Machine Learning Derived SAR Vertical Reflectivity Profiles for Forest Height Estimations

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Abstract

Forests have a crucial role in the global carbon cycle, storing vast amounts of carbon in their biomass and soils. For understanding forest structure and its contribution to the carbon cycle, it is essential to accurately estimate forest height [1]**.** It has been demonstrated that the Interferometric Synthetic Aperture Radar (InSAR) is a powerful remote sensing technology for estimating forest height, providing high-resolution forest height and vertical structure information [2]. However, InSAR-based forest height estimation is affected by temporal decorrelation, the underlying assumption for the vertical reflectivity profile (VRP), and topographic effects [3]. Due to the gap between realistic conditions and model parameters, these factors can impact the accuracy and performance of the physical model used for inversion. In addition, the PM overestimates the small trees and underestimates the high trees because of their sensitivity. Machine learning techniques have been developed to mitigate these effects and improve accuracy, but might lack generalization and interpretability. Because they are not constrained by a physically viable solution.

The InSAR physical models for forest height inversion relay on assuming a VRP for the model inversion. However, the underlying VRPs are dependent on forest structure and density, topography, acquisition geometry, and wavelength. In this paper, a hybrid modeling (ML + PM) approach is used to describe VRPs, then subsequently using VRPs as an input for an interferometric coherence model [4]–[6]. To define the VRPs as a set of coefficients, we use the Legendre series with seven Polynomials [4]. Whereas, the Legendre coefficients are derived using multilayer perceptron (MLP) from the input features of the network. Thereafter, the interferometric coherence model uses as inputs vertical-wavenumber, forest height, and derived VRPs to simulate the estimated coherence values during the training phase. The objective of the training phase is to find a set of coefficients that minimize the difference between the observed coherence from TanDEM-X and the estimated coherence from the interferometric coherence model. This framework provides abilities to derive the VRPs variability as a function of a multi-model dataset. Our proposed method consists of two main steps for inference to estimate the forest height: (1) applying the MLP model for determining the VRPs from the given input features and (2) applying PM techniques to predict the forest height.

We evaluated our proposed method using real-world InSAR data and LVIS LiDAR data acquired during the AfriSAR campaign over forested areas in Gabon [7]. We compared our method with other state-of-the-art methods, including fusion-based inversion from GEDI and TanDEM-X methods and traditional physical models [8]–[10]. The results demonstrate that our suggested method achieves high accuracy and can compensate for bias in the case of the general underestimation issue for high trees.

The paper aims to establish a novel hybrid modeling approach utilizing the integration of machine learning and physical modeling for forest height estimation. We incorporate multi-model data for the forest height estimation from single baseline single-polarimetric TanDEM-X (single-pass) interferometric coherence measurements. We discuss the challenges that need to be addressed and how

to integrate a multi-modal (LiDAR, Polarimetric SAR, etc.) in a general ML framework constrained with the PM.

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