8th International Workshop on Retrieval of Bio- & Geo-physical Parameters from SAR Data for Land Applications

Wednesday, 15 November 2023 - Friday, 17 November 2023

Rome, Italy

Programme

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Welcome (09:00 - 09:20)

Forestry I: Modelling and Retrieval (09:20 - 10:40)

-Conveners: López-Martínez, Carlos (Universitat Politècnica de Catalunya); Lavalle, Marco (NASA JPL)

Quantifying forest aboveground biomass globally with spaceborne SAR datasets: the CCI Biomass CORE algorithm (09:20)

Presenter: SANTORO, Maurizio (GAMMA Remote Sensing)

The Climate Change Initiative (CCI) Biomass project foresees the generation of forest aboveground biomass (AGB) estimates for several years between 2005 and 2022 at high resolution and globally. This is a challenging task, as accurately measuring the organic mass stored in forests relies on mathematical models applied to observations, either near or far-field. The difficulty lies in achieving both spatial detail and temporal consistency in AGB estimates, primarily because no single satellite mission has consistently collected data with the same level of geometric and radiometric quality over more than a decade. The only viable solution to overcome such limitations is to combine observations and models to reduce both random noise and individual systematic biases. The CCI Biomass CORE retrieval algorithm, presently in its fifth version, combines estimates of AGB from C- and L-band SAR missions. These estimates are generated using physically-based models that incorporate allometric functions trained on spaceborne LiDAR observations. By combining AGB estimates from multiple SAR observations with varying frequencies and polarizations, the algorithm reduces uncertainty compared to individual AGB estimates. Furthermore, a temporal stability measure is applied to minimize unnatural fluctuations in AGB estimates, given the moderate-to-weak sensitivity of SAR observables to AGB. Although the integration of models based on multiple satellite observations has matured, AGB estimates still carry a significant degree of uncertainty. This is due to the limited sensitivity of SAR observations to diverse forest structures and the generalizations made within the modeling framework. Indeed, a workaround solution was implemented to train the retrieval model because of the lack of a densely populated dataset of AGB measurements from ground surveys. Consequently, the algorithm may not fully adapt to local forest structural conditions. In this talk, we will present the evolution of the CCI CORE algorithm and discuss its current limitations. Additionally, we will explore potential avenues for reducing these limitations by considering various scenarios involving different satellite missions. This discussion will be situated within the context of quantifying AGB changes, highlighting the current disparity between user requirements and the capabilities available to AGB map producers.

Combining Multi-Mission Datasets and Structure Measurements to Estimate Tropical Forest Biomass in the Scope of the ESA BIOMASS Mission (09:40)

Presenter: HARTWEG, Benedikt (German Aerospace Center (DLR) & University of Munich (LMU))

Current remote sensing based approaches for forest biomass estimation evolve around the use of allometric relationships at different spatial and temporal scales. Three main input parameters are used for the biomass estimation: the tree height, either at the individual level, or at the respective resolution cell size, the allometric factor and the allometric exponent. This formula for the biomass estimation is widely known as the simplified power law function. The allometric factor alpha accounts for density variations in the forest stand. The allometric exponent on the other hand represents species composition and variations in the growing conditions, thus involves a more profound knowledge of the forests and the implementation of forest field inventory data. Actual implementations of such an approach by means of TanDEM-X / GEDI measurements rely on forest height estimates obtained from the combination of interferometric TanDEM-X and GEDI waveform measurements and allometric parameters derived from the existing GEDI biomass product. This way, a forest height map at 25m resolution scale, matching the GEDI footprint of equally 25m radius, is generated. Future implementations must focus on the BIOMASS L2B FH product scale of 200m resolution. From this, a considerable scale difference becomes apparent. As a preliminary step, this scale difference between Tandem-X/GEDI Products and the BIOMASS L2B FH scale is analyzed with existing waveform LiDAR measurements of the NASA LVIS instrument. Tropical forests in Gabon and Costa Rica were analyzed. By creating a baseline scenario with the provided LVIS biomass product, a multitude of different forest height map scales was analyzed with their respective effect on the outcoming biomass map. It became apparent that scale differences between different sensors cannot be neglected and induce – at least in the case of the analyzed parameter forest height – a considerable error. By the experiment with the mentioned LVIS dataset, biomass increases of up to 80t / ha were detected between a 25 m scale (e.g. Tandem-X, LVIS or GEDI) and a 200m scale (e.g. BIOMASS). Throughout working with the LVIS dataset, extreme variations of the resulting biomass values for the individual canopy height classes became apparent. Now, in addition to the mentioned datasets and methods, simulated data from the UFZ FORMIND forest growth model was implemented, rendering a perfect sandbox for further analysis. The high variance in biomass values was also confirmed in the FORMIND biomass product. Different species compositions and growing conditions (which would directly attribute to changes in wood density) can be ruled out, as these variances are already prominent at rather small scales (e.g. 50 ha datasets of LVIS). Thus, density variations in the forests are suspected to be the underlying driver. As of right now, forest density can not be directly measured with remote sensing methods, thus, the complexity, or rather forest structure is applied as a proxy. As of this moment, two approaches are being tested to estimate the forest structure at different spatial scales. One consists of a spatially adapted horizontal forest structure index, calculated from the phase centers of TanDEM-X measurements. The other revolves around using wavelet decompositions to likewise create a structure index and thus segment the canopy height to biomass point cloud into smaller areas, subsequently enabling the use of spatially adapted allometries. Both approaches show promising results and both the performance and applicability will be further discussed by means of simulated and real experiment data.

Estimating the properties of tropical dryland forests with ALOS L-band polarimetric data (10:00)

Presenter: QUEGAN, Shaun (University of Sheffield)

The global dry tropics are currently the largest, most sensitive, and fastest increasing component of the land carbon sink, but proper characterization of their role requires accurate estimates of the forest processes occurring within this region. L-band Synthetic Aperture Radar (SAR) observations are currently our best option to consistently map these processes: i) they are available globally since 2007 (JAXA ALOS-1 and ALOS-2), and ii) are sensitive to forest structure, such as aboveground biomass up to ~ 100 t/ha. Here we use high-quality ground observations from Africa, Australia and Latin America to understand the impact of forest structure and site characteristics on L-band radar data. Fully-polarimetric L-band SAR data from ALOS-1 PALSAR-1 and ALOS-2 PALSAR-2 sensors over the ground sites were interpreted in terms of scattering mechanisms (surface scattering, volume scattering, double bounce) inferred using the Freeman & Durden, van Zyl and Cloude & Pottier polarimetric decompositions. Within the forest sites, volume scattering is clearly identified as the dominant mechanism over the wooded vegetation types though it is mixed with a weaker return from surface scattering and, in most cases, a much weaker return from double bounce. Double bounce is usually small, probably because of weaker scatter from dry soils and the prevalence of multi-stem tree types. However, across the landscape there is much greater variation, with surface scattering dominating in non-wooded areas and a more even balance of surface and volume scattering in mixed areas. Volume scattering is sensitive to above-ground biomass density (AGBD) up to ~100 t ha-1, after which saturation occurs, but the response to AGBD is strongly affected by stocking density (much less so by average tree biomass). We will present these results in the context of structural equation modelling and discuss their implications for forest information recovery using only the more widely available ALOS dual-pol data.

Insights of MIPERS-4D simulations for the retrieval of forest height and biomass: study cases related to the BIOMASS mission (10:20)

Presenter: VILLARD, Ludovic (CESBIO)

Given its unique penetration capabilities and sensitivity to woody elements, radar remote sensing techniques at P and L bands are certainly the most promising tools for wide scale retrieval of forest parameters. Nonetheless, the radar signal sensitivity is prone to multifactorial effects, and the retrieval methods (mostly correlative or network based) are often limited by an insufficient number of training samples_ For a better understanding of these multifactorial effects, sensitivity analysis can be performed trough the use of Electromagnetic (En) models (e.g MIPERS-4D hereinafter), providing likelihood estimates of the retrieved parameters. In this study, a specific focus is given on forest height and biomass retrieval from P and L bands. Regarding forest height retrieval, several assumptions are investigated, such as the uncorrelation between volume and ground scattering (being a key hypothesis behind the so-called RVoG and more generally two-components models), and the 3dB threshold assumption coming with the exploitation of Tomo SAR based reflectivity profiles. More challenging, we also see that the retrieval of forest biomass depends on a wider range of unknown parameters, such as the intrinsic relation between the canopy fresh matter and the total dry biomass (forest AGB). These results will be also discussed and cross compared with respect to experimental data and estimates derived from recent airborne and tower-based experiment. Interstingly, we will also see that this cross analysis with the latter contribute to the spatialisation of temporal results observed at local scale, providing semi-empirical relations adapted to regional retrieval.

Comfort break (10:40 - 11:00)

Forestry II: InSAR applications (11:00 - 12:00)

-Conveners: Tebaldini, Stefano (Politecnico di Milano); Ferro-Famil, Laurent (ISAE-SUAPERO & CESBIO, University of Toulouse, France)

Boreal Forest Characterization with Sentinel-1 Coherence (11:00)

Presenter: HERRERA-GIMÉNEZ, Marc (IEEC UPC)

Importance of the specific conditions in forestry areas for the interferometric coherence retrieval, especially the effect over taller and shorter trees. A preliminary study over two different test sites on the seasonality and meteorological effects in the C-band 6-day coherence with Sentinel-1.

POLARIMETRIC-INTERFEROMETRIC TEMPORAL SAR COHERENCE: PHYSICAL MODELS AND RETRIEVAL ALGORITHMS FOR FOREST PARAMETER ESTIMATION (11:20)

Presenter: LAVALLE, Marco (NASA JPL)

The polarimetric-interferometric temporal SAR coherence is defined as the normalized correlation between two SAR single-look image (SLC) samples acquired at different times and free of other decorrelation effects such those associated with thermal noise, perpendicular baseline, and processing artifacts [1]. The temporal coherence gauges "how coherent" the signal scattered from the imaged scene within the multi-looked radar resolution cell remains from one acquisition to another. Lower coherence values indicate larger changes compared to higher coherence values. These changes can be geometric (e.g., motion or addition of scatterers) or dielectric (e.g., alteration of moisture content or temperature). Polarization diversity allows the selection of a scattering mechanism from the received signal. As they relate to different properties of the imaged scene, distinct scattering mechanisms within the same resolution cell undergo different changes over time, leading to different temporal coherence levels. In recent years, some studies have emphasized the significant impact of land cover on temporal coherence and its evolution over time, specifically how multiple temporal coherence samples vary within a time series as the temporal interval increases [2-4]. Generally, scattered signals lose coherency more rapidly as the time gap between acquisitions widens, which is influenced by the structure of the target. Complex and penetrable targets like vegetation tend to decorrelate faster over time compared to bare soil. Such complex targets also likely display greater temporal coherence diversity as a function of polarization, and in relation to radar and observation parameters (e.g., radar wavelengths and incidence angles). Understanding the interplay between the characteristics of the imaged scene (e.g., vegetation) and the polarimetric-interferometric coherence for different time intervals, as well as the opportunities for parameter estimation, is an active area of research in the Bio-GeoSAR community. This talk aims to offer the community a comprehensive review of the most recent advances in temporal coherence modeling, coupled with potential parameter estimation algorithms grounded in these models. The primary temporal coherence model to be presented in detail is based on the random-motion-over-ground model (RMoG+) [5]. This model factors in the addition of backscatter soil/canopy changes between acquisitions and the dependency on the temporal interval to model coherence time series. We will evaluate the model using available data sets, including time series from Sentinel-1, ALOS-2, and potentially airborne UAVSAR/AirMOSS time-series at L and P bands. This research work is topical considering current and upcoming L-band SAR missions like SAOCOM, NISAR (2024), ROSE-L (2028/2030), and ALOS-4. These missions will capture SLC time-series within a narrow orbital tube, enabling global, recurrent observations of temporal coherence and presenting novel opportunities for land parameter estimation. [1] Zebker, H. A., and J. Villasenor, "Decorrelation in interferometric radar echoes," in IEEE Transactions on Geoscience and Remote Sensing, vol. 30, no. 5, pp. 950-959, Sept. 1992, doi: 10.1109/36.175330. [2] Lavalle, M., C. Telli, N. Pierdicca, U. Khati, O. Cartus, and J. Kellndorfer, "Model-based retrieval of forest parameters from Sentinel-1 coherence and backscatter time series," IEEE Geoscience and Remote Sensing Letters, vol. 20, pp. 1–5, 2023. [3] Sica, F., A. Pulella, M. Nannini, M. Pinheiro, and P. Rizzoli, "Repeat- pass SAR interferometry for land cover classification: A methodology using Sentinel-1 Short-Time-Series," Remote Sensing of Environment, vol. 232, pp. 111277, 2019. [4] Seppi, S.A., C. López-Martinez, M. J. Joseau. "Assessment of L-Band SAOCOM InSAR Coherence and Its Comparison with C-Band: A Case Study over Managed Forests in Argentina." Remote Sensing, vol. 14.22, pp. 5652, 2022. [5] Lavalle, M., and M. Simard, and S. Hensley, "A temporal decorrelation model for polarimetric radar interferometers," Geosc. and Rem. Sens., IEEE Trans. on, vol. 50, no. 7, pp. 2880–2888, July 2012.

Analysis of the SAOCOM L-Band System Capabilities for Forest Height Estimation (11:40)

Presenter: LÓPEZ-MARTÍNEZ, Carlos (Universitat Politècnica de Catalunya)

This work presents the first results of canopy forest height mapping with L-Band SAOCOM data by means of Polarimetric SAR Interferometry (Pol-InSAR). SAOCOM stands for Satélite Argentino de Observación con Microondas and it is operated by CONAE, the Argentinean space agency. For this study case, a collocated temporal series of SAOCOM full polarimetric images covering the years 2021 and 2022 was acquired, with a temporal baseline of 8 days between acquisitions. The study area corresponds to Corrientes, Argentina, which is one of the main forest production regions in the country, and where field measurements provided by local producers were available in order to validate the obtained results, along with canopy height measurements from the Global Ecosystem Dynamics Investigation (GEDI) mission. The main planted species in Corrientes are Pinus and Eucalyptus, with forest heights ranging from 10 to 35 meters at the age of maturity. In the first step of this research, we carried out an exploratory assessment of the different decorrelation sources affecting the interferometric pairs. On one side, the temporal decorrelation term was analyzed with support of the different temporal spans between the existing images. On the other hand, the volumetric decorrelation was assessed by analyzing the sensitivity of the interferometric coherence to forest canopy height coming from field inventories and GEDI measurements. The results showed that, provided the shortest temporal span was guaranteed, that is, 8 days, a relationship between canopy height and interferometric coherence could be observed and estimated by models such as the Random Volume over Ground (RVoG). In a second step, a multi-baseline Pol-InSAR approach was adopted, following the methodology proposed by Denbina and Simard (2018) and Pourshamsi et al (2018) with Land Vegetation and Ice Sensor (LVIS) and UAVSAR data. Field data measurements and GEDI transects acquired over the study periods were used to select the RVoG-inverted maps that best represented the different forest heights present in the study areas. The results show that this multi-baseline selection approach is more appropriate than a single-baseline one, given the high variability that SAOCOM presents in the spatial baseline between acquisitions, and the lack of orbital control over this parameter, unlike other missions such as Sentinel-1 or UAVSAR. This study presents, for the first time, forest canopy height maps of 8-day temporal baselines, L-band, orbital interferograms, along a temporal window of almost two years. The conclusions yielded by this preliminary research are of great importance for the understanding of the Pol-InSAR capabilities of SAOCOM in the field of forest height mapping. The generalization of these results to other types of forests, such as boreal, tropical, or Mediterranean forests, is a foremost task, especially regarding the future L-band SAR missions like ROSE-L and NISAR. It is also important to assess the suitability of the RVoG model to characterize the structure of these forests with L-band data retrieved by the Argentinean constellation.

Lunch break (12:00 - 13:40)

Forestry II: InSAR applications (13:40 - 14:40)

-Conveners: Ferro-Famil, Laurent (ISAE-SUAPERO & CESBIO, University of Toulouse, France); Tebaldini, Stefano (Politecnico di Milano)

Combining AI Techniques with Physical Models: Forest Height Inversion from TanDEM-X InSAR Data Using a Hybrid Modeling Approach (13:40)

Presenter: MANSOUR, Islam (German Aerospace Center (DLR))

In the realm of artificial intelligence, specifically utilizing methodologies such as machine learning and deep learning, a conspicuous display of substantial potential across various parameter estimation problems has been demonstrated. However, such AI techniques are often employed without the incorporation of domain-specific knowledge or expertise raising concerns about the explainability and robustness of the implemented methodologies. In contrast, physical models (PMs) offer a significantly enhanced level of deterministic robustness. However, it is imperative to recognize that these models can exhibit performance limitations owing to their inherent simplicity and/or strictness. Moreover, the accuracy of their inversion process is circumscribed by the assumptions and simplifications that underlie them, particularly those applied to the vertical reflectivity function, which are prerequisites for achieving a well-balanced inversion problem. As a result, it becomes imperative to advocate for hybrid modeling approach by the integration of AI techniques with physical models, especially in the context of forest height estimation derived from TanDEM-X coherence measurements. Accurate estimation of forest height is crucial for understanding forest structure and biomass, which in turn plays a pivotal role in climate change mitigation and ecosystem management. In this study, we propose a novel hybrid modeling approach that combines machine learning techniques and physical models to invert forest height from TanDEM-X InSAR (Interferometric Synthetic Aperture Radar) data. This approach might be relevant for the Biomass mission for understating the forest and its structures. The conventional methods for forest height estimation from InSAR data often rely solely on physical models, which are based on Polarimetric InSAR (Pol-InSAR) measurements as an established application demonstrated and validated at large scales for a wide variety of boreal and tropical forest sites at different frequencies (from X- down to P- band) [1], [2]. However, it may suffer from limitations in complex forest environments with varying topography forest types and underlying assumptions [3]. On the other side, machine learning approaches have demonstrated great potential in capturing complex relationships within data but may lack the physical interpretability required for robust forest height estimation. Furthermore, the limited availability of training datasets that covers a variety of condition might cause issues with the generalizability of the machine learning model. The hybrid modeling approach bridges this gap by integrating the strengths of both approaches. We leverage a dataset of TanDEM-X InSAR observations, and LVIS forest height measurements over Gabon, Africa. The MultiLayer Perceptron (MLP) is employed to learn complex patterns and relationships from the data, to derive the vertical reflectivity profile. Whereas the vertical reflectivity profile is defined as a set of coefficients utilizing a Legendre series decomposition [4]. We incorporate physical models to enhance the interpretability and generalizability of the predictions. By fusing the machine learning predictions with the physical model outputs, we obtain a hybrid forest height estimation that combines the advantages of both approaches. Moreover, it provides optimum performance and robustness. We incorporate multi-model data for the forest height estimation from single baseline single-polarimetric TanDEM-X interferometric coherence measurements. We discuss the challenges that need to be addressed and how to integrate a multi-modal (LiDAR, multi-spectral images, Polarimetric SAR, etc.) in a general hybrid modelling framework. Keywords: Forest height inversion, TanDEM-X InSAR data, hybrid modeling, machine learning, physical models, remote sensing. [1] V. Carcarra-Bes, M. Pardini, C. Choi, R. Guliaev, and K. P. Papathanassiou, “Tandem-X and Gedi Data Fusion for a Continuous Forest Height Mapping at Large Scales,” pp. 796–799, 2021, doi: 10.1109/igarss47720.2021.9554655. [2] S. K. Lee et al., “Spaceborne GEDI and TanDEM-X data fusion for enhanced forest height and biomass,” AGUFM, vol. 2018, pp. B44E-14, 2018, Accessed: May 03, 2021. [Online]. Available: https://ui.adsabs.harvard.edu/abs/2018AGUFM.B44E..14L/abstract [3] A. T. Caicoya, F. Kugler, K. Papathanassiou, P. Biber, and H. Pretzsch, “Biomass estimation as a function of vertical forest structure and forest height - Potential and limitations for Radar Remote Sensing,” in 8th European Conference on Synthetic Aperture Radar, 2010, pp. 1–4. [4] S. R. Cloude, “Polarization coherence tomography,” Radio Sci, vol. 41, no. 4, Jul. 2006, doi: 10.1029/2005RS003436.

TanDEM-X and Sentinel-1 InSAR Coherence for Mapping Forests using Deep Learning (14:00)

Presenter: RIZZOLI, Paola (DLR)

Forests are of paramount importance for the Earth’s global ecosystem. They act as effective carbon sinks, reducing the concentration of greenhouse gas in the atmosphere, and help mitigating climate change effects. This delicate ecosystem is currently threatened and degraded by anthropogenic activities and natural hazards, such as deforestation, agricultural activities, farming, fires, floods, winds and soil erosion. The availability of reliable, up-to-date measurements of forest resources and evolution is therefore of great importance for environmental preservation and climate change mitigation. In this scenario, Synthetic Aperture Radar (SAR) systems, thanks to their capability to operate in presence of clouds, represent an attractive alternative to optical sensors for remote sensing surveys over forested areas, such as tropical and boreal forests, which are hidden by clouds for most of the year. In this work, we will present the activities currently being carried out at DLR for mapping forests at large scale and high resolution, with the aim to regularly monitor vegetated areas and to detect long-term changing trends. Focusing on the Amazon rainforest basin, we will investigate the added-value of SAR interferometry (InSAR) in combination with artificial intelligence algorithms, having to cope with the lack of large datasets of labelled data for training deep learning algorithms. In particular, we will concentrate on the differences between bistatic and repeat-pass InSAR configurations, using the examples of the TanDEM-X and Sentinel-1 missions, respectively, proposing different deep learning-based frameworks which exploit the peculiarity of each mission. Regarding TanDEM-X bistatic data, we will show how we can rely on self-supervised learning approaches and AI-based InSAR denoising algorithms for generating accurate forest maps with a ground resolution down to only 6 meters. This resolution outperforms all currently available spaceborne-based land cover products, setting the groundwork for an effective detection of forest degradation phenomena and selective logging activities. The absence of temporal decorrelation in TanDEM-X bistatic InSAR data allows us to generate highly accurate forest maps using only one single acquisition, but due to the limited acquisition capabilities it is not possible to perform a regular revisit of large-scale areas. For this reason, spaceborne SAR missions which can provide regular revisit, such as Sentinel-1, become of great interest for the development of an operational framework for monitoring of extended vegetated areas. In this case, the challenge to overcome is how to deal with the presence of temporal decorrelation in repeat-pass data. To this aim, we assume a reasonable stationarity of the illuminated scene during a short time period of about one month and we compute both backscatter and multi-temporal coherence stacks (computed at different temporal baselines) from Sentinel-1 short time series. These are used as input features to a convolutional neural network (CNN) for performing a multi-layer semantic segmentation task. Early results on a dedicated test site in Rondonia, Brazil, showed a very promising performance by combining backscatter information with coherence stacks at a temporal baseline of only 12 and 24 days, and that seasonal effects can be mitigated by properly designing the network training strategy. Here, the final goal is the development of a pre-operational framework, running on high performance computing facilities, for the regular monitoring of the Amazon basin, the detection of changes and the setup of a reliable, cloud cover independent early warning system for deforestation activities and forest degradation phenomena. Finally, we will compare pros and cons of single-pass (bistatic) versus repeat-pass InSAR, discussing their main peculiarities and limitations. In particular, we will concentrate on the analysis of the interferometric coherence and on the relationship between volume and temporal decorrelation with respect to forest mapping, demonstrating the importance of combining multiple sensors for enhancing the overall capability to monitor forests dynamics at large-scale.

Applications and challenges of deep learning approaches for forest height estimation from InSAR products (14:20)

Presenter: CARCERERI, Daniel (German Aerospace Center (DLR))

Forests form the largest terrestrial ecosystem by area, and hold primary relevance in the carbon cycle. Continuous and precise monitoring of its dynamics, is of paramount importance to study and quantify the impact of anthropogenic caused degradation from events, such as logging and farming activities, but also wildfires, floods or storms of increasing intensities and linked to the man-made climate change. In this context, the generation of readily available, precise and large-scale estimates of forests' properties, and of their temporal evolution is essential. Spaceborne Synthetic Aperture Radar (SAR) systems are invaluable to this goal, as they operate on the required geographical and temporal scales, independent of weather conditions or time of day. In this work, we present some of our findings related to the synergistic use of satellite-acquired SAR imagery and deep learning algorithms for the estimation of bio-physical parameters. We focus our investigation on the added value of interferometric SAR (InSAR) products in relation to the more commonly used backscattering information, by presenting the benefits and the challenges associated to available feature pools. Furthermore, we quantify the benefits of single-pass over repeat-pass InSAR acquisitions, emphasizing the relevance of current and future bistatic missions, such as TanDEM-X and Harmony, in comparison to their repeat-pass counterparts. Finally, we provide a basic comparison of our proposed deep learning approach with the more commonly used physical-based models, highlighting both the key benefits and the challenges associated with AI-based approaches. All of the presented results have been obtained using DLR's TanDEM-X and ESA's Sentinel-1 products, and have been validated over the tropical sites of NASA/ESA 2016 AfriSAR campaign in Gabon, Africa. The obtained results are extremely promising in view of large-scale mapping, displaying the distinctive advantage of requiring only a single input acquisition for inference.

INTERACTIVE SESSION (14:40 - 15:40)

Machine learning and Sentinel-1 and Sentinel-2 multi-temporal Analysis-Ready-Data (ARD) for estimating mixed pixel woody and herbaceous vegetation in South African protected savannas: Benfontein Nature Reserve (14:40)

Presenter: NGHIYALWA, Hilma (Friedrich Schiller University Jena & University of Namibia)

Approximately more than 50% of Africa's land surface is covered by the savanna biome. Estimation of savanna vegetation are essential to provide detailed land cover information. Prediction of savanna vegetation at pixel level is important for conservation purposes, understanding bush encroachment, herbivory and fire dynamics in savannas. However, estimating vegetation cover in the savannas can be challenging due to the dynamic factors such as climate, fires and herbivory which interact with the savannas at different scales contributing to high cover heterogeneity and the mixed pixel problem. Sentinel-1 C-band is a radar remote sensing which can ideally complement the optical data which are affected by weather. SAR has especially been used for forest mapping, deforestation and forest degradation. Radar backscatter sensitivity to forest structural change offers new methods especially where optical time series are not available. Fewer studies which combine radar and optical for mapping savanna vegetation fractions are reported. This is despite that increased accuracies are reported when radar and optical data are combined for savanna vegetation mapping. Therefor combining radar and optical remote sensing data presents an opportunity to explore methods for estimating African savanna vegetation fractions. Mixed pixel analysis quantifies the proportions of vegetation within a single pixel. This poster presentation presents results on the use of multi-temporal Sentinel-1 VV, VH and VV Coherence combined with Sentinel-2 data multi-temporal statistics to estimate woody vegetation fractions in Benfontein Nature Reserve project in South African savanna environment using machine learning regressions, with fieldwork supported by South African Environmental Observation Network (SAEON) and in conjunction with South African Land Degradation Monitor (SALDI). Training data is collected by combining fieldwork and data collected from Very High Resolution (VHR) images, along with Analysis Ready Data (ARD) Sentinel-1 and Sentinel-2 multi-temporal statistics which are used as predictors and applied to machine learning regressions to estimate woody vegetation and grass combined with baresoil fractions. The analysis is performed at a pixel level to estimate the percent of vegetation within each each pixel. A combination of Sentinel-1 and Sentinel-2 performs slightly better than Sentinel-1 and Sentinel-2 alone. The lowest accuracies are observed for Sentinel-1 models alone.

BIOMASS Forest Products: Evolutions and Perspectives (15:00)

Presenter: BANDA, Francesco (aresys)

The next ESA's Earth Explorer will be BIOMASS, its launch is estimated in 2025 and its primary aim is to collect Synthetic Aperture Radar (SAR) acquisitions to improve the understanding of global forest status and temporal evolution [1]. BIOMASS is also the first P-band spaceborne SAR, with operational repeat-pass polarimetric-interferometric capabilities. This gives sensitivity to the full tree structure, as well as new opportunities to investigate sub-canopy topography and subsurface. Repeat cycle is optimized to be robust to temporal decorrelation and coverage is global except for Europe and North America due to international regulations. Ionospheric effects and disturbances are considered tolerable and mitigated through dedicated processing, which accounts also for coregistration and topography compensation [2]. Although, the main operational phase is interferometric dual-baseline (global coverage taking about seven months), there will be a first experimental tomographic phase, during which seven passes are collected over each location to enable 3D mapping (global coverage taking about fourteen months). In this presentation we discuss the evolution of scientific forest products generation, which started from first prototypes [1] and lead during the last three years to the current operational implementation [3]. We also highlight insights and perspectives, some of which form the basis for further evolutions. The three main forest products generated by BIOMASS will be Forest Disturbance (FD), Forest height (FH) and Above Ground Biomass (AGB). FD development is still in progress. On one side polarimetric analysis has been used to study the effects of environmental changes, which can compromise change detection methods based on the polarimetric covariance matrix [4]. On another side, investigation focused on detecting changes in a series of forest/non-forest classifications. Forest/non-forest classification is also needed for FH and AGB processing. Regarding FH, the effort was mainly devoted to investigating the use of tomographic reflectivity to improve classic polarimetric-interferometric model inversion [5]. The evolution of AGB estimation [6] has been focused on refining implementation at global scale, by defining regional and forest class partitioning to help in tailoring the algorithm to differing forest circumstances. A semi-empirical scattering model relating canopy signal to AGB is inverted to obtain model parameters where external reference is available, to subsequently compute AGB over an entire region. Attention is focused on identifying the most suitable source of reference data, additional work has been performed regarding helpful ancillary data and ground rejection techniques. Testing on campaign acquisitions reprocessed to BIOMASS resolution are also presented to support the discussion. References [1] F. Banda et al., “The BIOMASS Level 2 Prototype Processor: Design and Experimental Results of Above-Ground Biomass Estimation”, Remote Sensing 2020 [2] F. Banda, et al., “BIOMASS Interferometric Calibration Processor Design”, IGARSS 2023 [3] M. Pinheiro et al., “The Biomass Processing Suite (BPS): an Overview of BIOMASS Operational Processor and Products”, POLINSAR 2023 [4] A. Alonso-González et al., “Polarimetric SAR Time Series Change Analysis Over Agricultural Areas”, IEEE TGRS 2020 [5] R. Guliaev et al. "Forest height estimation by means of TanDEM-X InSAR and waveform lidar data." IEEE JSTARS 2021 [6] M. Soja et al., “Design and Parameter Estimation Robustness of the Global Above-Ground Biomass Estimation Algorithm for ESA’s 7th Earth Explorer Mission BIOMASS”, IGARSS 2023

Forest Vertical Structure Characterization Using SAR Tomography and Deep Learning (15:00)

Presenter: AGHABABAEI, Hossein (ITC, university of Twente.)

Wenyu Yang [1] , H. Aghababaei [2], Giampaolo Ferraioli [1] [1] Dipartimento di Ingegneria, Università degli Studi di Napoli “Parthenope,” 80143, Naples, Italy [2] University of Twente, Faculty of Geo-Information Science and Earth Observation Enschede, The Netherlands Characterizing and monitoring forests are essential for tracking climate change and quantifying the global carbon cycle, particularly through aboveground biomass (AGB) mapping. This involves identifying their vertical structure, representing tree, trunk, and crown arrangement—an important productivity and biomass indicator recognized by the scientific community [1]. Traditionally, forest monitoring requires costly and time-intensive in situ fieldwork, yielding precise data. In contrast, remote sensing methods offer widespread, frequent coverage. Techniques ensuring under-foliage penetration and 3D measurements, such as high-resolution waveform lidar and Synthetic Aperture Radar (SAR) tomography (TomoSAR) [2], are ideal for forest monitoring. SAR stands out due to its weather independence and broad coverage. Yet, SAR images project 3D data into a 2D domain. TomoSAR solves this issue by synthesizing a vertical array, enabling full 3D imaging. TomoSAR is indeed a unique tool for accurate 3D forest reconstruction, delivering reliable biophysical data like vertical structure and biomass, akin to terrestrial and lidar approaches. Various standard spectral estimation techniques, such as Beamforming and Capon, have been employed to reconstruct the distribution of vertical backscattering from multi-baseline SAR images of forested regions [3]. Results from numerous airborne campaigns, including BioSAR [4], AFRISAR [5], and TropiSAR [6], have demonstrated the effectiveness of these methods. This progress indicates a promising direction for deriving and reconstructing 3D backscattering images of forested areas from spaceborne data. Currently, several missions, including BIOMASS [7], NISAR[8], and the Tandem-L SAR [9], are scheduled for launch in the next two years. Utilizing low-frequency images from these systems provides optimal SAR images for in-depth examination of forested areas due to their high signal penetration capabilities. However, a key distinction between upcoming spaceborne data and existing airborne multi-baseline SAR images lies in the baseline distribution of the sensors, temporal decorrelation and atmospheric effects that can affect quality of tomographic inversion. Recently, deep learning based methods have become a fundamental methodology for different remote sensing image processing tasks as well as for SAR image processing [10-11]. This study aims to take the advantages of deep learning to improve forest height estimation in tomographic framework. Observing the estimation of the forest height from a classification point of view, a fully connected network is designed to extract the abstract features for height retrieval over covariance matrix of tomographic data along with the LiDAR data as the reference. The main and noteworthy outcome of the proposed solution lies in its ability to generate a resilient ground and canopy height model, irrespective of the presence or absence of calibration phase errors (atmospheric errors) in the images. References [1] Hardiman BS, Bohrer G, Gough CM, Vogel CS, Curtisi PS. The role of canopy structural complexity in wood net primary production of a maturing northern deciduous forest. Ecology. 2011 Sep;92(9):1818-27. doi: 10.1890/10-2192.1. PMID: 21939078. [2] Aghababaei, H., Ferraioli, G., Ferro-Famil, L., Huang, Y., d'Alessandro, M. M., Pascazio, V., ... & Tebaldini, S. (2020). Forest SAR tomography: Principles and applications. IEEE geoscience and remote sensing magazine, 8(2), 30-45.. 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WIMEX (Wave Interaction Models EXploitation) (15:00)

Presenter: RIVOLTA, Giancarlo (Progressive Systems)
G. Rivolta, C. Orrù, M. Iesué, C. Camporeale, A. Mujeeb, M. Zribi, E. Ayari, N. Baghdadi,N. Sami, J. Cohen, J. Jorge Ruiz, J. Lemmetyinen, A. Fiengo, F. Ticconi, and D. Comite Forward and inverse models developed by the Earth Observation (EO) scientific community describe, respectively, the relation between electromagnetic waves interacting with natural surfaces and the methodologies for retrieving bio-geophysical variables from remotely sensed data. Yet the current landscape – marked by the development of an extensive and heterogeneous suite of models – reveals some limitations. These encompass models not systematically implemented; models tested and validated only on small amounts of data; and limited integration of the models with the emerging Artificial Intelligence (AI)-based inversion techniques. In this poster, we introduce the Wave Interaction Models EXploitation (WIMEX) framework, which aims at addressing these challenges, in the frame of an ESA-funded project. The framework, leveraging the unprecedented amount of EO data today available, creates a systematic approach to the development, validation, and use of existing and future forward and inverse models for increased efficiency and flexibility. Unlike existing solutions, WIMEX is designed to be model-independent, accommodate, manage, and operate any forward and inverse model independently of sensor and model objectives, supporting the use of cloud infrastructure for improving performance. This versatility reinforces the framework role in supporting existing and next-generation EO missions. Moreover, being designed to interface with different EO data sources (EO data, in situ data, ad-hoc datasets, etc.), it supports the design, development and validation of forward models, the generation and storing of look-up tables and datacubes in a flexible way. It assists with the use of these outputs for testing and calibrating inverse models, through processes like neural networks training and use, as well as for performing sensitivity analyses across broad ranges of input parameters. It also facilitates the application of inverse models over extensive volumes of EO data, hence improving the statistics of the retrieved bio-geophysical variables and enhancing their interpretation. WIMEX also aims to boost the design of new and/or more accurate inverse models seamlessly combining their implementation with AI-based inversion techniques. This added value helps improving the overall performance of the models and

aligns with the evolving needs of the research community. The prototype version of WIMEX, set to be released in the second half of 2024, demonstrates its efficacy and flexibility for remote sensing over land applications, specifically through the management and execution of forward and inverse models targeting soil moisture and snow water equivalent. In the near future, upcoming versions will incorporate support to additional sensors and variables, as well as diverse missions, to enhance user experience and address a wider spectrum of requirements.

Project Office BIOMASS – Build a user community for ESA BIOMASS Mission (15:00)

Presenter: YANG, Hui

The European Space Agency (ESA) BIOMASS mission will be the first operational development of a fully polarimetric P-band synthetic aperture radar (SAR) in space. Compared to all previous SAR mission, BIOMASS mission offers major advances by incorporating three distinct techniques, i.e., SAR Polarimetry (PolSAR), Polarimetric SAR Interferometry (Pol-InSAR), and SAR Tomography (TomoSAR) to provide information on forest properties. The primary objective of BIOMASS mission is to generate the global distribution of forest above□ground biomass (AGB). This product can reduce the uncertainties in carbon stocks and carbon fluxes associated with Land Use Change, forest degradation, and forest regrowth. In addition, this mission has several secondary objectives, which are mapping subsurface geology, measuring terrain topography under dense vegetation, and estimating glacier and ice sheet velocities. The Project Office BIOMASS has been established with the aim of coordinating the scientific dissemination of the ESA BIOMASS Mission. On one hand, the Project Office BIOMASS is dedicated to aligning with BIOMASS mission objectives towards advancing the current understanding the role of terrestrial ecosystem dynamics within the context of the global carbon cycle under climate change. For example, the project works on quantifying the terrestrial carbon balance over the decadal scales which plays an important role in mitigating the atmospheric CO_2 concentration, and characterizing the link between spatial variability in high-resolution biomass and disturbance dynamics and land use change, which represents key prediction challenges in Earth System Models. On the other hand, the coordination activities by the Project Office BIOMASS include the organization of regular scientific workshops dedicated to diverse topics related to biomass. To date, ten such workshops have been conducted. Furthermore, the project has initiated on-site training programs, i.e., organizing a summer school, which aims to train and engage the young research communities in the upcoming BIOMASS mission objectives. In addition, the Project Office BIOMASS has conducted a survey to obtain the data requirements of various biomass data users, including those engaged in remote sensing, Earth system modelling, and forest monitoring. Subsequently, a gap analysis has been drafted based on this survey, proposing approaches to bridge mission objectives with expectations from the biomass data users.

Supporting Open Science with the BIOMASS Mission Algorithm and Analysis Platform (MAAP) (15:20)

Presenters: ALBINET, Clément (ESA), QUEUNE, Tamara (ESA)

BIOMASS is ESA's 7th Explorer Mission. It features for the first time ever a spaceborne quad polarimetric SAR at P-band. BIOMASS is a polar orbiting satellite aiming primarily at deriving forest biophysical variables essential to the understanding of the carbon cycle. In order to further support the science behind the upcoming BIOMASS satellite mission, ESA will set up a cloud-computing platform called Multi-Mission Algorithm and Analysis Platform (MAAP) currently under development. The MAAP will provide high performing computing capabilities and algorithmic resources closer to the BIOMASS data (but also other satellites, airborne and in situ data). To best ensure that users are able to collaborate across the platform and to access needed resources, the MAAP requires all data, algorithms, and software to conform to open access and open-source policies. In addition to aiding researchers, the MAAP will focus on sharing data, science algorithms and compute resources in order to foster and accelerate scientific research. During the interactive session at BioGeoSAR-2023, a demonstration of the MAAP will be provided.

<u>Forestry III: Change and Disturbances</u> (15:40 - 17:20)

-Conveners: Santoro, Maurizio (GAMMA Remote Sensing); Quegan, Shaun (University of Sheffield)

Sensitivity of SAR Tomographic Reconstructions to Forest Structure Changes (15:40)

Presenter: PARDINI, Matteo (German Aerospace Center (DLR))

Low frequency (P- or L-band) Synthetic Aperture Radar (SAR) pulses can penetrate through even dense vegetation layers until the ground, and thus interact with vegetation elements (depending on frequency, polarization and dielectric properties) located at different heights. For this, a set of SAR images acquired under slightly different angular directions along displaced tracks or orbits is required to reconstruct the 3D distribution of the backscattered power, also called reflectivity, and constitutes the measurement principle of interferometric and tomographic SAR (TomoSAR) measurements. The application of TomoSAR techniques enables the reconstruction of the 3D reflectivity [1]. Despite first general investigations [2], a systematic understanding of the potentials of TomoSAR reconstructions to reflect 3D reflectivity changes induced by changes of 3D physical structure (growth, management, logging, mortality, disturbance etc.), and their parametrization at different spatial and temporal scales are missing critical aspects. The objective of this presentation is to discuss the sensitivity of TomoSAR reconstructions to specific forest structural changes in time by means of real TomoSAR data. In this analysis, forest structure changes are first detected and characterized by analyzing the 3D distributions of fine-beam lidar returns in acquisitions performed close in time to the SAR acquisitions. Then, the appearance of the individuated changes in the available TomoSAR reconstructions is addressed not only at profile level, but also in terms of TomoSAR-derived structure indices aggregating multiple adjacent TomoSAR profiles within a cell [2]. The outcomes are expected to provide conclusions not only about the characteristics (especially in terms of spatial resolution) of TomoSAR acquisitions able to detect these types of changes, but also about ambiguities with reflectivity changes corresponding to weather/seasonal dielectric changes occurring at the same time [3]. The discussion is supported by processing multiple L-band TomoSAR and lidar data sets acquired over the forest of Traunstein (south of Germany) in a 10-year time span (2013-2023). The TomoSAR data acquisitions were carried out by means of the DLR's F-SAR airborne platform, and realized time intervals from hours up to months and years with underlying daily, weekly and seasonal dielectric-induced reflectivity changes. References: [1] A. Moreira, P. Prats-Iraola, M. Younis, G. Krieger, I. Hajnsek, K. P. Papathanassiou, “A Tutorial on Synthetic Aperture Radar," IEEE Geoscience and Remote Sensing Magazine, vol. 1, no. 1, pp. 6-43, March 2013. [2] V. Cazcarra-Bes, M. Tello-Alonso, R. Fischer, M. Heym, and K. Papathanassiou, “Monitoring of Forest Structure Dynamics by Means of L-Band SAR Tomography,” Remote Sensing, vol. 9, no. 12, p. 1229, Nov. 2017 [3] M. Pardini, K. P. Papathanassiou, F. Lombardini, “Impact of Dielectric Changes on L-Band 3-D SAR Reflectivity Profiles of Forest Volumes,” IEEE Transactions on Geoscience and Remote Sensing, vol. 56, no. 12, pp. 7324-7337, Dec. 2018.

Understanding Forest Change from P-band Polarimetric and Interferometric SAR Data (16:00)

Presenter: ROMERO-PUIG, Noelia

Understanding the changes taking place in the forest structure is key for the correct assessment of forest biomass and productivity. By exploiting polarimetric SAR acquisitions [1], different techniques have been proposed in the past to address changes [2, 3]. These techniques, however, are limited to the detection of changes in terms of radiometric information, i.e. amount of change. In [4], a polarimetric change analysis methodology which takes a step further into the interpretation of the changes between different SAR acquisitions is introduced. This methodology provides a representation of the changes based on the type of change (type of scattering mechanisms) weighted by the amount of change (increasing or decreasing radiometric intensity). From the radar point of view, forest are complex scenarios. As a result, the polarimetric change analysis [4] over forest scenes at P-band applies on a relatively high entropy scenario. This means that only with polarimetric acquisitions, many ambiguities and uncertainties arise from the superposition of dielectric, phenological and/or structural changes. A way to provide sensitivity to the vertical structure of the forest, and thus break down (some) of these ambiguities, is to incorporate interferometry. By exploiting both polarimetric and interferometric SAR (Pol-InSAR) acquisitions, the radar return from the forest canopy can be decomposed into ground and volume scattering components [5]. This allows to increase the observation space by applying the polarimetric change analysis over the two separated radar components. In this contribution, we evaluate forest change following the described Pol-InSAR methodology over different P-band datasets. To this end, data acquired by DLR's airborne F-SAR sensor in the framework of the TMPSAR campaign are used. This campaign covers several years. In particular, multi-baseline fully polarimetric P-band data are available for years 2021, 2022 and, very recently, also for 2023. The test site is located around the temperate forest of Traunstein, in the south-east of Germany. It can be divided into two main forest areas, known as Traunstein and Froschham, for which reference lidar data are available. The first results of applying the polarimetric change analysis over the separated ground and volume components have proven to be sensitive to forest structural changes. As the most recent works also corroborate [6, 7], the challenge still remains in the interpretation of the nature of such changes. The large wavelength (around 70 cm) of P-band SAR data allows the signal to penetrate into the forest canopy and reach the ground. This leads to a slightly lower entropy scenario when compared to other higher frequencies, as L-band, which makes P-band particularly suitable for the interpretation of forest changes. Different forest change scenarios will be targeted and analyzed in detail, comparing the complementary information between their polarimetric and interferometric signatures. Further results of this study will support the development of strategies to exploit data from the upcoming ESA BIOMASS mission. REFERENCES [1] S. Cloude, Polarisation: Applications in Remote Sensing.New York, NY, USA: Oxford Univ. Press, 2009. [2] K. Conradsen, A. A. Nielsen, J. Schou, and H. Skriver, “A test statistic in the complex wishart distribution and its application to change detection in polarimetric SAR data,” IEEE Trans. Geosci. Remote Sens., vol. 41, no. 1, pp. 4–19, Jan. 2003. [3] A. Marino, S. R. Cloude, and J. M. Lopez-Sanchez, “A new polarimetric change detector in radar imagery,” IEEE Trans. Geosci. Remote Sens., vol. 51, no. 5, pp. 2986–3000, May 2013. [4] A. Alonso-González, C. López-Martínez, K. P. Papathanassiou and I. Hajnsek, “Polarimetric SAR Time Series Change Analysis Over Agricultural Areas,” in IEEE Trans. Geosci. and Remote Sens., vol. 58, no. 10, pp. 7317-7330, Oct. 2020. [5] A. Alonso-Gonzalez and K. P. Papathanassiou, “Multibaseline Two Layer Model PolInSAR Ground and Volume Separation,” in EUSAR 2018; 12th European Conference on Synthetic Aperture Radar, pp. 1-5. VDE, June 2018. [6] S. Cloude, “A Physical Approach to POLSAR Time Series Change Analysis,” IEEE Geosci. Remote Sens. Letters, vol. 19, pp. 1-4, 2022. [7] A. Marino and M. Nannini, “Signal Models for Changes in Polarimetric SAR Data,” IEEE Trans, Geosci. and Remote Sens., vol. 60, pp. 1-18, 2022.

New Near Real-Time Deforestation Monitoring Technique Based on Bayesian Inference (16:20)

Presenter: BOTTANI, Marta (ISAE Supaero, TéSA, CNES)

The world's forests have undergone substantial changes in the last decades. In the tropics, 17% of moist forests disappeared between 1990 and 2019, through deforestation and forest degradation [7]. These changes contribute greatly to biodiversity loss through habitat destruction, soil erosion, terrestrial water cycle disturbances, and anthropogenic CO_2 emissions. Continuous monitoring of global deforestation is a fundamental tool to support preservation actions and to stop further destruction of vegetation. Several forest disturbance detection systems have already been developed, mainly based on space-borne optical remote sensing [4] which is severely limited by cloud coverage in the tropics. Contrarily to optical imagery, SAR products have the great potential of being insensitive to the presence of clouds. In recent years, several SAR-based systems have been developed and are now operational in different dense forest areas across the tropics [2], [3], [5], [6]. Despite the extensive coverage and temporal density of acquisitions, C-band SAR data like Sentinel-1 are not ideal for deforestation monitoring since the returned backscatter can be altered by variations in soil moisture and others. In this work, we investigate a new method to monitor forest loss in a near real-time manner exploiting the principle of Bayesian inference. In particular, forest loss is treated as a change-point detection problem within a univariate time series (i.e. Sentinel-1 single polarization), in which each new observation contributes to the prob□ability of having or not deforestation in a Bayesian-like manner [1]. Detection delay and false alarm reduction have been investigated through the extension of the algorithm to the multivariate case of dual-polarization Sentinel-1 acquisitions. Given the synchronous nature of VV, VH acquisitions, such a modification allows an increase in the equivalent number of looks on a pixel on the ground, hence augmenting the level of confidence of an issued alert. A validation campaign has been conducted to assess the performance of the method. The test sites are located in French Guiana and Brazil where deforestation takes place constantly and near real-time monitoring is fundamental for law enforcement practices. Additionally, a comparison with a well-known deforestation monitoring technique, namely Maximum Likelihood Ratio Test, has been performed to further evaluate the proposed method. Conclusively, the potential of extending the current method to asynchronous data sources such as Sentinel-2 optical data is addressed. [1] Adams and MacKay. Bayesian Online Changepoint Detection. 2007. arXiv: 0710.3742 [stat.ML]. [2] Bouvet et al. “Use of the SAR Shadowing Effect for Deforestation Detection with Sentinel-1 Time Se□ries”. In: Remote Sensing (2018). [3] Doblas et al. “DETER-R: An Operational Near-Real Time Tropical Forest Disturbance Warning System Based on Sentinel-1 Time Series Analysis”. In: Remote Sensing (2022). [4] Hansen et al. “Humid tropical forest disturbance alerts using Landsat data”. In: Environmental Research Letters (2016). [5] Mermoz et al. “Continuous Detection of Forest Loss in Vietnam, Laos, and Cambodia Using Sentinel-1 Data”. In: Remote Sensing (2021). [6] Reiche et al. “Forest disturbance alerts for the Congo Basin using Sentinel-1”. In: Environmental Re□search Letters (2021). [7] Vancutsem et al. “Long-term (1990–2019) monitoring of forest cover changes in the humid tropics”. In: Science Advances 7 (2021).

Retrieve of disturbance regime from high-resolution biomass observations (16:40)

Presenter: WANG, Siyuan (Max-Planck Institute for Biogeochemistry, Jena, Germany)

Different disturbance events lead to a varied response of terrestrial biomass, which regulates the terrestrial ecosystems' short- and long-term carbon cycle dynamics. Quantifying the disturbance regimes is essential to understanding and reducing the uncertainty of vegetation mortality and its effects on biomass. Based on the synthetic exercise, we revealed a strong link between three disturbance regime parameters, μ (probability scale), α (clustering degree), β (intensity slope), and the spatial pattern of emergent biomass. Relying on this connection, we are applying the real-world observation from a high-resolution biomass dataset, the GlobBiomass with a spatial resolution of 25 m, to infer the regional disturbance regime. We first compared the remote sensing-based and model-simulated biomass statistics, the significant difference within several statistics that played an important role in predicting disturbance regimes was identified. This mismatch would lead to model extrapolation in predicting realistic disturbance regimes. To avoid this, we carried out a series of refinement exercises, including increasing the simulation scenarios for the disturbance regime, the process of photosynthesis, the recovery rates, the shapes of the disturbance shapes, and adjusting the spatial resolution of simulation and observation. In the end, we found that the difference comes from the mismatch in spatial representation, and the aggregation process could significantly reduce these differences. We then quantify the discrepancy between observation and simulation across gradient scales in different regions of the world to determine the best degree of aggregation. Finally, the aggregated statistics from the remote sensing observations were integrated into the trained machine learning parameter inversion model at the best degree to produce the spatially continuous distribution of the three disturbance regime parameters. Given the novelty of assessing disturbance regimes with high-resolution biomass data, Our study provides insight into how to reduce the difference between model simulation and observation to avoid extrapolation, and offers opportunities to evaluate and improve the representation of disturbance dynamics in dynamic vegetation and Earth system models.

Estimate phenological metrics and identify forest disturbance from Sentinel-1 C-SAR time series (17:00)

Presenter: FILIPPONI, Federico (ISPRA)

Detection of land surface phenology at the landscape scale enables to investigate the spatio-temporal patterns of plant phenology and their relationship with environmental variability and climatic drivers. In fact, vegetation phenology is highly sensitive to climate conditions and is a climate change fingerprint. Along with the availability of high resolution satellite time series and proven methodologies to extract temporal information from satellite acquisitions, comes the need for procedures to generate high resolution Earth observation derived phenological metrics that could serve a wide range of applications, like monitor ecological status, environmental conditions, climate change impacts on ecosystems, cropland practices, and ecosystem disturbances. Forest disturbances, like logging and wildfires, determine a loss in terms of woody biomass and modify Earth carbon balance. Earth observation capacity to monitor forest disturbance and regeneration plays a fundamental role in supporting sustainable ecosystem management and surveillance. Procedures for monitoring and classifying forest disturbances using satellite Earth observation data have improved over the past years, with the development of many algorithms that exploit dense time series at high spatial resolution. Characterization of forest disturbance, like identification of event occurrence dates, represents public authorities and practitioners information needs related to altered ecosystems. Results from the applications of Sentinel-1 satellite derived high spatial resolution phenological metrics in the field of forest disturbance are here presented. The proposed procedure estimates phenological metrics using local curve fitting and local derivatives to identify phenophases, operating without thresholds or a priori information. A set of different Radar Vegetation Indices (RVI), estimated from Sentinel-1 satellites observations, has been tested to derive phenological metrics using a local smoothing procedure. Proper radiometric radiometric terrain correction allowed the synergic use of multiple relative orbit acquisitions, and the use of weighted smoothing procedure enhance vegetation indices time series integrity. A comparison with Leaf Area Index (LAI) derived phenological metrics, estimated from high spatial resolution optical satellite time series, shows strengths and weaknesses for the two source datasets. High spatial resolution smoothed time series and phenological metrics open up to the provision of novel temporal information about forest phenology anomalies, and useful monitoring system to scrutinize spatio-temporal patterns of forest disturbances, as demonstrated from a showcase of forest logging in central Italy. This study highlights the importance of integrated data and methologies to support the processes of vegetation recognition and monitoring activities. Earth observation SAR time series represent a promising tool for a wide range of applications, as monitor terrestrial ecosystems, environmental conditions, and cropland practices.

ROUND TABLE (17:20 - 18:00)

Ice breaker (18:00 - 19:00)

Thursday, 16 November 2023

Soil and Hydrology I (09:00 - 10:40)

-Conveners: Mattia, Francesco (CNR-IREA); Haarpaintner, Jörg (NORCE Climate & Environment)

Studying the effects of forest water dynamics using the BorealScat-2 tower-based multi-frequency and tomographic radar (09:00)

Presenter: ULANDER, Lars (Chalmers University of Technology)

BorealScat-2 is a new tower-based tomographic radar experiment located in a boreal forest site in northern Sweden which acquires data in the frequency bands from P- to C-band. It is of similar design as its predecessor BorealScat except that the antenna frame (P- to L-band) can be moved along a 4 m aperture. The moveable frame increases the number of independent samples, thus reducing backscatter fluctuations. It also enables focused 3D imaging by combining tomographic and SAR processing when the backscatter is temporally stable. The system was designed for exceptionally fine temporal, spatial and radiometric resolution to reveal the subtle variations due to vegetation water dynamics. Together with an extensive in-situ atmospheric and ecosystem sensor network, the experiment allows investigations of new SAR applications pertaining to the sensing of vegetation water content, vertical moisture distribution and vegetation-atmosphere fluxes. Such new remote sensing observations over sub-daily timescales are particularly needed during hot summer conditions where plants are at greatest risk of drought-induced degradation. We show that multi-temporal BorealScat-2 observations are capable of resolving the spatiotemporal variations due to changes in vegetation water status related to vegetation water content and forest-atmosphere water fluxes.

Analysing the sensitivity of Sentinel-1 SAR to water dynamics in vegetation in a combined model approach (09:20)

Presenter: KRANZ, Johanna

Changes in plant phenology as for example earlier leaf unfolding and delayed autumn senescence can result in variations in the carbon and water cycle. Studies investigating the impact of phenological shifts on biophysical processes such as water availability are still limited. Due to the sensitivity of radar satellite observations to both, structural and dielectric properties of the scattering materials, microwave remote sensing offers the potential to analyse structural (i.e. canopy biomass) and physiological (i.e. water status) dynamics in vegetation. Here, we aim to derive annual water dynamics of vegetation canopies from the Sentinel-1 C-band radar backscatter signal by removing the influence of vegetation structure on the backscatter seasonality. To decouple the phenology of vegetation structure from the moisture content dynamics, a semi-empirical backscattering model (Water Cloud Model, WCM) is combined with a canopy water balance model. The WCM aims to separate contributions of soil and vegetation to the total backscatter. When introducing physical parameters for vegetation structure like leaf area index (LAI) and moisture like leaf fresh moisture content (LFMC) to describe the vegetation backscatter, the effect of the seasonal variability of both variables on the radar signal can be assessed. The canopy water balance model estimates interception and changes in the canopy saturation and storage capacity of the vegetation using precipitation and throughfall measurements. To calibrate the two models, we use measurements of LFMC and of canopy interception for the Tharandt ecosystem site in Germany in 2022, which is part of the ICOS and FLUXNET network. The calibrated model is then used to analyse the individual effects of both vegetation descriptors, LAI and LFMC, by fixing either one and looking at the changes in the seasonality of the S1 signal. The combined use of both models will allow to remove the structural-related changes in the Sentinel-1 radar backscatter to finally retrieve vegetation water dynamics over larger areas.

Sub-daily Land Atmosphere INTEractions (SLAINTE) from sub-daily SAR (09:40)

Presenter: STEELE-DUNNE, Susan (TU Delft)

SAR is increasingly used in the fields of agriculture, forestry, soil moisture and hydrology, providing finer spatial resolution information than passive microwave remote sensing and scatterometry. However, there is an emerging demand for SAR imagery at finer temporal scales. Specifically, there is an observation gap at sub-daily scales. While SAR imagery is theoretically available from several commercial providers, the cost and limited availability limits their value for scientific applications related to sub-daily process understanding. Here, we will present some results from a ESA New Earth Observation Mission Idea study where we developed a concept based on sub-daily SAR to address scientific objectives related to vegetation water, carbon and health, agricultural water use, geo-hydrological hazard and land-precipitation feedbacks. Given the scope of BioGeoSAR, the focus in this presentation will be on the state-of-the-art in terms of suitable forward modeling and retrieval approaches and the knowledge and observation gaps that need to be filled to extend their use to sub-daily scales.

HIGH RESOLUTION MAPPING OF SOIL MOISTURE AND VEGETATION BIOMASS USING X- AND C- BAND SAR AND MACHINE LEARNING (10:00)

Presenter: SANTI, Emanuele (CNR - IFAC)

This study deals with the high-resolution mapping of soil moisture (SMC) and crop biomass (expressed as plant water content PWC) in agricultural fields by using SAR data at C and X bands. For this purpose, timeseries of Sentinel-1 (S-1, at VV and VH polarizations) and COSMO-SkyMed (CSK, StripMap Himage at HH polarization) images have been collected for some years in an agricultural area located in Tuscany (Central Italy), mainly covered by wheat, corn, sorghum, sunflower, pastures, and vineyards. CSK images have been kindly provided by the Italian Space Agency (ASI) in the framework of scientific projects and Open Calls, whereas S-1 and S-2 data have been downloaded from Copernicus system. In situ measurements of the main soil and vegetation parameters, including PWC, SMC and soil roughness, have been collected in correspondence of each satellite overpass to provide the reference data. The backscattering (□°) dependence on SMC and PWC was firstly investigated at both frequencies. The sensitivity analysis confirmed the better sensitivity of X- than C- band to PWC of agricultural fields, by pointing out the well-known dependence on crop type. In detail, crops characterized by large leaves and thick stems (broad leaf crops) cause an increasing of backscattering as the plants grow and the biomass increases; whereas crops characterized by narrow leaves and thin and dense stems (narrow leaf crops) cause a decreasing trend of backscattering during the growth phase [1]. Conversely, the analysis of □° as a function of SMC confirmed that C- is more sensitive to SMC than X- band, being the latter more influenced by the vegetation effects. Based on these results, a method for estimating SMC and PWC at high resolution based on S-1, CSK, and machine learning (ML) has been developed. The method articulated in three steps: as first, a fully supervised crop classification based on CSK data and deep learning has been implemented to separate broad- and narrow-leaf crops. The classifier has been trained with ground data gathered during the measurement campaigns [2]. In the second step, SMC maps at high resolution have been generated by using the Artificial Neural Networks (ANN) based approach proposed in [3], which exploits the S-1 images for disaggregating low resolution SMC product generated from AMSR2 radiometer by the IFAC's HydroAlgo algorithm [4]. In the third step, the CSK images are used as input of the PWC retrieval algorithm together with the maps of classified crops and SMC. The PWC algorithm is based on ANN as well: to generate a dataset sufficient for training, the experimental measurements have been merged with data simulated by a forward electromagnetic model obtained by coupling the Water Cloud Model (WCM – [5]) with the Advanced Integral Equation Model (AIEM – [6]). The obtained results were almost encouraging: the validation of SMC algorithm carried out against in-situ measurements resulted in correlation coefficient (R)= 0.74 and Root Mean Square Error (RMSE)=0.034 m3/m3 when using S-1 only and R= 0.89 and RMSE =0.025 m3/m3 when exploiting the S-1 and CSK synergy. The validation for PWC algorithm was carried out independently for each crop type: for example, it reached R=0.92 and RMSE =0.58 kg/m2 for the wheat crops. The prosecution of this research will aim at extending spatially and temporally the investigations, by including other crops and seasons and the intercomparison of other ML approaches, as random forest (RF) and Support Vector Regressor (SVR). REFERENCES [1] S. Paloscia, E. Santi, G. Fontanelli, F. Montomoli, M. Brogioni, G. Macelloni, P. Pampaloni, S. 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High spatio-temporal soil moisture retrieval over agricultural fields using a microwave radiative transfer model framework (10:20)

Presenter: WEISS, Thomas (Fraunhofer Institute for Computer Graphics Research (IGD))

Soil moisture plays a key role in land surface processes such as water, carbon and energy fluxes. SAR satellites, like Sentinel-1, have proven to be particularly useful to derive high spatio-temporal soil moisture estimates. Thus, microwave radiative transfer models are often used to derive soil moisture estimates from SAR satellites. But, as the derivation of soil moisture, especially over vegetated agricultural areas, is complicated, additional information about the vegetation state is usually required. Luckily, information about the vegetation can be derived by optical satellites like Sentinel-2. Other challenges in the retrieval process of high spatial (field scale) soil moisture patterns are the correct estimation in terms of absolute values and reproducing the temporal dynamics. Thus, existing medium resolution (1km x 1km) soil moisture products can be used as a priori information to enhance the quality of high spatio-temporal soil moisture estimates. This study presents a data assimilation approach to downscale a medium resolution (1km x 1km) soil moisture product (RADOLAN API) to field scale (max. 10m x 10m). Within the data assimilation scheme, a radiative transfer model framework (Oh04 + SSRT) is run by data from Sentinel-1 and Sentinel-2 and constraint by the medium resolution soil moisture product (prior information). Thus, in the end soil moisture estimates at field scale (10m-100m) can be retrieved. The retrieval approach is validated with in-situ data acquired at the Munich-North-Isar (MNI) test site (southern Germany, Bavaria) during the vegetation periods of 2017 and 2018.

Comfort break (10:40 - 11:00)

General Land Applications (11:00 - 12:00)

-Conveners: Romero-Puig, Noelia (German Aerospace Center (DLR)); Rizzoli, Paola (DLR)

Soil texture prediction using optical and radar remote sensing data in a random forest approach (11:00)

Presenter: MEYER, Swen (University of Rostock, Geodesy and Geoinformatics)

The application of precision agriculture (PA) helps reduce ecosystem damage from agricultural emissions without compromising food security. One problem farmers face in implementing PA applications is the lack of high spatial resolution soil information. For this study, the research project "pH-BB: Precision Liming in Brandenburg" provided data from 1091 soil samples collected and analyzed in the laboratory for clay (C), silt (U), and sand (S) textures from 3 farms in Brandenburg, Germany. Google Earth Engine was used to process earth observation data (EO) from 415 Sentinel-1 (S1) SAR scenes of one orbit and 41 cloud-free Sentinel-2 (S2) scenes that fully covered the study areas from March 01, 2016 - December 14, 2022. Vegetation and ground indices were calculated using the S2 optical data; radar backscatter in VV and VH polarization was extracted from the S1 data. Long-term patterns in the EO data were identified using statistical parameters (coefficient of variation, standard deviation, mean and maximum pixel values) along the temporal axis. Together with the calculated terrain attributes, 61 covariate grids were finally available for model building. The reference samples (RS) were randomly divided into a training dataset (70%,) and a validation dataset (30%). A random forest machine learning algorithm was used to train two individual models for the alr-transformed target variables C and U. The developed models were then applied to the grids of covariates to predict the alr-transformed target variables. The final maps (2053 km2 at 10*10m resolution) for all 3 texture fractions were calculated by back transformation. In the derived models, the EO data had the greatest importance. In the validation, the spatial distribution of the C, U, and S fractions could be predicted with an RMSE of 6.8, 7.2, and 11.3 mass %, respectively. Errors were lower in the sand-dominated soil classes, while they increased in the clay-dominated soil classes. With a mean error of 7-11 mass-%, the approach shows good potential for evaluating topsoil texture of agricultural land at high spatial resolution (10m), for global applications or as preliminary information for high-resolution soil geophysical mapping.

Sentinel-1 time-series to detect alluvial small-scale gold mining in the Dem. Rep. Congo (11:20)

Presenter: HAARPAINTNER, Jörg (NORCE Climate & Environment)

Mineral extraction is an important part of the economy in the Democratic Republic of Congo (DRC). Artisanal and small-scale alluvial gold mining has been a source of livelihood, but as it is mostly operated informally, it is also a driver of illicit activities, child labor, conflict financing, human abuse and of course environmental degradation like water contamination, deforestation and erosion. As part of its cooperation with the DRC, the German Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)) therefore wishes to improve the control and monitoring of mining activities in DRC. One approach for better monitoring in cloud persistent regions is the use of satellite synthetic aperture radar, i.e. Sentinel1 CSAR data from the European Copernicus program. In this study, a 30x30 km2 region north of the town Bunia in the Ituri Province in DRC has been monitored using the whole Sentinel-1 time-series from 2017 to 2022. Alluvial gold mining practice comes with clearing of vegetation and deforestation, excavating soil and washing the soil which causes flooding of the area and the development of water pools. This results in a strong reduction in radar backscatter, specifically in VH polarization. VH backscatter γ°(VH) is a function of volume scattering which reflects mainly the vegetation. VH backscatter is high over forest, very low over bare soil and even lower over water. New developed alluvial gold mining areas can therefore be detected by thresholding the difference in backscatter Δγ°(VH) between two time periods t0 and t1. Instead of using single day scenes, speckle noise was reduced by producing quarter-yearly averaged mosaics of the whole time series, resulting in a time series of gold mining detection on a three-month basis from 2018-2022. The time series are then compared to very high resolution Planet Labs time series and validated with a set of 31 ground observations. Varying the threshold of the VH backscatter decrease between 3dB and 5 dB shows that lower thresholds lead to an earlier detection as they already detect the first process of vegetation loss whereas higher threshold mainly detect the newly formed water pools at a later stage of gold mining activities, though with less false detections. The optimal choice of parameters (time interval, integration time, and threshold) is relevant for the overall purpose of the monitoring, e.g. near-real time detection, manual selection of sites to visit by authorities, overall estimation of disturbed forest. Figure 1 shows an example of quarterly alluvial gold mining detection from the first quarter (Jan-Mar) 2018 to the last quarter (Oct-Dec) of 2022 using the mean 2017mosaic as reference.

Monitoring Soil Dynamics in the Netherlands Using Sentinel-1 Distributed Scatterer InSAR (11:40)

Presenter: CONROY, Philip (TU Delft)

See attached pdf for version with figs and equations **Introduction and Motivation** Land subsidence in the coastal peatlands of The Netherlands is becoming an increasingly critical issue as it is closely linked with sea level rise, flooding risks and greenhouse gas emissions due to soil oxidation [1,2]. Despite the importance of this problem, it is very difficult to accurately assess subsidence levels across the country. While InSAR techniques employing stable point scatterers (PS) have been successfully used to monitor subsidence in the Netherlands [3,4,5], these PS points are usually founded at greater depths, and are not representative of the motion of the neighbouring terrain. Several papers presented at Fringe 2023 [6,7] advocated for the complete ignoration of DS information and to simply interpolate PS data over a given AOI. While this approach may work to monitor tectonic or other

deep-seated deformation phenomena, it is not appropriate for measuring and characterizing shallow-based soil-related processes such as land-groundwater interactions and soil oxidation. Attempts to directly monitor the dynamics of peatland soils surface with distributed scatterer (DS) techniques have encountered significant challenges, the most significant of which is the seasonal loss of interferometric coherence every spring, which results in a discontinuous phase time series. Fig. 1 illustrates the problem of seasonal coherence loss. Sufficiently coherent interferometric combinations can be made between epochs in the autumn and winter seasons (indicated by the dashed red boxes), allowing time series analysis to be carried out. However, for several months every spring and summer, the observed interferometric coherence is so low that no useful information is likely to be present in any interferogram made with an acquisition during this period. A further complication is the fact that there are no coherent combinations which can be made between the two individual coherent periods (the NE upper-right and lower-leftSW regions of the matrix in Fig. 1), which implies that the two coherent periods are disconnected. We denote this phenomenon with the term loss-of-lock [8]. The disconnect between the two coherent periods means that the gap between them is no longer constrained by integer ambiguities; there exists an unknown real-valued shift between the periods which must be resolved in order to obtain a single, consistent time series. This shift represents the unknown and unmeasurable displacement history that occurred during the incoherent periods. **Methodology** We postulate that neighbouring parcels with matching land use, land cover, soil type, and groundwater management can be expected to behave in a similar manner, such that we can bridge the incoherent data gap described in Section 1 by combining the coherent observations of several similarly behaving regions to estimate a single set of common displacement model parameters. This model can then be used to estimate the vertical shifts between the time series segments according to the relation $\phi(t)=(-4\pi \cos\theta)/\lambda\cdot[M(x,t)+\Delta z]+\epsilon$. By taking the difference in time between phases, $\Delta\phi(t)$, the shift term Δz drops out and the model parameters of x can be estimated directly. The shift for a given coherent observation can subsequently be estimated by taking the average difference between the model and the phase time series over the coherent period. In this abstract, we show the results of an empirical hydrological model based on precipitation and evapotranspiration [9]. **Results** The methodology is tested in an area of interest around Zegveld, NL, shown in Fig. 2. This area is chosen due to the large peat deposits in the area, and the availability of in-situ validation data. Validation data is provided by extensometer measurements which provide a continuous time series of soil height measurements at one location [10]. The root mean squared error (RMSE) is evaluated between the group median result for the period of overlap (May 2020 - Jan. 2022), giving an RMSE of 6.7 mm. It should be noted that we do not expect these two measurements to match exactly, as the InSAR result is the median of a large spatial extent, while the extensometer data is from a single point. **Conclusion** We demonstrate a new methodology for estimating the ground motion of cultivated peatlands using DS time series InSAR. We show how discontinuities in a decorrelated time series can be bridged by considering the measurements of nearby similarly behaving regions. Our initial results show that the approach is promising, and we have been able to successfully validate our result against the ground truth data we have available with a low degree of error. To our knowledge, this is first accurate multi-year InSAR measurement of peatland surface motion in the Netherlands. **Acknowledgement** This research is part of the Living on Soft Soils (LOSS): Subsidence and Society project, and is supported by the Dutch Research Council (NWO-NWA-ORC), grant no.: NWA.1160.18.259, URL: nwa-loss.nl.
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Lunch break (12:00 - 13:40)

Soil and Hydrology II (13:40 - 15:00)

-Conveners: Santi, Emanuele (CNR - IFAC); Ulander, Lars (Chalmers University of Technology)

Model-based Tensor Decompositions for Bio- and Geophysical Parameter Retrieval (13:40)

Presenter: BASARGIN, Nikita (DLR & TUM)

The increasing availability of multidimensional SAR data motivates the development of new techniques for analysis, decomposition, and joint information extraction. In this work, we explore the integration of physical polarimetric models into tensor decompositions to estimate geophysical parameters like soil moisture. In vegetated areas, SAR backscatter signal contains both the information about the ground and the vegetation due to the penetration into the media. Therefore, to accurately estimate the soil parameters, the methods should take into account the vegetation backscatter. Polarimetric physical models approximate the signal with a sum of different components that describe both the ground and the vegetation contributions [1]. In order to avoid ambiguous model inversion, the total number of model parameters is limited by the number of observables. Current approaches typically use physical models with a small number of parameters. This can result in cases where the model is not able to accurately describe the data or has a small validity range. Moving towards the inversion of more complex models, we propose to enlarge the observation space by integrating and jointly processing additional data dimensions such as spatial, temporal or polarimetric information. We introduce model-based tensor decompositions that directly operate on data tensors representing them as a sum of model-based tensor components. The larger observation space combined with sharing of certain parameters along the new data dimensions allows to use more complex and accurate models. To illustrate the approach, we present a method to estimate soil moisture from a combination of polarimetric and spatial data, represented as a three-dimensional tensor. Given a small spatial image patch with several independent polarimetric coherency matrices in every pixel, we assume a constant soil moisture across the patch, while letting other parameters like vegetation backscatter intensity vary from pixel to pixel. The model inversion is formulated as an optimization problem. We use the physical model to reconstruct an approximation tensor from the physical parameters and iteratively minimize the distance between the approximation and the measured data. After convergence, the algorithm provides the physical parameters that fit the data best. Since the model is a differentiable mathematical function, minimization is performed with an optimizer based on gradient descent. The algorithm is implemented in PyTorch taking advantage of automatic differentiation and advanced optimizers. We evaluate the proposed method on high-resolution airborne F-SAR data obtained by DLR over agricultural areas during the HTERRA 2022 campaign in the province of Foggia, Italy. The decomposition provides a characterization of the dominant scattering mechanism for each resolution cell. In addition, soil moisture estimation at a 12 meter resolution is obtained. The larger observation space and the use of the more accurate model allow the inversion in more regions than compared to a simpler X-Bragg model. References [1] I. Hajnsek, T. Jagdhuber, H. Schon, and K. P. Papathanassiou, “Potential of estimating soil moisture under vegetation cover by means of PolSAR,” IEEE Transactions on Geoscience and Remote Sensing, vol. 47, no. 2, pp. 442–454, 2009.

Extraction of different scattering mechanisms for soil moisture retrieval over agricultural fields (14:00)

Presenter: PAPALE, Lorenzo Giuliano (Tor Vergata University of Rome)

Soil moisture is a critical parameter when agricultural practices, such as irrigation management, are involved and in 2010 it has been included among the Essential Climate Variable (ECV). Synthetic Aperture Radar (SAR) data allow estimating soil moisture based on high temporal frequency and accuracy. Unfortunately, radar data are not only sensitive to the dielectric properties of the soil, i.e. soil moisture content, but also to other parameters such as surface roughness and vegetation (i.e., growth stage, plant height, vegetation water content, etc.). During the years, SAR polarimetry has offered an important framework for soil moisture retrieval [1], [2], [3]. In particular, the use of a polarimetric SAR decomposition could help to separate the effects introduced by the vegetation from the ones related to the soil by extracting different scattering contributions: surface; double-bounce, coming from the interaction between the soil and the vertical structure of the plants; volume, related to the canopy. The objectives of this analysis are: 1) to analyze which scattering mechanisms is mostly correlated to soil moisture variations or changes in vegetation in view of a future integration within a soil moisture retrieval algorithm; 2) to compare the scattering contributions derived from the application of different polarimetric decompositions with the ones obtained from the fully polarimetric model developed at Tor Vergata University [3], offering the possibility to tune the polarimetric decompositions with the model; 3) to apply the polarimetric decomposition approach to a time-series of simulated covariance/coherency matrices (C3/T3) obtained from the Tor Vergata model and evaluate if the scattered power from the decompositions is correctly assigned to the proper scattering mechanisms. These objectives will be accomplished by applying different polarimetric SAR decompositions, such as the well-known Freeman-Durden 3-components decomposition [4], to a time-series of L-band full-polarimetric SAOCOM-1A data collected over five agricultural fields (i.e., corn fields) located in the Monte Buey area (Córdoba Province, Argentina) between October 2019 and February 2020. The temporal evolution of the backscattering coefficients at different polarizations and the scattered powers associated with the scattering contributions extracted from the polarimetric decompositions are evaluated with respect to both in-situ and satellite-derived parameters. The results obtained by applying the polarimetric decompositions will be compared with the ones obtained by the application of the Tor Vergata electromagnetic model, which is able to simulate the radar backscatter along with the three different contributions (surface, double-bounce, and volume) by using the in-situ data as training dataset. Finally, the polarimetric decompositions are applied to a time-series of simulated covariance/coherency matrices obtained from the Tor Vergata model in order to evaluate and compare the results in terms of scattering mechanisms. We recall that the main objective of this analysis is to assess the capability of separating the scattering contributions that are mostly correlated with the soil moisture variations from those influenced by the vegetation, and integrate them within a future soil moisture retrieval scheme. **Keywords**: electromagnetic modeling, Synthetic Aperture Radar, SAR polarimetry, L-band, SAOCOM-1A, soil moisture, vegetation, agriculture. **Acknowledgments** This work has been supported by the Italian Space Agency (ASI) in the framework of the Clexidra project. **References** [1] I. Hajnsek, T. Jagdhuber, H. Schon and K. P. Papathanassiou, “Potential of Estimating Soil Moisture Under Vegetation Cover by Means of PolSAR,” IEEE Trans. Geosci. Remote Sens., vol. 47, no. 2, pp. 442-454, Feb. 2009. [2] H. Wang, R. Magagi, K. Goita, T. Jagdhuber, I. Hajnsek, “Evaluation of Simplified Polarimetric Decomposition for Soil Moisture Retrieval over Vegetated Agricultural Fields,” Remote Sens. 2016, 8, 142. [3] H. Shi, L. Zhao, J. Yang, J. M. Lopez-Sanchez, J. Zhao, W. Sun, L. Shi, P. Li, “Soil moisture retrieval over agricultural fields from L-band multi-incidence and multitemporal PolSAR observations using polarimetric decomposition techniques,” Remote Sens. Env., vol. 261, 2021. [4] M. Bracaglia, P. Ferrazzoli, and L. Guerriero, “A fully polarimetric multiple scattering model for crops,” Remote Sens. Env., vol. 54,

no. 3, pp. 170-179, 1995. [5] A. Freeman and S. L. Durden, "A three-component scattering model for polarimetric SAR data," IEEE Trans. Geosci. Remote Sens., vol. 36, no. 3, pp. 963-973, May 1998.

A comprehensive approach for Enhancing Sub-Surface Soil Moisture Assessment from SAR Quad-Pol Datasets in the San Francisco Area, California. (14:20)

Presenter: RANA, Divyeshkumar (Sapienza University of Rome)

Accurate soil moisture determination over a region enhances our understanding of the hydrological processes, climate interaction and ecosystem dynamics. Timely soil moisture information can support sustainable agriculture, land and water management, urban planning and contributes to disaster preparedness such as floods and landslides. Synthetic Aperture Radar (SAR) data, particularly in different bands and frequencies, have proven highly effective in determining and classifying soil moisture in various geological and geographical scenarios. While single and dual-polarimetric SAR data have been widely used for assessing and monitoring soil moisture, dual polarimetric analysis faces challenges in accurately accounting for vegetation and soil roughness-induced depolarisation. Additionally, the lack of proper approaches for fully polarimetric data utilisation further limits our capabilities in this aspect. This research proposes an extensive approach to leverage dual-frequency SAR Quad-Pol datasets for assessing sub-surface moisture content. We present a case study in the San Francisco area to generate a fine-resolution moisture map. Moreover, we statistically compare the moisture content derived from L-Band (λ = 23 cm) and C-Band (λ = 6 cm) datasets. The current analysis utilises polarimetric parameters and incoherent decomposition through a model-based technique using PolSAR-Pro Software. Our findings reveal that soil moisture estimation in ALOS-2 (L-Band Data) is nearly double that of Radarsat-2 and Geofen-3 (C-Band Datasets) due to the greater penetration depth of L-Band. The proposed approach and comparative results hold the potential to yield valuable insights for determining precise sub-surface soil moisture assessment.

Daily Monitoring of the May 2023 Emilia-Romagna Flood Using COSMO-SkyMed data (14:40)

Presenter: PULVIRENTI, Luca (CIMA Research Foundation)

In May 2023 the northern Italian region of Emilia-Romagna was hit by a series of floods. The first one occurred on 2-3 May after several months of drought. More severe floods hit Emilia-Romagna starting from 16–17 May 2023. During the latter event, more than 20 rivers burst their banks, about 15 people were killed, thousands people were displaced, and public transportation was stopped. A daily monitoring of the flood, starting from 16 May 2023, was requested by the Italian Department of Civil Protection (DPC). Synthetic Aperture Radar (SAR) systems are particularly useful for flood mapping because of the synoptic view and the capability to provide data both day and night and in any meteorological conditions. Moreover, calm water is easily detected in SAR images because it has a distinguishable radar signature characterized by a low radar return. However the majority of SAR systems has a revisit time that does not comply with a daily monitoring. Moreover, a complete monitoring of the Emilia-Romagna flood required to observe different areas on the same day, especially during the first days of the flood. It was therefore necessary to rely on a SAR system offering both an on demand capability and the possibility to simultaneously observe different areas. The COSMO-SkyMed (CSK) constellation, hosting an X-band SAR, can operate as an on-demand system to ensure a timely provision of data. Presently, also the COSMO-SkyMed Second Generation (CSG) is deployed. It provides service continuity for the first generation while improving performance, functionality, and system services for the user community. The satellite daily monitoring of the Emilia-Romagna flood was performed in the period 17 May – 3 July 2023 using data provided from both CSK and CSG. The activity included: 1) the tasking of the satellite (at least 36 h before the acquisition time) to observe the areas mostly affected by the flood according to the information daily gathered by DPC; 2) the calibration and the geocoding of the SAR data; 3) the generation of the flood maps. To generate the flood maps, a change detection algorithm was applied. Note that only for a subset of the images of the flood it was possible to find in the archive a pre-event image acquired with the same geometry (interferometric pair). To apply change detection for the other post-event images too, a set of pre-flood images covering whole area hit by the flood was gathered. Among these images the most suitable one was selected based on the orbit (ascending or descending), the overlap with the considered post-event image, and the incidence angle. The main outcomes of the satellite monitoring of the Email-Romagna flood will be presented at the conference.

Comfort break (15:00 - 15:20)

Agriculture (15:20 - 17:20)

-Conveners: Pulvirenti, Luca (CIMA Research Foundation); Steele-Dunne, Susan (TU Delft)

InSAR Closure Phases over South Spain Agricultural Areas: Observations and Modelling (15:20)

Presenter: YUAN, Yan

A recent study demonstrates that closure phases (Φ_{123}), constructed by a circular summation of three interferometric phases, have a geophysical component [1]. Constructing closure phases with consecutive 6-day Sentinel-1 acquisitions that are interferometrically multilooked, we observed consistent positive annual mean closure phases in South Spain agricultural areas. Taking corn fields area as an example, Figure 1 shows area-averaged time series of radar observables with precipitation data and

Sentinel-3 Leaf Area Index (LAI) products. The observed closure phases exhibit consistently positive magnitudes during vegetation development, and the evolution of such positive closure phases appear to be related to the phenological stages of plants. In existing literature, De Zan et al. developed two analytical expressions to model closure phases. One is a dielectric model which considers soil moisture variation induced closure phase, another model accounts for volume scattering in combination with perpendicular baselines[1,2,3]. Modeled closure phases with these known mechanisms show fluctuations in sign and no correlation with the evolution of vegetation development. Therefore, the observed consistently positive closure phases suggest the existence of additional mechanisms. We try to interpret observed closure phases by proposing two conceptual models that consider vegetation development. Firstly, taking the dielectric variation within plant canopy into consideration and describing the canopy with the dielectric constant of an equivalent medium, we developed a conceptual dielectric closure phase model as an analogy to the preliminary soil moisture model. Secondly, since neither of known mechanisms accounts for the vertical motion of plants, we proposed a skewed motion model considering the line-of-sight (LoS) motion of the scatterers within the vegetation canopy with a skewed velocity distribution. Both of our conceptual models could explain the magnitudes and the consistently positive sign of the observed closure phases. Our research shows plant growth related positive closure phases with real data examples. Both our conceptual models manage to produce plausible positive closure phases. This study provides further insight into the origins of geophysical closure phases. Thus, it sheds light on a new opportunity to monitor crop-growth with radar satellites.

UNDERSTANDING THE IMPACT OF PLANT ROW ORIENTATION ON SENTINEL-1 BACKSCATTER TIME-SERIES OF AGRICULTURAL FIELDS (15:40)

Presenter: ARSLANOVA, Linara (Friedrich-Schiller University of Jena)

The number of applications using SAR backscatter time series for crop production and monitoring has increased in recent years, and understanding of the radar signal’s interaction with different crop types in experimental and theoretical studies has improved. However, there is still a lack of information concerning different parameters, such as row orientation, especially for Sentinel-1. The early studies from ERS-1 [1, 2], Radarsat-2 [3], and portable scatterometers [4, 5] have proven the impact of row orientation in backscatter time-series analysis. It has been reported that the backscatter is higher when the SAR signal targets row orientation perpendicular and lower when targets parallel (σ0 of θ90° > σ0 of θ0°). Moreover, according to the experiment of Ulaby et al. in 1976 [5] with multifrequency scatterometers, the look direction dependence was observed in fields of wheat, soybeans, and corn for frequencies below 4.25 GHz for co-polarized (hh, vv, up to Δ=6dB) and not present for cross-polarized at all frequencies even as low as 1 GHz [5]. On the other hand, Auquière et al. [2] reported backscatter (σ0) change for ERS-1 (5.3 GHz, Δ=3dB) due to row orientation (on 33 corn fields). In our study, we also observed the trend for backscatter (γ0) retrieved from Sentinel-1 (5.405 GHz) in three study areas (39 fields) and four crop types (rapeseed, winter wheat, spring barley, and corn), which we attribute to the impact due to row orientation. However, the results in our work are slightly divergent from other works listed above: apart from that the trend being present for co-polarized (vv) backscatter, the trend was also observed for rapeseed in cross-polarized (vh) backscatter. The results suggest that the attenuation on crop stems occurs at θ90°(/θ0°) and θ[30/60°±10]. look directions. We hypothesize that the maximum of attenuation occurs at 30°(/60°) of the look direction (when the maximum exposure of the number of stems is directed toward the sensor) and less attenuation at 0° of the look direction (parallel to row orientation) in compare to 90° (perpendicular to row orientation) of look direction (0° < 90° < [30/60°±10]). In other words, it is related to the different distances between plant rows in orthogonal and perpendicular directions and the width of the crop steam. According to Ulaby et al. in 1976 [5] experiment, the dependence on row orientation is coupled with incidence angle, the influence of which is being explored at the moment. The in-situ data was not available to verify the results; however, the trend was observed in three study areas and, therefore, considered valid. In this talk, we will give a detailed description of the method used to generate results and discuss our interpretation and possible factors underlying this effect. This study is funded by the German Federal Ministry for Economic Affairs and Energy (FKZ: 50EE1901) to develop an application for crop monitoring based on Sentinel-1 data and is carried out in collaboration with CLAAS E-Systems GmbH. REFERENCES [1] Wegmüller U; Santoro M; Mattia F; Balenzano A; Satalino G; Marzahn P; Fischer G; Ludwig R; Floury N. (2011): Progress in the understanding of narrow directional microwave scattering of agricultural fields. Remote Sensing of Environment. 115(10):2423–2433. doi:10.1016/j.rse.2011.04.026. [2] Auquière E.; Defourny P.; Baltazart V.; Guissart A. (1997): ERS SAR time series analysis for maize monitoring using experimental and modeling approaches. In Proceedings of the ESA ERS Conference, Florence, Italy, 5 March 1997; pp. 147–152. [3] Moran MS; Alonso L; Moreno JF; Cendrero Mateo MP; La Cruz DF de, Montoro A. (2012): A RADARSAT□2 Quad□Polarized Time Series for Monitoring Crop and Soil Conditions in Barrax, Spain. IEEE Trans. Geosci. Remote Sensing. 50(4):1057–1070. doi:10.1109/TGRS.2011.2166080. [4] McNairn H; Duguay C; Boisvert J; Huffman E; Brisco B. (2001): Defining the Sensitivity of Multi□Frequency and Multi□Polarized Radar Backscatter to Post□Harvest Crop Residue. Canadian Journal of Remote Sensing. 27(3):247–263. doi:10.1080/07038992.2001.10854941. [5] Ulaby, Fawwaz T.; Long, David G.; Blackwell, William J.; Elachi, Charles; Fung, Adrian K.; Ruf, Chris et al. (2014): Microwave radar and radiometric remote sensing. Ann Arbor: The University of Michigan Press.

Polarimetric Decomposition Using A Physics-Based ML Approach: A Sensitivity Analysis For Soil Moisture Retrieval (16:00)

Presenter: PAPALE, Lorenzo Giuliano (Tor Vergata University of Rome)

The agricultural asset is facing a transition towards an increasingly sustainable resources management. In this context, soil moisture represents a key geophysical variable for many precision farming applications such as smart irrigation and crop yield estimation. Synthetic Aperture Radar (SAR) has been demonstrated to be one of the most valuable sources of information for accurate and continuative estimation of soil moisture with high spatial and temporal resolutions in almost any weather conditions. However, when observing the soil in agricultural areas, the developing vegetation cover causes additional signal attenuation and scattering mechanisms, leading to less accurate soil moisture retrievals. Artificial Neural Networks (ANNs) have been demonstrated to be an important instrument for Earth Observation (EO) applications designed to retrieve information from Remote Sensing (RS) data. In general, when using AI for geophysical parameters estimation, there is a risk that the physical meaning behind the ANN mapping criteria becomes challenging to understand. Nevertheless, if properly trained, AI algorithms can reproduce the physics associated with the phenomenon we are observing, as shown in our previous work [2]. This study aims to synergically adopt electromagnetic data modelling and a Machine Learning (ML) algorithm to separate the different scattering contributions (i.e., volume, surface and double bounce scattering). More in detail, the component associated with the vegetation cover (volume scattering) is neglected so that only the surface and double bounce scattering can be used for more effective soil moisture retrieval algorithms. For this purpose, the “Tor Vergata” electromagnetic model developed by Bracaglia et al. [3] was adopted to generate a set of simulated Mueller matrices at L-band associated to the backscatter components which address the different canonical scattering mechanisms for VV, HH and HV polarizations. The simulated data were generated considering different values of vegetation- and soil-related variables (plant height and soil moisture/roughness) while setting the sensor configuration variables such as frequency and incidence angle [2]. Moreover, to motivate the choice of isolating and using the soil backscatter for soil moisture estimation, a preliminary analysis on the sensitivity of simulated total backscatter and the soil-related components to soil moisture was performed. As a first result, it is possible to observe that the total backscatter is less sensitive to soil moisture variations if compared to the soil related components. Besides, the Pearson correlation coefficient is higher when the soil backscatter component is considered. Then, the simulated dataset was used to train a properly designed ANN model taking as input the elements of the Mueller matrix and using the backscatter soil-related components (soil and double bounce scattering) in the selected polarizations as targets. In order to assess the performances of the proposed methodology, the ESA BelSAR2018 dataset, providing full-polarimetric SAR data at L-band, acquired with aerial surveys and in-situ soil moisture measurements, is considered to derive the correlation between the soil moisture itself and the soil-related backscatter estimated by the trained ANN model. Moreover, the sensitivity of those components to the soil moisture will be compared with the sensitivity shown by applying the canonical polarimetric decompositions (e.g., Freeman Durden [4], Generalized Freeman Durden [5], Pauli [6], Yamaguchi [7]). In this regard, it will be shown how the proposed approach can help in estimating soil moisture by mitigating the vegetation effect, demonstrating that the isolated soil-related backscatter components retrieved by the ANN are more sensitive to soil moisture if compared to the total received signal. **Keywords**: electromagnetic modeling, Machine Learning, Synthetic Aperture Radar, SAR polarimetry, L-band, soil moisture, vegetation, agriculture. **Acknowledgments** We would like to thank the ESA BelSAR2018-Campaign (https://doi.org/10.5270/ESA-bccf2d9) team for the collection of the SAR and on-field datasets used in this work. **References** [1] Xing, M.; Chen, L.; Wang, J.; Shang, J.; Huang, X. Soil Moisture Retrieval Using SAR Backscattering Ratio Method during the Crop Growing Season. Remote Sens. 2022, 14, 3210. [2] L. G. Papale, F. Del Frate, L. Guerriero and G. 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Modelling Biophysical Parameters of Alpine Grassland from Sentinel-1 SAR and Sentinel-2 Data using Spatial Gap-filling (16:20)

Presenter: GÖHNER, Caroline (Eurac Research, Institute for Earth Observation, 39100 Bolzano, Italy)

As part of the Grassland Research and Innovation Lab within the Horizon Europe project ScaleAgData (https://scaleagdata.eu/en), we assess the potential of Sentinel-1 (S1) SAR data to enrich the time series of grassland biophysical parameters derived from Sentinel-2 (S2) optical data in South Tyrol and Trentino, in North-Eastern Italy. Many studies have demonstrated the potential of SAR data in accurately estimating biophysical parameters of crops. However, over grasslands, there are fewer applications because of the difficulties in disentangling the different effects that influence the SAR signal, including vegetation composition, soil moisture, and terrain roughness. Further research is needed to optimize the estimation of grassland biophysical parameters from SAR data, including Leaf Area Index (LAI) and above-ground biomass, thus enhancing its usability for grassland monitoring and management. In contrast to the optical S2 data, S1 SAR is independent of the frequent cloud coverage in the Alps. By penetrating the grass canopy and by its dual-polarisation mode it provides useful information about vegetation structure, biomass, and moisture content. The acquisition in both descending and ascending orbits by the constellation (2016-2021) provides the high temporal resolution needed especially for managed meadows, where mowing leads to rapid changes in biomass content. These advantages make S1 SAR imagery promising for data fusion with S2-based LAI maps. Still, the topographic effects of the Alps must be corrected as they lead to foreshortening and layover which causes gaps with no data coverage. In this study we exploit different machine learning regressors to estimate LAI from S1 data, utilizing S2 LAI derived by the S2 SNAP biophysical processor as the target variable, and day of the year (DOY), soil moisture data, and various features derived from S1 SAR backscattering as predictors. Different indices and polarisations as well as descending versus ascending mode are examined. We cluster the meadows in the Alps by altitudinal zones and assess the performance of non-linear regressors, such as Random Forest (RF) and Gaussian Process Regressor (GPR) across these zones. Preliminary results show that for both regressors especially DOY, combinations of VV and VH polarisation and soil moisture lead to highly accurate predictions on a test set ($R^2 = 0.91$, RMSE = 0.29 for RF, $R^2 = 0.83$, RMSE = 0.4 for GPR). In addition to the modelling experiments, we collect ground-derived key biophysical parameters, including LAI, above-ground biomass, vegetation composition, and soil moisture at eight forage production meadows over South Tyrol and Trentino during the growing season in 2023. This data will be used to validate the LAI product obtained from the S1-S2 data fusion and to derive a model to estimate grassland above-ground biomass from the gap-filled LAI. Finally, these estimations will serve to improve a drought index that Eurac Research has developed to estimate mountain grassland yield losses due to drought conditions for insurance purposes.

Case studies on the retrieval and classification of agricultural parameters (16:40)

Presenter: MATTIA, Francesco (CNR-IREA)

To promote the efficient and fruitful use of water, land, and energy in sustainable agriculture, knowledge and sophisticated management are required. Earth observation (EO) products with high spatial and temporal resolution have been useful in observing agricultural processes and assisting effective management. They will support the shift to green agriculture when included in sophisticated environmental management frameworks. To gain widespread acceptance, it is, however, crucial to constantly check their accuracy and make use of supplementary data sources. In the presentation, a few case studies involving the use of multi-frequency SAR data to map and monitor the spatial and temporal variability of land surface parameters and agricultural operations will be used as examples. The emphasis is on assessing algorithms for the retrieval of surface soil moisture (SSM) and vegetation water content (VWC), classification, and monitoring of irrigation extent and tillage practices at high resolution. The approach of the algorithms is based on incoherent and coherent change detection. Results indicate that high spatial and temporal resolution interleaved SSM products can be produced by combining C- and L-band SAR data. They also showed great potential for tillage classification at large scales. Additionally, for the classification of irrigated areas, a useful complementarity between SAR and optical multi-spectral data has evolved. SAR data, in particular, can offer accurate early projections of the extent of irrigated areas.

TanDEM-X for Tree Height Mapping in the Parklands of Burkina Faso (17:00)

Presenter: SOJA, Maciej (Wageningen Environmental Research)

Mapping of tree height is of great importance for management, planning, and research related to agroforestry parklands in Africa. In this work, we study spotlight-mode TanDEM-X data for tree height mapping in Saponé, Burkina Faso, a test site characterised by a low average canopy cover (~15%) and a mean tree height of 9.0 m. Seven TDM acquisitions from January-April 2018 are used to create high-resolution (~3 m) maps of interferometric phase height and mean canopy elevation. A model-based processing approach is developed, compensating for some effects of the side-looking geometry of SAR. Compared with phase height, mean canopy elevation provides a more realistic canopy height map, a better tree positioning accuracy, and better tree height estimation performance when assessed using 915 trees inventoried in situ and representing 15 different species/genera. Two bias effects are observed, discussed, and compensated using empirical models. The best-performing model using only TDM data provides tree height estimates with a standard error (SE) of 2.8 m (31% of the average height) and a correlation coefficient of 75%. The estimation performance is further improved when TDM height data are combined with in situ measurements. This is a promising result in view of future synergies with other remote sensing techniques or ground measurement-supported monitoring of well-known trees.

<u>ROUND TABLE</u> (17:20 - 18:00)

Friday, 17 November 2023

Ice and Snow I: TomoSAR and Bistatic applications (09:00 - 10:40)

-Conveners: Nagler, Thomas (ENVEO IT GmbH); Rott, Helmut (ENVEO IT)

SNOW PARAMETER RETRIEVAL BY SPACEBORNE MIMO FDM SAR TOMOGRAPHY (09:00)

Presenter: TEBALDINI, Stefano (Politecnico di Milano)

Although seasonal snow cover is widely recognized as a critical water resource, accurate SWE assessment is still challenging when considered at an operational level, especially in regions characterized by complex topography [1]. SWE retrieval methods based on polarimetry are inherently linked to the assumption of specific models of the snowpack, [1], [2], [3],[4], [5]. Such approaches can turn out to be problematic in heterogeneous areas, where the link between Radar observables and snow parameters is modulated by local conditions. DInSAR-based methods allow for a direct conversion of the interferometric phase between SAR acquisitions from two different dates into the SWE variation that took place in between [1], [6], [7], [8], [9]. The underlying physical model stems from the fundamental assumption of a transparent snowpack [7], [8].DInSAR-based SWE retrieval is expected to perform best at lower frequencies such as L-Band, where the assumption of a transparent snowpack is inherently better verified and interferometric coherence is generally higher [9]. A downside of such technique is that the resulting accuracy is critically dependent on the capability to compensate for topography and tropospheric delays at local scale, which can be quite a challenging task in mountain regions [9]. In addition, the amount of SWE at a given date needs to be calculated by integrating differential measurements, which might introduce propagation errors. Interestingly, direct measurement of absolute SWE at a given date is enabled by SAR Tomography (TomoSAR), which leverages multiple across-track baselines to provide direct imaging of the snowpack. Experimental works on the use of tomography demonstrated that X- and Ku-Band waves provide sensitivity to scattering from both the air/snow and snow/terrain interfaces in dry snow, as well as the possibility to image the multi-layered structure of the snowpack [10], [11], [12]. This methodology was successfully applied in [12], demonstrating not only the retrieval of bulk density, but also the possibility to study snow density within each detected layer. Within this paper, we aim at investigating the extent to within which the result in [12] can be reproduced by using a formation of Multiple-Input-Multiple-Output (MIMO) X-Band SAR satellites. The formation is assumed to implement a Frequency Division Multiplexing (FDM) access scheme, where all satellites transmit simultaneously on different frequency bands and receive the echoes scattered by the Earth's surface in all transmitted bands. Fine vertical resolution is achieved by developing a novel approach to set the satellite positions, referred to as Minimum Redundancy Wavenumber Illumination. As a result, we show two examples where formations of 4 or 5 satellites are deployed to provide the equivalent of 17 and 26 monostatic acquisitions, respectively, allowing for tomographic imaging of the snowpack at a vertical resolution better than half a meter. The proposed concept is supported by numerical simulations and sensitivity analyses, which advocate for the feasibility of accurate retrieval of snow parameters. REFERENCES [1]. Tsang. L, et al. Global monitoring of snow water equivalent using high-frequency radar remote sensing, The Cryosphere, 16, 3531–3573, 2022, https://doi.org/10.5194/tc-16-3531-2022 [2]. H. 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Snow Parameter Estimation by Simultaneous Multiple Squint Differential InSAR: A Study for the Harmony Mission (09:20)

Presenter: BENEDIKTER, Andreas (German Aerospace Center (DLR))

Spaceborne differential SAR interferometry has been demonstrated to potentially allow for snow water equivalent (SWE) change measurements on a spatial scale, resolution, and accuracy unprecedented by other sensor concepts [1][2]. However, its operational use is hindered mainly because of: i) low coherence areas resulting from temporal decorrelation, largely complicating a robust phase unwrapping, ii) inaccurate density estimates introducing systematic errors in the phase-to-SWE inversion, and iii) an unknown phase offset due to the 2π ambiguity of the interferometric measurement and therefore a strongly biased SWE estimate. We present strategies to tackle these shortcomings by exploiting simultaneously acquired interferograms with different squint angles. The different line-of-sights result in differential phase delays introduced by a SWE change due to the varying path length through the snow cover. The phase difference between the interferograms may be exploited to produce a low-resolution SWE estimate without the need for phase unwrapping and to resolve the 2π phase ambiguity of the single interferogram, following a similar rational as delta-k approaches for absolute phase estimation [3][4]. In contrast to delta-k approaches, the ratio between the interferograms acquired with different squint angles is a direct measure of the dielectric permittivity of the snow and can be related to the snow density. Estimates of the snow density and permittivity are required for an unbiased SWE estimate and may be relevant for other sensor modalities or snow modelling approaches. The performance of the strategies is evaluated for the Harmony mission (ESA's Earth Explorer 10), demonstrating great potential given the large squint diversity of the Harmony constellation. By means of simulated D-InSAR acquisitions of the Sentinel-1 and Harmony satellites that are based on real Sentinel-1 repeat-pass acquisitions covering a snow accumulation event in northern Alaska, we show that convincing inversion results of both SWE change and density may be obtained for realistic assumptions on coherence levels and spatial SWE variability. Beyond Harmony, also the Co-Flier concepts of NASA JPL with receive-only companions for upcoming L-band missions may be candidates to implement the proposed techniques. [1] T. Guneriussen, K. Hogda, H. Johnsen, and I. Lauknes, “InSAR for estimation of changes in snow water equivalent of dry snow,” IEEE Transactions on Geoscience and Remote Sensing, vol. 39, no. 10, pp. 2101–2108, 2001. [2] K. Belinska, G. Fischer, T. Nagler, and I. Hajnsek, “Snow water equivalent estimation using differential SAR interferometry and co-polar phase differences from airborne SAR data,” in IGARSS 2022 – 2022 IEEE International Geoscience and Remote Sensing Symposium, 2022, pp. 4545–4548 [3] G. Engen, T. Guneriussen, and Y. Overrein, “Delta-K interferometric SAR technique for snow water equivalent (SWE) retrieval,” IEEE Geoscience and Remote Sensing Letters, vol. 1, no. 2, pp. 57–61, 2004 [4] S. Madsen, H. Zebker, and J. Martin, “Topographic mapping using radar interferometry: processing techniques,” IEEE Transactions on Geoscience and Remote Sensing, vol. 31, no. 1, pp. 246–256, 1993

On the Potential of Bistatic SAR Features for Monitoring Snow Facies over Ice Sheets and Radar Penetration Estimation (09:40)

Presenter: BECKER CAMPOS, Alexandre (FAU Erlangen-Nürnberg/DLR)

Ice sheets play a critical role in regulating global climate and sea-level rise. To enhance the accuracy of climate modeling and predictions, it is essential to comprehend the intricate processes of snow accumulation, transformation, and melting that transpire on ice sheets. A fundamental component of monitoring ice sheets involves identifying distinct layers or units within the snowpack, known as snow facies, each possessing unique physical properties. These snow facies can be classified as: the inner dry snow zone, where melt is absent; the percolation zone, where limited annual melt leads to larger snow grains and small ice structures; the wet snow zone, characterized by substantial summer melt and the presence of multiple ice layers; and the outer ablation zone, where the previous year's accumulation fully melts during summer, revealing bare ice and surface moraine. Variations in melt levels across these snow facies can influence the radar wave penetration when using spaceborne synthetic aperture radar (SAR) to monitor snow- and ice-covered regions. This impacts, e.g., the estimation of the radar mean phase center, which is necessary for the generation of digital elevation models (DEM), leading to penetration bias and an underestimation of the surface topographic height. Accurately estimating this penetration bias is therefore pivotal for reducing uncertainties in determining snow depth, ice thickness, and glacier mass balance through DEM differencing. Previous works have demonstrated the effectiveness of interferometric SAR (InSAR) features for segmenting snow facies and for penetration depth estimation. Bistatic SAR missions like TanDEM-X are particularly well-suited for these tasks thanks to the absence of temporal decorrelation effects, which allows for the generation of high-quality InSAR products. In this work, we explore the capability of bistatic SAR features and deep learning methods for snow facies segmentation in Greenland and Antarctica. We propose a weakly supervised learning convolutional neural network (CNN)-based approach that leverages raster intersections during the mosaicking process of multiple TanDEM-X acquisitions, allowing us to optimize a robust model for various bistatic acquisition geometries. We compare the segmentation results with cumulative melt maps and in situ measurements, demonstrating the potential of bistatic missions for monitoring the evolution of snow facies. Lastly, we discuss how the features extracted for this purpose can be used to estimate the penetration bias of bistatic X-band SAR systems, independently of acquisition parameters. Given the lack of large reference data sets for the estimation of the penetration bias, this work aims at understanding the impact of an effective bistatic feature extraction and utilization, which allows for reducing the amount of labelled data required to fulfill a fully supervised regression task. This is a crucial aspect for, on the one hand, improving the accuracy of the TanDEM-X DEMs over snow and ice-covered areas, and, on the other hand, preparing for future bistatic InSAR missions, such as the forthcoming ESA Harmony mission, which will require similar paradigms for coping with radar penetration into volumes.

Monitoring Cryosphere Sub-Surfaces with BIOMASS mission (10:00)

Presenter: TAILLADE, Thibault (ESRIN)

For the first time in Earth observation, the BIOMASS mission will collect polarimetric P-band SAR data from space that could help monitor large-scale subsurface areas of Antarctica. Indeed, such electromagnetic frequencies penetrate dry ice and snow and may provide information about the stratification and depths of cryospheric elements. This capability will provide easily interpretable vertical structural profiles supporting the discovery and analysis of glaciological features (e.g. ice thickness, subglacial lakes, crevasses) and enable innovative geophysical parameter retrievals. Potentially this will improve glaciological research and the estimation of ice mass balance in different parts of the world. The main focus of this study is to evaluate BIOMASS tomographic capabilities for mapping the vertical structures of cryospheric features such as ice sheets, ice floes, or glaciers. In the first part, we briefly introduce the mission and its baseline variations with latitude during the TOM (tomographic) phase. Due to vertical resolution and ambiguity properties in high latitudes, we show that this phase may be relevant for thick cryosphere element mapping such as ice shelves, we present a simulation scenario for ice shelf basal topography mapping. In the second part, we highlight interesting opportunities provided by the COM (commission) phase for which higher vertical resolution can be achieved with the possibility of gathering up to 21 tomographic acquisitions while remaining below the critical baseline. Finally, we discuss the different options, trade-offs, and solutions that can be adopted for the optimal use of BIOMASS mission for tomographic mapping of the cryosphere.

Pol-InSAR and TomoSAR for Subsurface Ice Sheet Information Retrieval with a Perspective on BIOMASS (10:20)

Presenter: FISCHER, Georg (German Aerospace Center (DLR))

A key uncertainty in mass balance studies of glaciers and ice sheets is still today the density for the volume-to-mass conversion. This is not only reported on a global scale [1] but also for recent local studies [2], where even the presence of in situ measurements can only partly capture the density uncertainty [3]. The volume-to-mass conversion factor can span a wide range from 0 to 2000 kg m^{−3} but many studies use fixed density values such as 850 ± 60 kg m^{−3} [4]. Therefore, there is a clear need for improved spatial and temporal information about ice sheet subsurface properties. Polarimetric and multi-baseline interferometric SAR techniques are promising tools to investigate the subsurface properties of glaciers and ice sheets, due to the signal penetration of up to several tens of meters into dry snow, firn, and ice. (Pol-)InSAR models were shown to provide information about refrozen melt layers [5] and signal extinction [6]. With TomoSAR, the imaging of subsurface features in glaciers [7], and ice sheets [8][9] was demonstrated and the effect of subsurface layers, different ice types, firn bodies, and crevasses was recognized. Such subsurface structure information can provide at most an indirect information about density and a related parameter retrieval method is missing. Further, a general challenge is the ambiguity between the depth of scatterers and the density, because the density determines the permittivity which is required to account for the slower signal propagation speed in the subsurface. One way of addressing this is the integration of polarimetric measurements. PolSAR models provide a link between the co-polarization HH-VV phase difference (CPD) and the dielectric anisotropy of the firn volume [10]. This modeling approach establishes a relationship of the measured CPD to firn density, firn anisotropy and the vertical backscattering distribution. The integration of vertical backscatter profiles from Pol-InSAR or TomoSAR into the PolSAR CPD model theoretically allows the inversion of firn density from polarimetric and interferometric SAR data. This is investigated with experimental airborne F-SAR data over Greenland. First experiments [11], albeit promising, did not answer yet to which degree a practical inversion is possible. Open questions are the sensitivity and requirements in terms of incidence angles and baselines. The results of this study should give an indication if such an approach might be feasible with future spaceborne SAR systems. In this context, we will investigate first ideas for potential subsurface information retrieval with BIOMASS that go beyond pure tomographic imaging, since there is a unique chance for suitable baselines over Antarctica during the commissioning phase [12]. Large areas of Antarctica might have a too homogeneous subsurface structure that will be difficult to grasp with the tomographic capabilities of BIOMASS. However, selected cases exist, with e.g. a strong firn-ice contrast, where the potential to derive subsurface structure information with BIOMASS will be assessed. A further evaluation will concern the nominal tomographic phase of BIOMASS, which lacks suitable baselines at high latitudes. Still, some particular subsurface features in the Patagonian ice fields could be a target of interest. [1] D.G. Vaughan et al., “Observations: Cryosphere,” in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, [Stocker, T.F. et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, USA, 2013. [2] K. Shahateet, T. Seehaus, F. Navarro, C. Sommer, and M. 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Polarisation Phase Differences in L-Band SAR Data," Remote Sensing, vol. 13, no. 21, p. 4448, Nov. 2021, doi: 10.3390/rs13214448. [11] G. Fischer, K. Papathanassiou, I. Hajnsek, and G. Parrella, "Combining PolSAR, Pol-InSAR and TomoSAR for Snow and Ice Subsurface Characterization," in Proceedings of the ESA POLinSAR Workshop, Online, Apr. 2021. [12] T. Taillade et al., "Monitoring Cryosphere Sub-Surfaces with BIOMASS mission," in preparation, ESA BioGeoSAR Workshop, Rome, Nov. 2023.

Comfort break (10:40 - 11:00)

Forestry IV: TomoSAR applications (11:00 - 12:00)

-Conveners: Villard, Ludovic (CESBIO); Pardini, Matteo (German Aerospace Center (DLR))

Characterization of tropical forests using parametric SAR tomography: preparation of the upcoming ESA BIOMASS mission (11:00)

Presenter: BOU, Pierre-Antoine

SAR tomography is a useful technique for monitoring and estimating forest geophysical parameters, as demonstrated by airborne measurements [1]. The future ESA BIOMASS mission aims to map the above-ground biomass and tree height of tropical forest on a global scale and to estimate the underlying ground topography. To do so a tomographic imaging mode will be applied to multi-baseline PolInSAR data acquired by the mission. These geophysical descriptors are derived from an estimate of the reflectivity distribution in the vertical dimension, typically computed using non-parametric spectral estimation techniques such as beamforming or the Capon technique [1,2]. Parametric tomography: However, these techniques have a limited resolution and can be affected by spurious peaks and sidelobes. To overcome these hindrances, adaptive estimation approaches have emerged that directly model the vertical reflectivity distribution using a combination of functional bases such as orthogonal wavelets [3]. As shown in [4], such a technique is very well adapted to the observation of tropical forests in P-band and models the vertical reflectivity of the forest with a very limited number of contributions. Nevertheless, this estimation approach is computationally intensive and requires hyperparameter tuning, which may be specific to a particular type of forest cover. In the same paper [4], the authors demonstrated that the vertical reflectivity profile can be effectively modelled with two contributions, confirming the arbitrary hypothesis derived in the framework of polarimetric SAR interferometry and polarimetric SAR tomography in [5,6]. In this paper, we propose to characterise the tropical forest using a single polarisation technique at P-band based on the use of two contributions: a very narrow reflectivity peak corresponding to the ground and a bell-shaped function representing the canopy. Therefore, several types of functions are investigated to model the volume response such as the exponential shape [5], the gaussian profile [7] with varying widths including an infinitively narrow width, or the rectangular profile. Comparison of profile model performance: This approach is applied to data sets acquired over two different continents. The first one was acquired by ONERA in 2009 in the frame of the TropiSAR campaign over French Guiana (South America) and the second one by the DLR F-SAR sensor in Gabon (Africa). In both cases, data sets are simulated with a degraded resolution equivalent to that of the future BIOMASS mission SAR images. In the high-resolution airborne cases, results show a good retrieval performance for ground topography and tree height estimation for all the functional profiles studied. A standard deviation of 1.5 m is obtained for the ground and 2.6 m for the tree height estimation. All investigated profiles are found to be suitable to adequately reconstruct the reflectivity distribution in height. The performances obtained are comparable to those obtained by PolTomoSAR at full resolution, and this approach is less complex. In the context of BIOMASS like resolution, the results are finer with this approach. This is because it doesn't have to choose between the ground contribution and the volume contribution, which is modified by the BIOMASS resolution. References: [1] H. Aghababaei, G. Ferraioli, L. Ferro-Famil, Y. Huang, M. Mariotti D'Alessandro, V. Pascazio, G. Schirinzi, S. Tebaldini, "Forest SAR Tomography : Principles and Applications", IEEE Geoscience and Remote Sensing Magazine, Volume 8, Issue 2, pp30 – 45, June 2020 [2] F. Gini, F. Lombardini, "Multibaseline cross-track SAR interferometry : a signal processing perspective", IEEE Aerospace and Electronic Systems magazine, Volume 20, Issue 8, pp71 – 93, August 2005 [3] E.Aguilera, M. Nannini and A.Reigber, "Wavelet-based compressed sensing for SAR Tomography of forested areas", IEEE Transactions on Geoscience and Remote Sensing, Volume 51, Issue 12, pp5283 – 5295, December 2013 [4] L. Ferro-Famil, Y. Huang and N. Ge, "Estimation of the vertical structure of a tropical forest using basis functions and parametric SAR Tomography", in IGARSS 2022 – 2022 IEEE International Geoscience and Remote Sensing Symposium, July 2022, pp.599-602 [5] S.R. Cloude and K.P. Papathanassiou, "Three-stage inversion process for polarimetric SAR interferometry", IEE Procedings – Radar, Sonar and Navigation, Volume 150, Issue 3, pp125 – 134, June 2003 [6] S. Tebaldini, "Single and multipolarimetric SAR tomography of Forested Areas : A parametric approach", IEEE Transactions on Geoscience and Remote sensing, Volume 48, Issue 5, pp2375 – 2387, May 2010 [7] F. Garestier and T. Le Toan, "Estimation of the Backscatter Vertical profile of a Pine Forest Using Single Baseline P-band (Pol-)InSAR Data", IEEE Transactions on Geoscience and Remote Sensing, Volume 48, Issue 9, pp3340-3348, September 2010

Multi-Wavelength Mono- And Bi-Static Phenomenological Analysis of the Kermeter Temperate forest: Results From The Tomosense Campaign (11:20)

Presenter: TEBALDINI, Stefano (Politecnico di Milano)

The TomoSense experiment was conceived to provide the scientific community with unprecedented data to study the features of radar scattering from temperate forests, comprising tomographic and fully polarimetric SAR surveys at P-, L-, and C-band, acquired in mono- and bistatic mode by simultaneously flying two aircraft. The TomoSense dataset is complemented by a detailed forest census, Terrestrial Laser Scanning (TLS), and Airborne Lidar Scanning (ALS) products. All campaign activities were finally and successfully closed in fall 2021, resulting in an amount of over 1800 SAR images at different polarizations, frequency bands, and acquisition modes. A significant part of data processing activities was dedicated to interferometric and tomographic calibration of SAR data, necessary to finely estimate platform motion and achieve accurate tomographic focusing Calibration activities resulted in the generation of finely coregisted, phase calibrated, and ground steered complex SAR image stacks at all frequency bands, which were included in the final data delivery to ESA. Calibrated image stacks were afterwards processed to generate multi-frequency mono- and bi-static Tomographic cubes representing forest scattering in three dimensions, intended to serve as the basis for all subsequent scientific analyses and also included in the final data delivery. Scientific analyses were conducted by investigating the connection of Tomographic cubes to biophysical parameters. Essential to these activities was the availability of a large amount of biophysical information from independent measurements, including field-works, TLS, and ALS. Based on the large amount of results produced by the study, the following conclusions are drawn. P- and L-Band: Both P and L band are observed to provide sensitivity to the whole vegetation layer, in that both frequencies allow for a clear detection of terrain and forest canopies. Moreover, both frequencies are robust w.r.t. temporal decorrelation over few hours, resulting in the possibility to produce high-quality tomographic imaging from repeat-pass campaign data. Interestingly, bistatic data at L-Band are observed to contain weaker contributions from the terrain level than mono-static data. As a result, the Ground-to-Volume backscatter power ratio (G2V) is systematically larger for monostatic measurements by up to 4 dB, depending on polarization and local conditions (understory, topography). Forest height could be successfully estimated using repeat pass mono-static P- and L-Band data, repeat pass bi-static L-Band data, as well as using only simultaneous interferograms from each bistatic pass. Interestingly, the use of normalized tomographic indicators like fractional volume intensity was observed to provide sensitivity to AGB as well, the best result being assessed in slightly over 20% on the aggregated forest class using bistatic L-Band data. C-Band: Tomographic analysis of C-Band data indicates that the residual coherence in repeat-pass interferograms is mostly determined by scattering from the ground level, whereas the signal from the forest canopy is nearly impossible to detect because of temporal decorrelation. Analysis of interferograms formed by mono- and bi-static data collected in the same flight reveals that tall forests decorrelate almost immediately because of wind gusts, thus confirming the results from the BorealScat experiment. However, tomographic processing allowed for exploiting vestigial coherence from the vegetation, resulting in the possibility to detect forest canopies in parts of the image and observe a good match w.r.t. Lidar height. Overall, results obtained at this site indicate that C-Band waves care capable of penetrating down to the ground level. This finding provides an element in support of the feasibility of C-Band tomography of temperate forests, clearly provided that acquisitions are taken at a temporal baseline of a few tens of milliseconds. The TomoSense data-base: one important product of the study consists in the creation of a data-base intended to serve as an important basis for studies on microwave scattering from forested areas in the context of future studies on Earth Observation missions. The data-base comprises complex SAR images and tomographic cubes at different levels of processing, as well as ALS-derived maps of forest height and AGB, forest census, and TLS profiles. Complex SAR images in the data-base are already finely coregistered, phase calibrated, and ground steered, in such a way as to enable future researchers to directly implemented any kind of interferometric or tomographic processing without having to deal with the subtleties of airborne SAR data. In addition to that, the data-base comprises tomographic cubes representing forest scattering in 3D both in Radar and geographical coordinates, which are intended for use by non-Radar experts. Overall, we emphasize that the amplitude of the TomoSense data-base is such that a number of questions had to be left unexplored within the time of the study, and in particular those concerning the joint use of different tomographic observables. For this reason, it is our opinion that the TomoSense data-base will represent a most valuable tool for student and researchers in the next years.

Performance of PolTomoSAR imaging for tropical forest characterization in the BIOMASS configuration (11:40)

Presenter: FERRO-FAMIL, Laurent (ISAE-SUAPERO & CESBIO, University of Toulouse, France)

Tomographic Synthetic Aperture Radar (SAR), TomoSAR, is an electromagnetic imaging technique able to map the 3D reflectivity of complex environments. It is generally implemented using radar signals acquired over a 2D aperture, i.e. using a set of coherent 2D SAR images measured from slightly shifted trajectories. Forested environments can be efficiently characterized using TomoSAR acquisitions operated at lower frequency bands, such as P or L bands, as larger wavelength values ensure both a deep penetration of dense forest covers, as well as a better preservation of signal coherence over time. Polarimetric TomoSAR (PolTomoSAR) uses polarization diversity in order to further discriminate signals originating from the canopy or from the underlying ground of a forest. Several applications of PolTomoSAR advanced signal processing techniques on data acquired during airborne campaigns, have demonstrated that this type of configuration could be exploited in order to estimate some key parameters of forest covers, such as tree height, ground topography, biomass, structure . . . The imminent launch of the European Space Agency (ESA) BIOMASS spaceborne mission, that includes a polarimetric SAR device operating at P band, will provide a unique opportunity to accurately study densely forested regions, and in particular tropical regions. The estimation of the performance bounds, i.e. the best achievable precision for a given observed medium and given acquisition conditions, reveals a fundamental importance for both the evaluation of the different existing estimation approaches, but also for the validation of the mission products. This paper proposes to first set up a methodological background for the computation of PolTomoSAR performance bounds that remains valid for single-polarization observations, multi-polarized ones, in PolinSAR configuration, or using more than two baselines. The performance of different modes is evaluated using Bayesian inference [1], and statistical processing classically used for the resolution of inverse problems [2]. Among all the descriptors of a forest cover, three main parameters are considered: the Digital Terrain Model (DTM), i.e. the topography of the underlying ground, the Canopy Height Model (CHM) or tree height and the Above Ground Biomass (AGB). As AGB is not directly estimated by PolTomoSAR imaging, various proxies are investigated [3]. The second part of this work concerns the influence of spatial resolutions, i.e. in range and azimuth directions, on the performance of PolTomoSAR. The particular case of BIOMASS with resolution of 12.5 m in azimuth and 25 m in slant range is investigated and compared with airborne measurements with a resolution of approximately 1m. Deteriorated resolution properties are accounted for using two approaches. The first one is based on an low-resolution adaptation of forest structure description with and unchanged theoretical derivation of the performance limits. The second technique extend the modeling of the forest reflectivity to include an additional axis in the inference process. The validity and accuracy of the proposed methods are illustrated using the PolTomoSAR data set acquired at P band over the tropical forest test site of Paracou, in French Guiana, during the TropiSAR campaign in the summer 2009, using the ONERA’s SETHI system. It consists of six polarimetric and interferometric images having a spatial resolution of 1.5m in azimuth and 1.2m in range [4]. From this airborne data set, images having the spatial resolution of spaceborne BIOMASS acquisitions, 12.5m in azimuth and 25m in range [5, 6], are generated. [1] George Casella and Roger Berger, Statistical Inference, Duxbury Resource Center, June 2001.[2] Albert Tarantola, Inverse Problem Theory and Methods for Model Parameter Estimation, Society for Industrial and Applied Mathematics, USA, 2004. [3] D. Ho Tong Minh, T. L. Toan, F. Rocca, S. Tebaldini, M. M. d’Alessandro, and L. Villard, “Relating p-band synthetic aperture radar tomography to tropical forest biomass,” IEEE Transactions on Geoscience and Remote Sensing, vol. 52, no. 2, pp. 967–979, 2014. [4] Pascale Dubois-Fernandez, Hélène Oriot, Colette Coulombeix, Hubert Cantalloube, Olivier Plessis, Thuy Le Toan, Sandrine Daniel, Jerome Chave, Lilian Blanc, and Malcolm Davidson, “TropiSAR, a SAR data acquisition campaign in French Guiana,” 07 2010, pp. 1 – 4. [5] Maciej J. Soja, Shaun Quegan, Mauro M. d’Alessandro, Francesco Banda, Klaus Scipal, Stefano Tebaldini, and Lars M.H. Ulander, “Mapping above-ground biomass in tropical forests with ground-cancelled p-band sar and limited reference data,” Remote Sensing of Environment, vol. 253, pp. 112153, 2021. [6] L. Ferro-Famil, Y. Huang, L. Villard, T. Le Toan, and T. Koleck, “Comparison of biomass acquisition modes for the characterization of forests,” in 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, 2021, pp. 1545–1548.

Lunch break (12:00 - 13:40)

Ice and Snow II: Modelling and Retrieval (13:40 - 15:00)

-Conveners: Taillade, Thibault (ESRIN); Fischer, Georg (German Aerospace Center (DLR))

Airborne experiment on SAR based observation of snow mass in Alpine terrain (13:40)

Presenter: ROTT, Helmut (ENVEO IT)

Airborne experiment on SAR based observation of snow mass in Alpine terrain Helmut Rott, Thomas Nagler, Stefan Scheiblauer, Ralf Horn, Jens Fischer, Matteo Pardini, Julia Kubanek Abstract In March 2021 a field experiment was conducted in the high Alpine test site Woergetal in the Austrian Alps, exploring the application potential and performance of snow mass (snow water equivalent, SWE) retrieval by C-and L-band SAR sensors. Multiple repeat-pass acquisitions were acquired on seven days with the airborne F-SAR of DLR, operating in dual frequency, C-band and L-band, polarimetric mode. The SAR data cover periods without snowfall and span also two snowfall events with mean accumulation (delta-SWE) amounts of 13 mm, respectively 65 mm. Snow depth transects and snow pit measurements were made at three comparatively level sections of the test site in different elevations. Main motivation for the experiment was the development and evaluation of concepts and tools for the utilization of the repeat-pass InSAR technique for snow mass monitoring, assessing the potential of future missions such as the Radar Observation System for Europe at L-band (ROSE-L), Sentinel-1 Next Generation (NG) and the geosynchronous C-band SAR mission Hydroterra that had been proposed in response to the ESA Call for Earth Explorer 10 Mission Ideas. Besides focussing on the use of repeat-pass interferometry for SWE retrieval, we also checked the information content of polarimetric parameters in respect to changes in snow mass. Among these, the C-band HH-VV co-polarized phase difference shows a distinct response to the accumulation of fresh snow, the spatial pattern of which, however, does not exactly reflect the observed snow depth. For the repeat-pass InSAR based SWE retrievals of the two snowfall events three approaches were implemented and evaluated using the following configurations: (i) C- and L-band repeat-pass data in full spatial resolution applying the conventional repeat-pass InSAR technique; (ii) simulated C-band repeat-pass data reflecting the spatial resolution and sampling of the Hydroterra system; (iii) C- and L-band repeat-pass data in full spatial resolution applying split-bandwidth processing to obtain two sub-band SLC images that are used to generate differential split-bandwidth (Delta-k) interferograms for each date. These interferograms are used for repeat-pass DInSAR processing. In each of these configurations the phase of corner reflectors, cleaned of snow, was used in the differential interferograms as reference for zero delta-SWE. With the Delta-k method the problem of 2-pi phase ambiguity due to intense snowfall events or long time spans can be overcome, though the sensitivity in respect to SWE is reduced. Examples of phase, coherence and SWE products, obtained by the three approaches, will be presented, the performance of the products will be compared, and the use and complementary for obtaining continuous SWE time series will be discussed.

RETRIEVAL OF SNOW WATER EQUIVALENT AND LIQUID WATER CONTENT WITH MACHINE LEARNING METHODS EXPLOITING X- AND C-BAND SAR DATA AND MODEL SIMULATIONS (14:00)

Presenter: PETTINATO, Simone (CNR-IFAC)

The estimation of snow parameters, such as snow water equivalent (SWE) and liquid water content (LWC), is an important task to support the water management and avalanche warning applications. The purpose of this study is twofold: in the first case we intend to retrieve the SWE using X-band SAR data, in the second case we want to retrieve LWC from X- and C-band SAR data. Many measurement campaigns have been carried out to acquire ground truth data on snow in the South Tyrol and Valle d'Aosta (Italy), and in-situ measurements, as snow depth, density, snow grain radius, temperature, were collected. In order to proceed with the in-depth analysis for the retrieval of SWE, the acquired in-situ snow information was used to simulate the X-band backscatter with the Dense Medium Radiative Transfer (DMRT) electromagnetic model [1]. The sensitivity of the CSK X-band □° to in-situ measurements of SWE was analyzed. Backscattered data were separated by ascending and descending orbits in order not to mix dry with wet snow. The correlation between □° and SWE is confirmed for ascending orbits (early morning), when snow is dry, with rather high correlation coefficient (R = 0.64); whereas the correlation becomes negligible for descending orbits (late afternoon), due to some presence of wet snow. Consequently, two machine learning models were considered to implement the SWE retrieval algorithm. The first was based on Artificial Neural Networks (ANN), [2], whilst the second exploited the Support Vector Regression (SVR) theory [3]. These algorithms were trained with both experimental data and DMRT model simulations, and finally were applied to a selection of CSK HIMAGE HH polarized scenes collected on the South Tyrol test area. The results of the test performed on SWE parameter of the two selected algorithms showed a correlation coefficient R = 0.86 and R = 0.83 for ANN and SVR, respectively. These results demonstrated that the obtained SWE data agrees with the SWE measurement at the control points and in line with the season and the meteorological conditions. Validation should be obviously improved in the future, with a more consistent measurement dataset, in order to verify the replicability of the results. The LWC retrieval from X- and C-band SAR data was based on ANN and Random Forest (RF) algorithms. In this case, the setup of the experiment considered CSK and Sentinel-1 (S1) data, acquired on the test site of Valle d'Aosta (Italy). The available product mode in this area is Interferometric Wide Swath (IW) and VV polarization. The training was based on data simulated by the Strong Fluctuation Theory (SFT), [4], that was modified to account for the scattering contribution from the soil under snow in the computation of the total backscattering of wet snow, thus significantly improving the simulation accuracy. The scope of the SFT reappraisal was to create a forward electromagnetic model capable of accurate simulation of wet snow backscattering with smaller computational cost than other popular models as the DMRT [1]. The fast computation allowed generating a training set of some thousands backscattering values by using pseudo random input soil and snow parameters whose distribution has been derived from the experimental data available. In this case too, the training was carried out by using the simulated σ° as inputs and the corresponding LWC as target. The trained algorithms were then validated against the in-situ and simulated snow parameters from SNOWPACK model, [5]. The validation of the ANN and RF algorithms showed R = 0.69 and R = 0.79 for C-band data, respectively. Concerning the X-band data, the validation results retrieved R = 0.60 and R = 0.69 for ANN and RF algorithms respectively. In both cases, RF outperformed ANN, despite several attempts for retraining and the iterative processing for defining the ANN best architecture. [1], Tsang L., J. Pan, D. Liang, Z. Li, D. W. Cline, and Y. Tan, "Modeling active microwave remote sensing of snow using dense media radiative transfer (DMRT) theory with multiple-scattering effects," IEEE Trans. Geosci. Remote Sens., 45, 4, 2007, pp. 990-1004. [2] SWE retrieval in Alpine areas with high-resolution COSMO-SkyMed X-band SAR data using Artificial Neural Networks and Support Vector Regression techniques," Proc. 2020 XXXIII General Assembly and Scientific Symposium of the Int. Union of Radio Science, URSI GASS, 2020, pp. 1-4. 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Monitoring ice sheet melt and refreeze using active microwave measurements (14:20)

Presenter: NAGLER, Thomas (ENVEO IT GmbH)

The area extent and duration of surface melt on ice sheets are important parameters for climate and cryosphere research and key indicators of climate change. The surface melting / refreezing condition is essential information for modelling glacier hydraulics and the surface energy budget. Data on surface meltwater production are also crucial for estimating changes in the subglacial water pressure, a main parameter for glacier speed-up. Surface melt plays an important role for the stability of ice shelves, as the amplification of surface melting as precursor to the break-up of ice shelves on the Antarctic Peninsula has shown. In the frame of the ESA Polar Cluster projects 4DGreenland and 4DAntarctica we developed an algorithm for generating maps of snowmelt extent based on multitemporal Sentinel-1 SAR and METOP-A/B/C ASCAT scatterometer data. The detection of melt relies on the strong absorption of the C-band radar signal by the presence of liquid water in the snowpack. The proposed algorithm exploits dense backscatter time series to identify the different stages of the melt/refreeze cycle. Using ASCAT data with about 5 km pixel spacing we generated time series with daily maps of melt / refreeze area at low spatial resolution providing an insight into the dynamics of changing surface conditions in Antarctica and Greenland. These products are intercompared to surface energy balance models in order to check the model performance in respect to the melting and surface refreezing conditions. On confined outlet glaciers the resolution of ASCAT is not suitable for detecting spatial details such as changes in melt conditions with elevation. For these glaciers we use time series of high resolution Sentinel-1 C-band SAR data, available in 6 to 12 days timesteps. In order to estimate the evolution of the increasing thickness of refrozen snow layers on top of wet snow, we use an approach based on backscatter modelling integrating C-band SAR data of Sentinel-1 and L-band SAR data of SAOCOM. In the presentation we will show time series of ASCAT melt products for Greenland and Antarctica and their relation to climate model output. Additionally, examples of the newly developed refreezing depth product, derived from Sentinel-1 and SAOCOM data, will be presented.

Polarimetric and interferometric analysis of heterogeneous ice types in the ablation zone of Greenland (14:40)

Presenter: SCHLENK, Patricia (German Aerospace Center)

In an experimental airborne SAR dataset, a complex and heterogeneous scattering pattern was found at the Russel glacier, also known as K-Transect, in western Greenland. In a first analysis, two potential ice types could be classified based on their distinct differences in scattering processes. A first glaciological theory for these two ice types is, on the one hand, temperate ice with low liquid water content and, on the other hand, cold and homogeneous glacial ice without liquid water content. A better understanding of the distribution and development of these two ice types could be a crucial information for surface-mass balance, glacier dynamics and hydro-glaciological processes [1]. Polarimetric and interferometric analyses of SAR data are a unique tool to investigate these ice types based on their sensitivity to different dielectric properties and scattering structures. In L-band, with a deep signal penetration into the ice sheet, the difference between the ice types is particularly pronounced which indicates a significant difference in subsurface structure of the two ice types [2]. In a Pauli decomposition of the research area, one ice type demonstrates a weak surface scattering, which is referred to as "black patches" due to its color in the RGB Pauli image. The other ice type shows as bright green which indicates strong volume scattering. The interferometric analysis confirms the first impression of the Pauli decomposition. A shallow penetration can be seen in the “black patches” with phase center depths between 0 and -2 m in HH and VV (0 to -5 m in HV), which aligns with high coherences, low volume decorrelation and surface scattering as the main scattering mechanism. The second ice type shows, in accordance with the high amount of volume scattering, a phase center depth up to -30m in HV (0 to -15m in HH and VV). The coherence decreases significantly over increasing baselines due a higher volume decorrelation. Conventional tomographic analysis of the “black patches” presents mainly surface scattering in all polarizations, which triggered the question whether this phenomenon is only related to the surface or if there is scattering below. Therefore, additional tomographic analysis with further steps for surface cancelation [3] and noise filtering was conducted and multiple ice layers in the subsurface with a low intensity could be determined. However, possible artefacts due to the filtering, ambiguities and sidelobes have to be further investigated to separate them from the actual subsurface signal. To validate the results of the tomographic investigation, (Pol-)InSAR modeling of the coherences and phase center depth over all baselines was executed. Hereby, the vertical backscattering distribution was modelled for the two ice types. The ice type with high volume scattering could be well explained through a “box” as a surface component which accounts for the rough surface and a uniform volume in the subsurface. The modeling of the “black patches” still remains a challenge, especially the weak but non-negligible subsurface and will be further investigated with a combination of SAR methods. For the glaciological context, an analysis of ALOS data indicates that this pattern originates higher up the ice sheet, starting possibly in the super-imposed ice zone. Further analysis of additional spaceborne and in-situ data will help to understand the glaciological origin and its formation processes. [1] Paterson, W. S. B., “The physics of glaciers”, 3rd edition, Oxford (1994), doi: 10.1016/c2009-0-14802-x [2] Pardini, Matteo et al., “A Multi-Frequency SAR Tomographic Characterization of Sub-Surface Ice Volumes”, European Conference on Synthetic Aperture Radar: Hamburg, Germany (2016) [3] Joerg, Hannah et al., “On the Separation of Ground and Volume Scattering Using Multibaseline SAR Data”, IEEE Geoscience and Remote Sensing Letters, Vol. 14, No. 9 p. 1570-1574 (2017)

Comfort break (15:00 - 15:20)

ROUND TABLE (15:20 - 16:00)

Conclusions & closure (16:00 - 16:20)