAV-SAR flights carried out in the morning, around mid-day, and in the afternoon. Each flight ideally comprises 30 consecutive circular passes over the same scene, providing dense interferometric sampling from approximately 20 s to about 10 min within a single flight and extending to several hours when acquisitions from different flights are combined. The SAR measurements are complemented by meteorological observations, soil-moisture measurements, ground-level photographs, and high-resolution UAV optical surveys to support the interpretation of the observed temporal decorrelation.
Preliminary results from the first processed campaign day demonstrate the effectiveness of the proposed trajectory refinement, with a clear improvement in interferometric coherence and near-zero residual phase over stable targets after calibration. Coherence matrices computed over different vegetated areas reveal markedly different temporal behaviors. Forest exhibits consistently low coherence over the investigated temporal scales, while the cornfield shows a rapid coherence decay, particularly under mature crop conditions. In contrast, medium-height vegetation and meadows generally exhibit higher temporal stability, although their behavior changes with seasonal vegetation conditions. These results highlight the sensitivity of short-term interferometric coherence to both vegetation type and seasonal state. Thermal-noise and spatial-decorrelation contributions are also assessed and found to be small compared with the measured coherence loss, indicating that the observed behavior is predominantly associated with temporal decorrelation. These results demonstrate the capability of the HydroDrone acquisition concept to densely characterize vegetation coherence evolution from tens of seconds to several hours.

10:20

10:20 **Coffee Break**
Break
10:40

10:40 **Ice and Snow I**
Session

10:40–11:00

Addressing Radar Penetration and Calibration Challenges for Accurate Glacier Elevation Change Monitoring with Current and Future InSAR Missions

Speaker
Alexandre Becker Campos (German Aerospace Center (DLR))

Description

Accurate and spatially comprehensive monitoring of changes in glacier elevation is crucial for understanding glaciological processes, such as snow depth and geodetic mass balance, as well as snow and ice dynamics. In-situ measurements, while precise, are spatially limited and logistically challenging. Alternatively, LiDAR sensors can provide highly accurate measurements but are constrained by limited spatial and temporal coverage due to sparse sampling and low revisit frequencies. In this context, interferometric synthetic aperture radar (InSAR) systems offer a valuable alternative for assessing those changes by providing high-resolution data over extended areas, independent of weather conditions or illumination. In this work, we address key associated challenges for deriving accurate elevation changes from InSAR Digital Surface Models (DSMs), specifically focusing on mitigating errors introduced by radar wave penetration into the snowpack and ensuring precise DSM calibration. Current approaches rely on simplified assumptions regarding the compensation for the penetration depth, often averaging DSMs acquired under varying conditions, which introduces substantial uncertainty, particularly in complex alpine environments. Similarly, accurate DSMs require a precise calibration due to the presence of residual offsets and tilts caused by a limited knowledge of the baseline, which is expensive and impractical for large-area monitoring. This contribution outlines a novel, end-to-end framework for robust glacier elevation change estimation from InSAR data. The core strategy is to compare precisely corrected DSMs to quantify seasonal and interseasonal elevation changes. A critical innovation lies in the correction through a three-stage methodology designed to tackle the limitations of existing techniques. First, we use an automated and reference-free approach for residual calibration of InSAR-derived DSMs by relying on natural calibration tie-points. This method eliminates the dependency on costly and potentially unavailable GPS or LiDAR ground truth data, while also compensating for residual offsets and tilts. Second, we implement a data-driven, deep learning-based approach to accurately estimate and correct for the radar penetration bias in snow-covered areas. Finally, after compensating the DSMs for both the calibration offset and tilts and the radar penetration bias, these corrected DSMs are used to perform DSM differencing to retrieve elevation changes. Preliminary results from the bistatic X-band TanDEM-X system indicate that the proposed framework enables accurate estimation of glacier elevation changes at decimeter-level accuracy. Additionally, we assess the potential for transferring the proposed approach to C-band using historical SRTM and available TanDEM-X data. This activity is currently under development within the ESA SUPSAR-Snow project and is potentially relevant for future InSAR bistatic missions such as the upcoming ESA Harmony mission. The proposed framework enables reliable, large-scale estimation of glacier elevation changes from InSAR DSM differencing, improving the current understanding of cryospheric processes and preparing for future InSAR spaceborne missions.

11:00–11:20

Super-Resolution Snowpack Tomography from X-Band UAV SAR Using Covariance-Based Compressive Sensing

Speaker

Luca Mantuano (Politecnico di Milano)

Description

Snowpack characterization is of significant interest for hydrological and climate applications, particularly in mountainous environments, where conventional remote sensing techniques may suffer from limited spatial resolution. Synthetic Aperture Radar (SAR) tomography provides the capability to resolve scattering contributions along the vertical direction and therefore represents a promising technique for retrieving both snowpack height and internal stratigraphy.
This work presents the results of an experimental X-band UAV-SAR campaign conducted in February 2026 in Cheneil, Valle d'Aosta, Italy. Thirty approximately parallel trajectories were flown at different altitudes using an FMCW radar operating at 10 GHz with a bandwidth of 400 MHz, providing the spatial baseline diversity required for tomographic imaging. The reconstructed snowpack structure is validated against manual snowpit observations and independent ground-based radar measurements. The in-situ measurements indicate a dry and vertically stratified snowpack with a total thickness of approximately 0.95 m.
Conventional tomographic processing based on beamforming and spectral estimation techniques, such as Capon and MUSIC, allows the ground and snow-air interfaces to be identified, providing snow-depth estimates in good agreement with the in-situ measurements. However, the available vertical aperture results in a resolution comparable to the total snowpack thickness, preventing a reliable characterization of its internal stratigraphy.
By modeling the interfaces between different snow layers as planar distributed scatterers located at different heights, a covariance-based compressive sensing approach is introduced to exploit the expected sparsity of the vertical scattering power profile and achieve super-resolution in the vertical direction. Covariance estimates obtained from the multi-baseline SAR stack are improved by jointly exploiting observations acquired at multiple squint angles, thereby increasing the effective number of looks while preserving the tomographic information. The vertical scattering power profile is then retrieved through sparse reconstruction directly from the estimated covariance matrix.
Application to the Cheneil dataset shows a substantial improvement in the separation of vertical scattering contributions compared with conventional tomographic processing. In addition to identifying the ground-snow and snow-air interfaces, the proposed method consistently reveals intermediate scattering layers within the snowpack. These features show good agreement with the stratigraphy observed in the snowpit measurements, demonstrating the potential of covariance-based sparse reconstruction for high-resolution characterization of snowpacks from UAV-SAR observations.

11:20–11:40

Closure Phase for Assessing Scattering-Structure Changes in Long-Wavelength SAR Observations

Speaker

Hossein Aghababaei (ITC, university of Twente.)

Description

Long-wavelength synthetic aperture radar (SAR) missions provide a unique opportunity to investigate changes within penetrable natural media. This study introduces a closure-phase-based framework for evaluating scene stability and scattering complexity using multi-temporal SAR observations.
For long-wavelength SAR systems, measurements over natural media such as forests, snow, and ice can contain contributions from multiple scattering components distributed within the penetrable medium. Under such conditions, nonzero interferometric closure phase is not necessarily indicative of temporal variation in SAR signal but can also arise from the vertical distribution and superposition of multiple scattering contributions. This study introduces a model-driven closure-phase stability index to distinguish expected scene-dependent closure behavior from inconsistencies across multi-baseline SAR observations.
The proposed formulation is derived through a Taylor expansion of closure phase with respect to vertical wavenumber, allowing known acquisition-geometry terms to be separated from coefficients characterizing the scattering structure of the resolution cell. The model is jointly fitted to the observed closure phases from all available acquisition triplets. The mismatch between the observed and model-consistent closure phases is then quantified through a circular residual and formulated as a pixel-wise scene stability index. Low values indicate closure behavior consistent with a common scattering structure across the acquisition stack, whereas larger values indicate increasing departure from this consistency. The proposed methodology is particularly relevant to long-wavelength missions such as BIOMASS P-band and NISAR L-band and is applicable across different multi-baseline configurations, from the relatively large perpendicular baselines of BIOMASS tomography to the smaller baseline separations typically encountered in NISAR observations. This flexibility allows closure-phase consistency to be investigated across different vertical-wavenumber sampling regimes, while the penetration capability of long-wavelength SAR provides sensitivity to changes in the internal scattering characteristics of vegetation, snow, ice, and other natural media.
Experimental analyses are conducted using BIOMASS observations over forest environments and NISAR observations over a glacier region in Nepal. Of particular interest, the availability of NISAR observations before and across the 26 August 2026 rock–glacier collapse provides an opportunity to investigate whether changes in interferometric and closure-phase consistency preceded the catastrophic failure. The NISAR-derived closure-phase stability index reveals localized changes in the scattering consistency of the glacier region prior to the subsequent failure, which may not readily apparent from SAR intensity observations alone. These results demonstrate the potential of closure-phase model consistency as a complementary diagnostic for detecting changes in the scattering state of penetrable natural media.

11:40–12:00

Retrieving Glacier Elevation Change and Geodetic Mass Balance from TanDEM-X InSAR Time Series

Speaker

Isabel Pieruschka (ETH Zürich)

Description

Synthetic aperture radar (SAR)-based Earth observation techniques provide an effective means of monitoring glacier changes over large spatial and extended temporal scales. The Swiss Alps offer an excellent opportunity for validating remote-sensing approaches to glacier monitoring due to the high availabilty of independent glacier observations. In particular, the Great Aletsch Glacier – the largest glacier in the Alps – provides an ideal environment for developing and validating SAR-based approaches, as it is not only a designated super-test site for the TanDEM-X mission, but is also extensively monitored through long-term field observations and in-situ measurements. The resulting dense temporal sampling provides an opportunity to investigate both the spatial distribution and temporal evolution of glacier elevation change and their implications for geodetic mass balance.

In this study, the InSAR DEM differencing framework established by Li & Hajnsek (2025) is applied to the Great Aletsch Glacier using TanDEM-X single-pass bistatic SAR data acquired between 2011 and 2026 and complemented by the SwissALTI3D digital elevation model (DEM) (swisstopo 2022). The framework consists of the generation of 164 DEMs using an iterative InSAR approach, followed by DEM differencing and void filling using Gaussian Process Regression. A non-stationary uncertainty analysis is subsequently employed to quantify uncertainties in the resulting elevation changes and mass balance. GPS measurements (Leinss & Bernhard 2021) and annual glacier mass balance observations from GLAMOS (1881-2023) are used to validate the derived height changes and mass balance estimates. The dense temporal sampling is further exploited to investigate temporal variations in glacier thinning rates.

The resulting DEM time series reveals substantial elevation losses across the glacier. The mean height change over the entire Aletsch Glacier is estimated at -1.79 m yr^{-1}, with considerably stronger thinning of -6.18 m yr^{-1} in the glacier tongue. The corresponding geodetic mass balance is estimated at -1.35 m w.e. yr^{-1}, closely matching the long-term mean annual mass balance of -1.39 m w.e. yr^{-1} reported by GLAMOS. A strong elevation dependence is found both for the height loss and the glacier mass balance.

These results demonstrate the potential of the InSAR DEM differencing framework applied on a dense time series to provide spatially distributed measurements of glacier elevation change and geodetic mass balance. The framework is subsequently extended to additional glaciers in the Swiss Alps to assess its transferability and potential for large-scale glacier monitoring.

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12:00–12:20

Subsurface Deformation Signatures in the Antarctic Ice Sheet from BIOMASS P-Band Polarimetry

Speaker

Sara-Patricia Schlenk (Microwaves and Radar Institute, German Aerospace Center (DLR); Institute of Microwaves and Photonics, Friedrich-Alexander University (FAU) Erlangen-Nuremberg)

Description

Microwave remote sensing has become an indispensable tool for monitoring the polar regions, as signal penetration into dry snow and ice makes Synthetic Aperture Radar (SAR) sensitive to subsurface structures [1]. This sensitivity generally increases toward longer wavelengths, providing access to deeper englacial scattering contributions [1,3,4]. ESA's BIOMASS mission, launched in April 2025, is the first spaceborne P-band SAR mission and provides fully polarimetric observations with unprecedented potential for investigating the internal structure of the Antarctic Ice Sheet.
First BIOMASS observations over Antarctica reveal pronounced spatial variations in the polarimetric response across different glaciological environments, including transitions between glacier facies, areas of strongly deformed ice, and regions influenced by mountainous topography. However, the physical origin of many of these patterns and their relation to subsurface ice structure require further investigation.
In this study [5], we investigate BIOMASS acquisitions from two crossing orbits over the Riiser-Larsen Ice Shelf and Lyddan Ice Rise region acquired in November 2025. The Lyddan Ice Rise forms a stationary obstacle within the surrounding floating ice shelf, forcing the ice flow to divert around it and producing zones of enhanced deformation. Airborne Radar Echo Sounding (RES) observations provide an independent reference for the englacial structure. In regions with comparatively undisturbed flow, the RES data show continuous internal layering, whereas toward the deformation zones around the ice rise these layers become increasingly tilted, folded, and disrupted.
The corresponding BIOMASS observations show systematic changes in the polarimetric scattering behaviour, particularly in the anisotropy and orientation-dependent response [2]. We investigate whether these signatures can be related to the deformation observed in the RES data. Surface and oriented-volume scattering models are used to reproduce the measured polarimetric response while accounting for variations in subsurface layer orientation and structural organisation. The comparison indicates that the pronounced polarimetric patterns around the Lyddan Ice Rise are more consistently explained by deformation-induced changes in internal structural organisation and anisotropy than by variations in mean layer tilt alone.
These first results demonstrate the sensitivity of spaceborne P-band polarimetry to deformation-related subsurface structure in Antarctic ice. Combining BIOMASS observations with RES measurements and polarimetric modelling provides a framework for physically interpreting these newly observed signatures. In the longer term, the extensive spatial coverage of BIOMASS may enable systematic identification of shear margins, deformation zones, and other structural features across Antarctica, providing new information on the relationship between englacial structure and ice dynamics.

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12:20

12:20

Round Table

Session

13:30