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Editorial

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Editorial for the Special Issue "SAR for Forest Mapping II"

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As vital natural resources, forests are of extreme importance for all living beings on our planet. They play a key role in controlling climate change; represent essential sources of energy (e.g., biomass), food, jobs, and livelihoods; and serve as a natural habitat to a large variety of animal species, which is essential for biodiversity preservation. Forest ecosystems are constantly shaped and changed by physical and biological disturbances, and eventual regeneration processes. As an example, forest degradation is currently occurring at an alarming rate, and it often occurs due to illegal anthropogenic activities such as logging and fires. Sensitive environments have been irreversibly damaged, with critical environmental and economic consequences at regional as well as global scales. Precise and efficient assessment and monitoring of forest resources, treatments, and recreational opportunities are therefore of crucial importance in order to develop early warning systems. In this scenario, synthetic aperture radar (SAR) remote sensing represents a unique technique to provide high-resolution images independently of daylight and in almost any weather conditions. In the past few decades, SAR imaging has demonstrated its suitability for forest mapping applications. The combination of polarimetric, interferometric, and/or tomographic information further increases its capabilities and its products' accuracy.

This Special Issue consists of nine research papers [1–9], which investigate several aspects related to forest parameter estimation and retrieval using SAR-based methods, such as the mapping of forest cover [1–3], above-ground biomass (AGB) [4], and growing stem volume (GSV) [5], as well as forest height inversion [6], forest structure characterization [7], the estimation of phenological changes [8], and damages in drought-affected forests [9] using SAR data time series. All the methods proposed in these papers were validated using real SAR data and benchmarked with state-of-the-art approaches, thus comprehensively demonstrating the theoretical and practical contributions of the research.

The first paper [1] aims at testing the ability of Sentinel-1 C-band data to separate forests from other common land use classes (i.e., urban, low vegetation, and water) in temperate and tropical forest scenarios. For this purpose, a support vector machine (SVM) classifier is trained using increasing feature sets starting from backscatter statistics and adding short- as well as long-term coherence from annual time series. The good accuracy of the proposed method is assessed using existing land cover datasets and spaceborne Lidar data.

The potential of combining deep learning with Sentinel-1 InSAR short-time-series (STS, corresponding to 24 days of acquisitions) to map endangered areas in the Amazon Basin is investigated in [2]. To this end, a U-Net-like convolutional neural network (CNN) is proposed for multi-layer semantic segmentation, trained using both multi-temporal backscatter and interferometric coherences at different temporal baselines. The experimental results are validated with an independent thematic map and confirm the potential of the proposed framework for the large-scale monitoring of the Amazon Rainforest, requiring less pre-processing, achieving a higher agreement with the external reference when

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compared to the other works in the literature, and allowing for a significant decrease in the required observation time for the generation of large-scale deforestation products.

Differently from Sentinel-1 mentioned above, the TanDEM-X X-band system allows for the recording of bistatic InSAR acquisitions, which provide additional information to the common amplitude images acquired using monostatic SAR systems, such as the volume decorrelation factor, which is a reliable indicator of the presence of vegetation. In [3], the capabilities of deep CNNs to map tropical forests on a large scale using TanDEM-X InSAR quicklook data are investigated. In particular, an ad hoc training strategy aimed at developing a robust model for global mapping purposes is proposed, with the aim of properly managing the large variety of different InSAR acquisition geometries that characterize the TanDEM-X global dataset. By applying the proposed method on single TanDEM-X images, a significant performance improvement with respect to the referenced clustering-based approach is achieved, highlighting the great potential for the method of mapping temporal changes occurring over forested areas to be used for the generation of large-scale deforestation maps.

Above-ground biomass (AGB) is a widely used parameter to evaluate the geographical and temporal variations and the potential carbon sink of forest ecosystems. The mapping of the forest AGB is therefore extremely important for assessing forest resources. To improve the accuracy of mapping forest AGB by means of polarimetric SAR, it is necessary to accurately interpret and evaluate the sensitivity of the polarimetric features related to polarimetric response in complex forests. In [4], several rotated polarimetric features are extracted from L-band quad-polarimetric ALOS PALSAR-2 images based on the uniform polarimetric matrix rotation theory. The sensitivity of rotated polarimetric features is evaluated using forest parameters, and the forest AGB is mapped with various combinatorial feature sets. The AGB measurements with various feature combinations are inverted using these optimal feature sets and multiple linear regression (MLR) models to explore the capabilities of various features to map the forest AGB. The obtained results confirm that different types of features extracted from quad-polarimetric SAR images have better compensation effects and that the accuracy of the mapped forest AGB is significantly improved.

SAR images have great potential for mapping the forest growing stem volume (GSV) in complex biophysical environments. The objective of the study published in [5] is to evaluate the capability of C-band dual-polarization SAR images acquired by the Chinese civilian Gaofen-3 (GF-3) satellite to map the GSV in evergreen coniferous forests. Several proposed features are extracted and applied to obtain optimal feature sets using different sorting and selection methods. The maps of the GSV in an evergreen coniferous forest are estimated by exploiting various machine learning algorithms and stacking ensemble learning methods. The results demonstrate that the accuracy of the mapped GSV is significantly improved when using stacking ensemble learning methods rather than various optimal feature sets and base models, verifying that dual-polarization GF-3 images have great potential to map the forest GSV in evergreen coniferous forests.

A novel method for estimating the forest canopy height model (CHM) based on single-baseline InSAR data and sub-look decomposition is proposed in [6]. Together with the derivation of coherent scattering modeling based on the scattering matrix of sublook observations, a time –frequency-based random volume over ground (TF-RVoG) model is proposed to describe the relationship between the sub-look coherence and the forest's biophysical parameters. Then, a modified three-stage method based on the TF-RVoG model is used for CHM retrieval. The performance of the proposed method was tested using airborne L-band E-SAR data in Northern Sweden, demonstrating its suitability and improvement compared to PolInSAR-based techniques.

Structural diversity is recognized as a complementary aspect of biological diversity and plays a fundamental role in forest management, conservation, and restoration, making the assessment of structural diversity an aspect of utmost importance in primary international processes dealing with biodiversity and sustainable forest management. Space-borne polarization coherence tomography (PCT) represents an attractive approach given its ability to provide a vertical reflectivity profile and spatiotemporal resolutions related to detecting a forest's structural changes; its potentials are investigated in [7] in a broad-leaved Hyrcanian forest in Iran using TanDEM-X single-polarization interferometric data. The performance of the prediction algorithms, which include multiple linear regression (MLR), k-nearest neighbors (k-NN), random forest (RF), and support vector regression (SVR), is compared. This research work provides insights into the feasibility of the TanDEM-X interferometer for the study of forest structure diversity by approximating the vertical reflectivity profile and presents promising results, although the accuracy is still limited, highlighting the need to assess the used framework in characterizing the reflectivity profile for future studies.

The observation and assessment of phenological changes is important to evaluate the natural regeneration processes of forests, and the work presented in [8] investigates the phenological cycle of the Paphos Forest in Cyprus using the SAR data acquired by ERS-1/2, Envisat, and Sentinel-1 from 1992 to 2021. The paper provides an in-depth understanding of the strengths and limitations of analyzing the time series of SAR data to find the drivers causing density-, foliage-, and/or moisture-related phenological changes.

Finally, reference [9] explores the capability of the Copernicus Sentinel-1 C-band radar data to monitor drought-induced tree canopy damage, which is a topic that is currently receiving research attention due to the increasing frequency of large-scale heat waves and massive tree mortality events. Droughts cause water deficits in trees and eventually lead to early foliage loss, so the Sentinel-1 radiometric signal and polarimetric indices are tested regarding their sensitivities to these effects in a deciduous broadleaf forest scenario. Due to the scattered nature of mortality in the study site, a temporal-only time series filtering scheme is employed, which provides a fine spatial resolution of down to 10 m for performing measurements at the scale of single trees. The anomaly between heavily damaged and non-damaged tree canopy samples is ultimately used to quantify the level of damage. The co-evolution of the optical Sentinel-2-based NDVI and the Sentinel-1 signal during the drought phases are evaluated to verify the complementarity of Sentinel-1 SAR to optical data, which lays out the promising potential of using SAR remote sensing information to assess drought-induced tree canopy damage in deciduous broadleaf forests.

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