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Mapping Forest Height in Gabon Using UAVSAR Multi-Baseline Polarimetric SAR Interferometry and Lidar Fusion

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1. Introduction

- We used airborne remote sensing data from NASA's Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) and Land, Vegetation, & Ice Sensor (LVIS) lidar to map forest canopy height for a study area in Pongara National Park, Gabon. These data were collected as part of NASA's AfriSAR campaign in 2016.
- We developed a new deep learning-based method to perform data fusion of radar and lidar forest height estimates. The result has the wide coverage area and high spatial resolution of UAVSAR, but with improved accuracy compared to a purely radar-based approach.
- Obtaining high resolution maps of forest height is important for understanding the ecosystem carbon budget, and for quantifying the effects of deforestation and forest growth. Forest biomass can be estimated from forest height using allometric equations derived from field measurements.
- Developing methods for fusion of radar and lidar data is vital to make optimum use of data from future spaceborne missions, such as the NASA-ISRO SAR (NISAR) and the Global Ecosystems Dynamics Investigation (GEDI) lidar. Our method is designed to be used with lidar data with a similar sample spacing as that expected from the GEDI mission.

3. Results

- The estimated forest canopy height map for our proposed method is shown in Fig. 4. This study area contains extensive mangrove and inland forest coverage, and a wide range of forest canopy heights up to 50 m.
- A density plot comparing the forest height estimates from the proposed method vs. the LVIS RH100 testing set (all LVIS samples not used to train the DNN) is shown in Fig. 5.
- A scatter plot comparing the proposed method to the maximum forest height of 17 field plots within the area is shown in Fig. 6.
- The results have greater accuracy than those using the standard baseline selection methods found in the literature, and greater spatial coverage (30 m spatial resolution, with no gaps between samples) than the LVIS data used for training. The results demonstrate strong agreement with both the LVIS testing set and the in situ field data (linear fits with r^2 of 0.87 and 0.97, respectively).

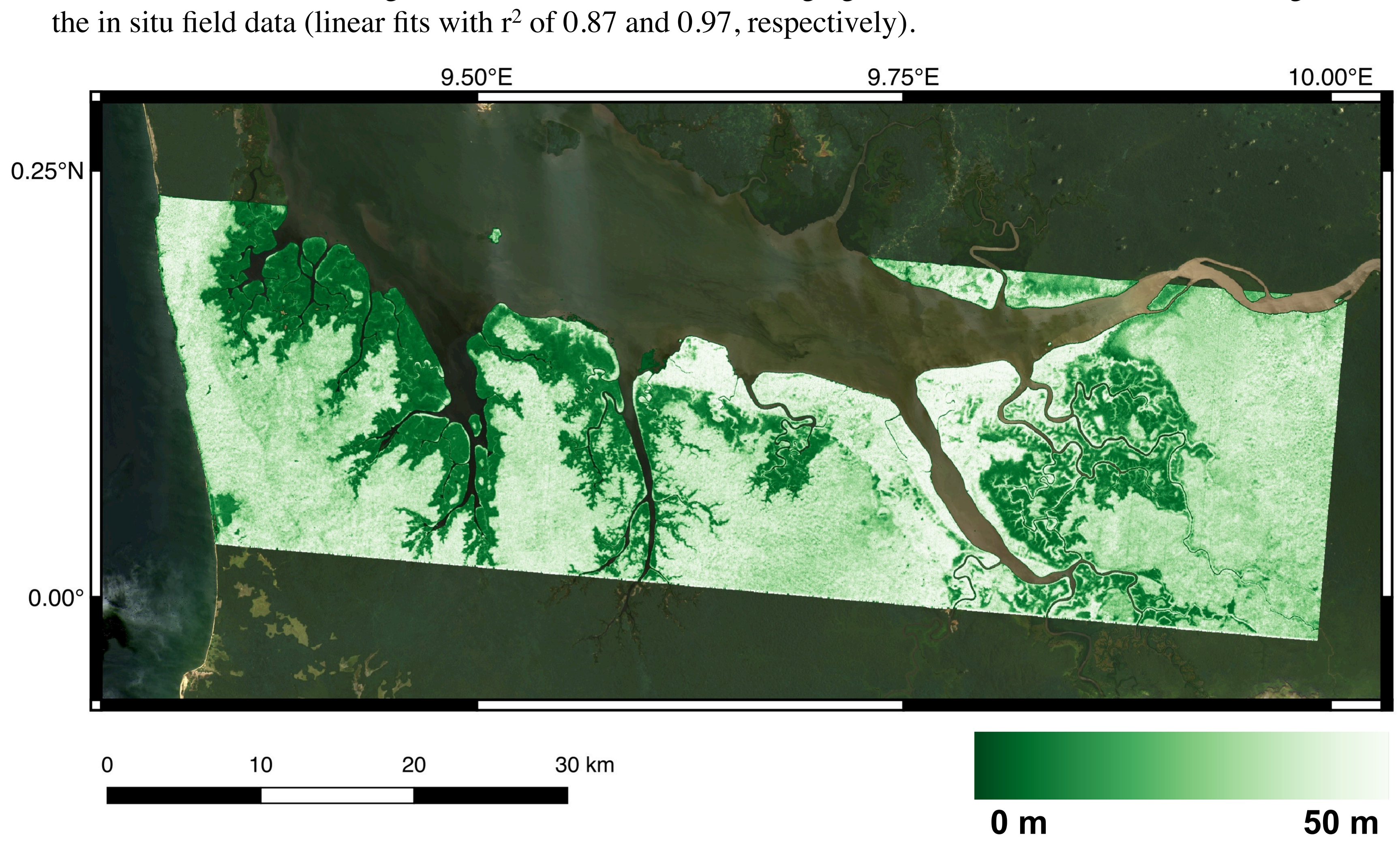

Fig. 4. Forest height map created using UAVSAR and LVIS fusion for Pongara National Park, Gabon. Overlaid on Landsat-8 imagery, available from U.S. Geological Survey.

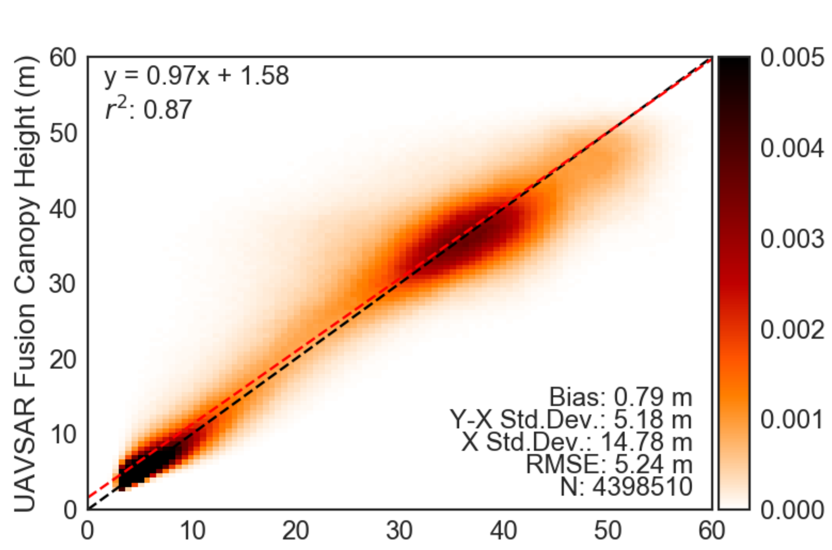

Fig. 5. Density plot of forest height using the proposed fusion method vs. LVIS RH100 forest height.

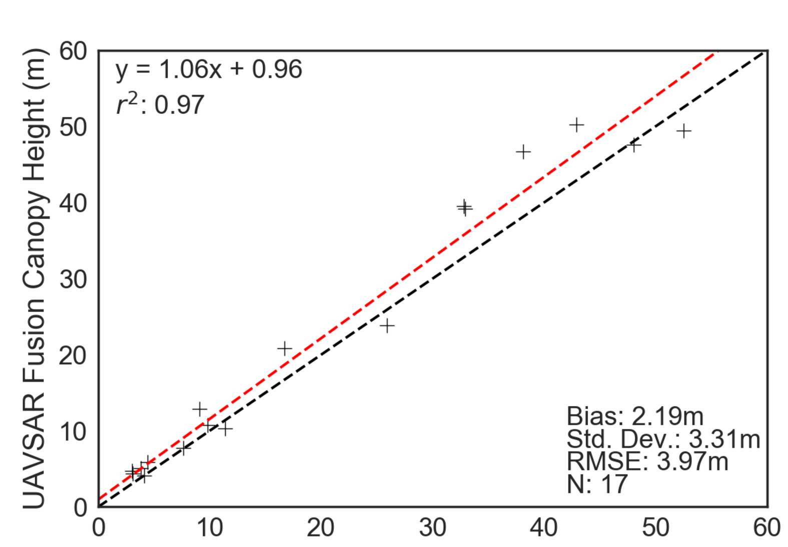

Fig. 6. Scatter plot of forest height using the proposed fusion method vs. field data.

2. Methods

- We estimate forest heights from the UAVSAR data using polarimetric synthetic aperture radar interferometry (PolInSAR) and the random volume over ground (RVoG) forest model, which relates the physical characteristics of the forest to the radar observations.
- For multi-baseline data (i.e., greater than two different flight tracks, see Fig. 1), we can estimate multiple independent forest height estimates from the various baselines which must then be weighted or selected in order to obtain a single forest height for each radar image pixel. For this dataset, UAVSAR data was collected from 4 spatially separated flight tracks, making baseline selection a vital step in the forest height estimation process.
- We tackled this baseline selection problem using a deep neural network (DNN) classifier. The input feature set contained a variety of radar-derived metrics based on the PolInSAR coherences and coherence region shape, viewing and terrain geometry, and radar backscatter. A flowchart of the method is shown in Fig. 2. The structure of the DNN classifier is shown in Fig. 3. The DNN was trained using a sparse subset of the LVIS relative height 100 (RH100) data with 600 m between simulated lidar tracks and 60 m sample spacing along track, similar to GEDI.

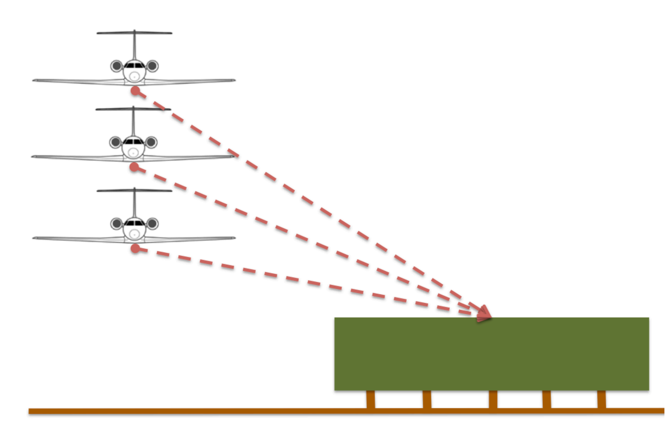

Fig. 1. Repeat UAVSAR passes over a forested area. Each pair of flight tracks can be used to form an interferometric baseline, with forest height sensitivity based on the spatial separation between the tracks.

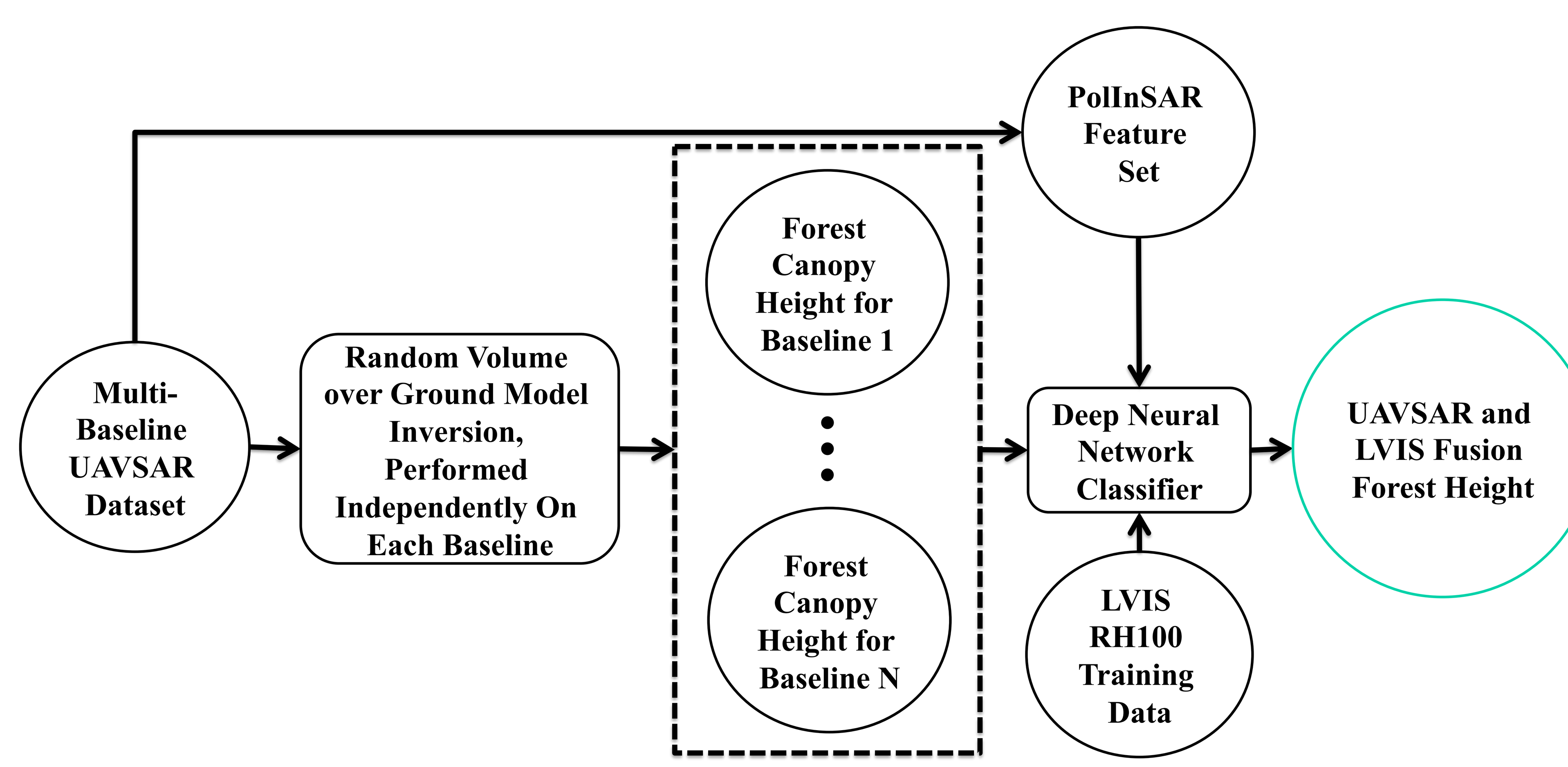

Fig. 2. Flowchart of the forest height fusion method.

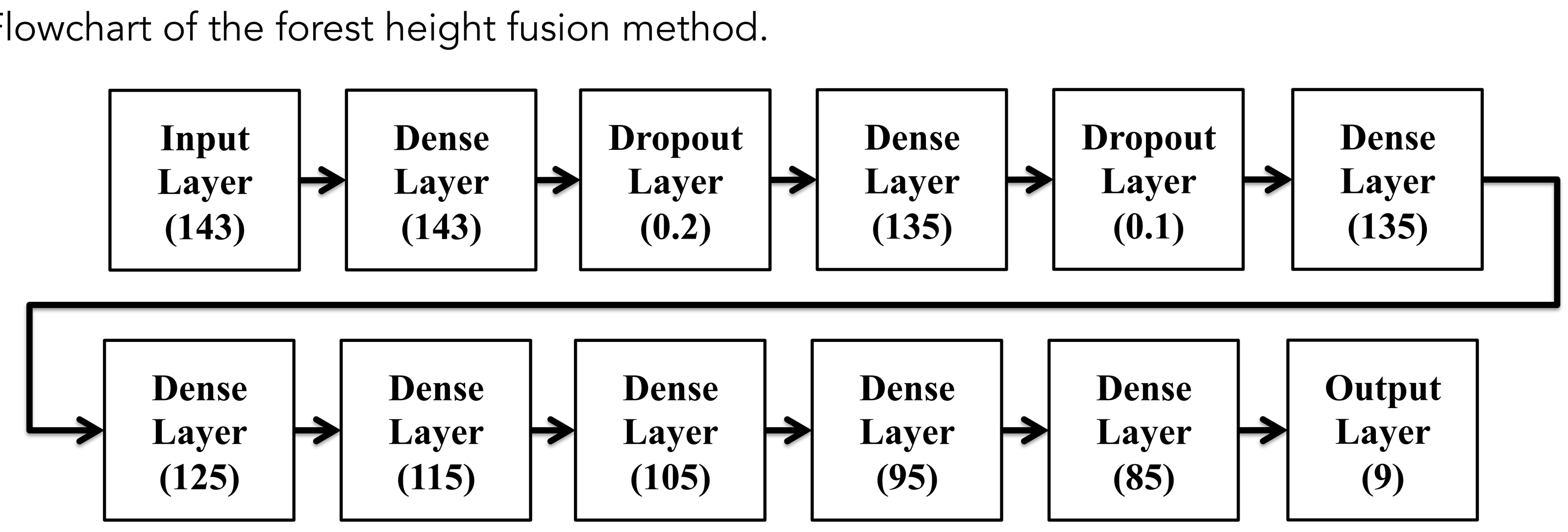

Fig. 3. Structure of the deep neural network classifier. For the input, output, and dense (hidden) layers, the number in parentheses is the number of neurons in the layer. For the dropout layers, the number in parentheses is the dropout factor (e.g., for a factor of 0.2, 20% of the inputs to that layer are randomly discarded, in order to reduce overfitting). The size of the layers gradually reduces in order to reduce the number of neurons to a more meaningful feature set (built-in feature selection). The dense layers use a rectified linear activation function, and the output layer uses a softmax activation function. The classifier is trained using the categorical cross entropy loss function and the Adam optimizer.

4. Conclusions

- **Developed a new method for fusion of PolInSAR and lidar data in order to generate more accurate PolInSAR forest height estimates. Resulting forest height maps have a high spatial resolution (30 m) and a wide coverage area (22 km swath width of UAVSAR).** The method considers the PolInSAR baseline selection process as a supervised classification problem, which we perform using a deep neural network classifier trained with sparsely distributed lidar-derived forest heights.
- **Produced forest height maps for Pongara National Park in the country of Gabon.** Results validated using LVIS samples excluded from the data fusion procedure with RMSE of 5.24 m, and using 17 field data plots with RMSE of 3.97 m. For comparison, we also performed baseline selection using standard radar-derived data quality metrics (coherence region eccentricity, and expected phase center height variance), but these methods resulted in less accurate forest height estimates (RMSE values of 7.4 m compared to the LVIS RH100 testing set and field data).
- **Results demonstrate the strong potential for fusion of spaceborne PolInSAR and lidar data**. Sparse lidar sample spacing of 600 m between tracks and 60 m along track is sufficient for training the classifier. Data from the Global Ecosystem Dynamics Investigation (GEDI) lidar will satisfy this requirement, though the data is expected to be noisier than the LVIS airborne lidar data used in this study. Future work can address the impact of the increased noise on the resulting fusion forest height maps, as well as on applying this method to other datasets and study areas.

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