On the role of Interferometric SAR features in deriving forest parameters using Deep Learning

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The wall-to-wall estimation of forest parameters is of fundamental relevance for monitoring and preservation efforts [1]. In this context, spaceborne synthetic aperture radar (SAR) systems represent an attractive information source for the retrieval of bio-physical parameters.

Up to now, modeling efforts founded on physical-based principles have represented the state of the art in forest parameter prediction, while simultaneously offering a theoretical interpretation of the electromagnetic interactions between the radar waves and the forest structure [2].
More recently, deep learning (DL)-based approaches have shown the potential to surpass the estimation accuracy of classical methods by learning the underlying relationship directly from the data without the need for privileged information sources [3]. Despite this, a major downside to DL-based approaches remains the difficult interpretation of the learnt models, due to their high dimensionality and non-linearity.

In this work we present a complete analysis on the derivation of forest parameters from single-pass interferometric SAR (InSAR) acquisitions using a DL-based modeling approach. First, we present a state-of-the-art model for the estimation of forest height from TanDEM-X single-pass interferometric data in the challenging context of the Gabonese tropical forests. Subsequently, we focus on assessing the relevance of the different SAR- and InSAR-derived predictors by systematically probing the model for different subsets of input data.
Finally, we motivate the relevance of each feature on the regression task based on the theory of SAR and InSAR image formation, and on experimental evidence.

In our analyses we find that the interferometric coherence and phase features hold the most relevant information regarding the inversion problem. Despite this, we also show that the backscatter maps help to discriminate the context of the regression problem.
Crucially, the acquisition digital elevation model (DEM) and the local incidence angle maps are shown to correctly inform the model about the side-looking acquisition geometry of the SAR system.
Finally, we use a LiDAR-derived digital terrain model (DTM) to discuss two further contributions. On the one hand, we show that the local mean phase center variability, captured within the acquisition DEM, uniquely allows the model to distinguish between presence and absence of short vegetation.
On the other hand, we demonstrate that for the local incidence angle computation the removal of the vegetation bias, present in the acquisition DEM, leads to significant performance improvements.

Overall, we demonstrate the need for DL-based approaches to move away from the "black-box" paradigm in favor of a more physics-aware definition of the model predictors, especially when considering SAR and InSAR data as the source of information.
In light of future and upcoming single- and repeat-pass missions, such as NISAR and Biomass, we highlight the necessity for interferometric capabilities in the context of forest parameters estimation.

[1] *Global Forest Resources Assessment 2020*. FAO, 2020. doi: 10.4060/ca9825en.
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[3] D. Carcereri, P. Rizzoli, D. Ienco, and L. Bruzzone, "A Deep Learning Framework for the Estimation of Forest Height From Bistatic TanDEM-X Data," *IEEE J. Sel. Top. Appl. Earth Observations Remote Sensing*, vol. 16, pp. 8334–8352, 2023, doi: 10.1109/JSTARS.2023.3310209.