Better Coherence, Better Height: Fusing Physical Models and Deep Learning for Forest Height Estimation from Interferometric SAR Data

Supplementary Material

6. Random Volume over Ground Model

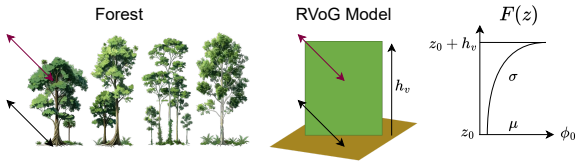


Figure 8. The RVoG model describes the forest structure as a two-layer scattering model with ground elevation z_0 and volume height h_v. $F(z)$ is the radar reflectivity of the forest scatters at different heights z and decays as a function of the extinction coefficient σ, the ground phase ϕ_0 and the ground-to-volume amplitude ratio μ.

The RVoG model illustrated in Figure 8 is one of the most commonly used physcial models for InSAR-based forest height inversions.

7. Study Sites of the AfriSAR Campaign

During training, reference height from the AfriSAR campaign is used. The study area for the campaign is Gabon as it is densely forested country with rich structural and functional biodiversity. During the AfriSAR campaign, over 7000 km^2 of waveform Lidar data from LVIS were collected from 10 key sites. The four regions used for training and testing are shown in Figure 9 and geographical coordinates are given in Table 2. The target data used in our study is open-access through AfriSAR campaign and avaialble via Nasa's EarthData portal.

The corresponding SAR acquisitions for this region are obtained by the TanDEM-X (DLR) satellite mission. In 2016, TanDEM-X was operated on the coinciding regions of the AfriSAR region for further scientific experiments with bistatic modes of operation. The SAR images used in this study are the CoSSC (Co-registered Single Look Slant Range Complex) product and derived features. Bistatic sensors such as TanDEM-X consist of two satellites flying in a close formation separated by a spatial baseline acquiring SAR data simultaneously from the same area. The two acquired SAR images are focused and spatially aligned before being used for further processing. The resulting dataset after performing computations for coherence, volumetric decorrelation, and resampling the LVIS Heights from AfriSAR campaign has a storage size of ∼19GB.

8. Performance Metrics

To test model performance we use the Root Mean Squared Error (RMSE)

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \tag{5}$$

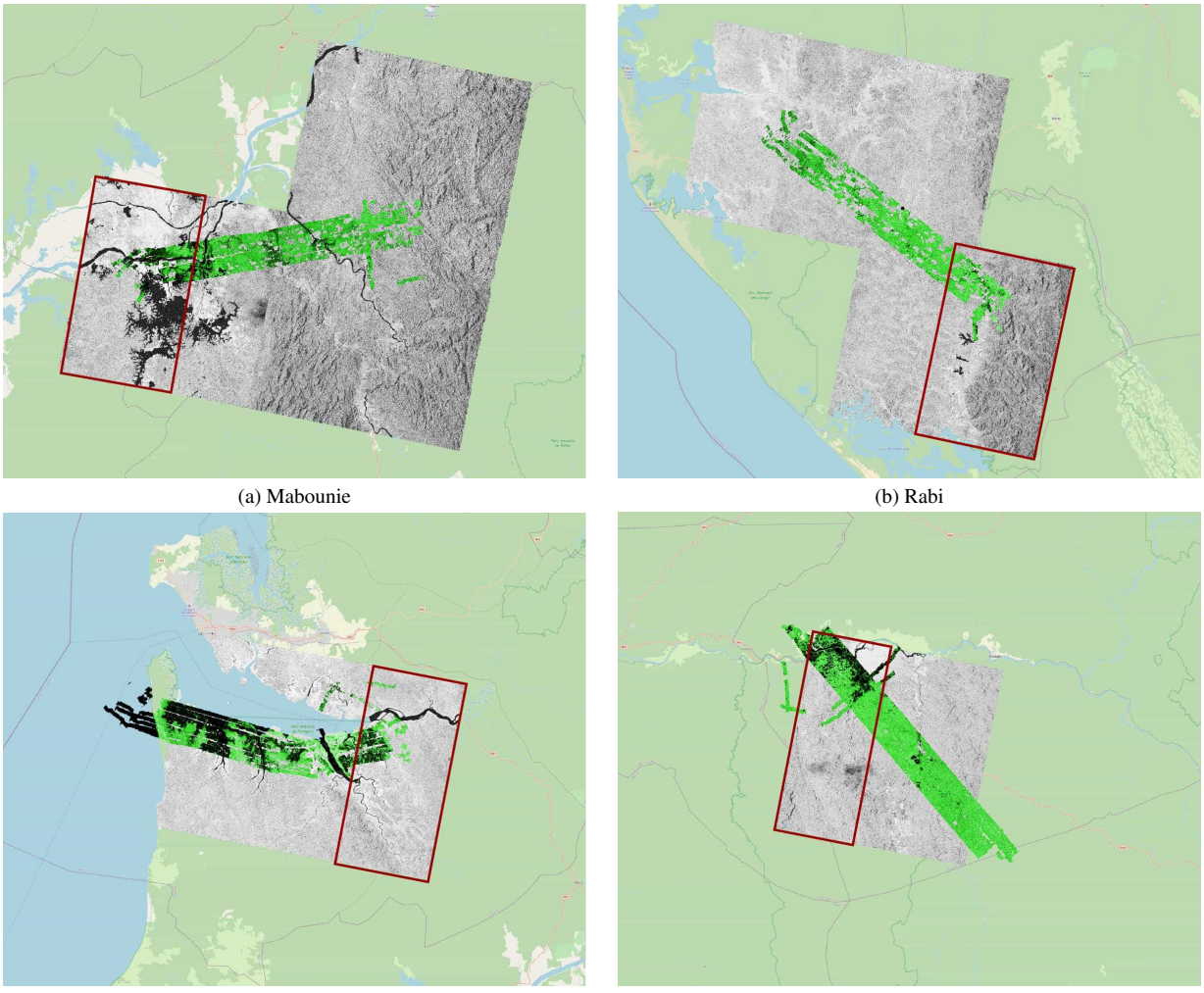
and the coefficient of determination R^2

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}, \tag{6}$$

where y_i is the reference height measurement (and $\bar{y}$ its mean value) and $\hat{y}_i$ is the predicted height.

9. Further CoHNet Qualitative Results

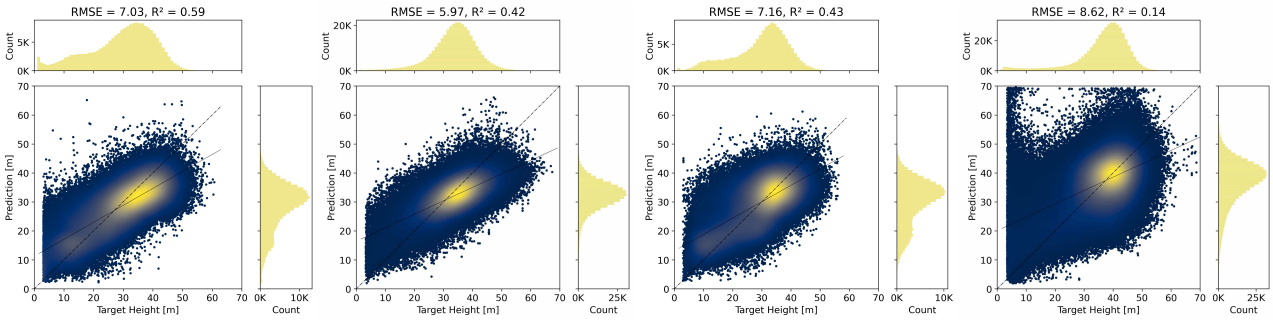
Figure 10 shows further quantitative results using density scatter plots with marginal height distributions for CoHNet forest estimates. While Figure 11 and Figure 13 show qualitative results of forest height prediction and estimated coherence values over all used Gabon regions such as Mabounie, Rabi, Pongara, and Lope.



(a) Mabounie (b) Rabi

(c) Pongara (d) Lope

Figure 9. Dataset visualization with training and test areas for the used regions of Mabounie, Rabi, Lope, and Pongara. The bright green color represents the target height measurements of LVIS overlaid on top of TanDEM-X coherence. Red rectangles indicate the test areas.



(a) Mabounie (b) Rabi (c) Pongara (d) Lope

Figure 10. Density scatter plots for height inversions with neural surrogate model using optimized volumetric decorrelation from CoHNet.

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Mabounie	9.935094	10.7425	-0.67959	-0.95097
Rabi	9.594942	10.27658	-1.68464	-2.29494
Pongara	9.179286	9.995917	0.265536	0.004522
Lope	11.39674	12.02394	-0.01559	-0.64224

Table 2. Geographical Coordinates of regions from Gabon used in this study.

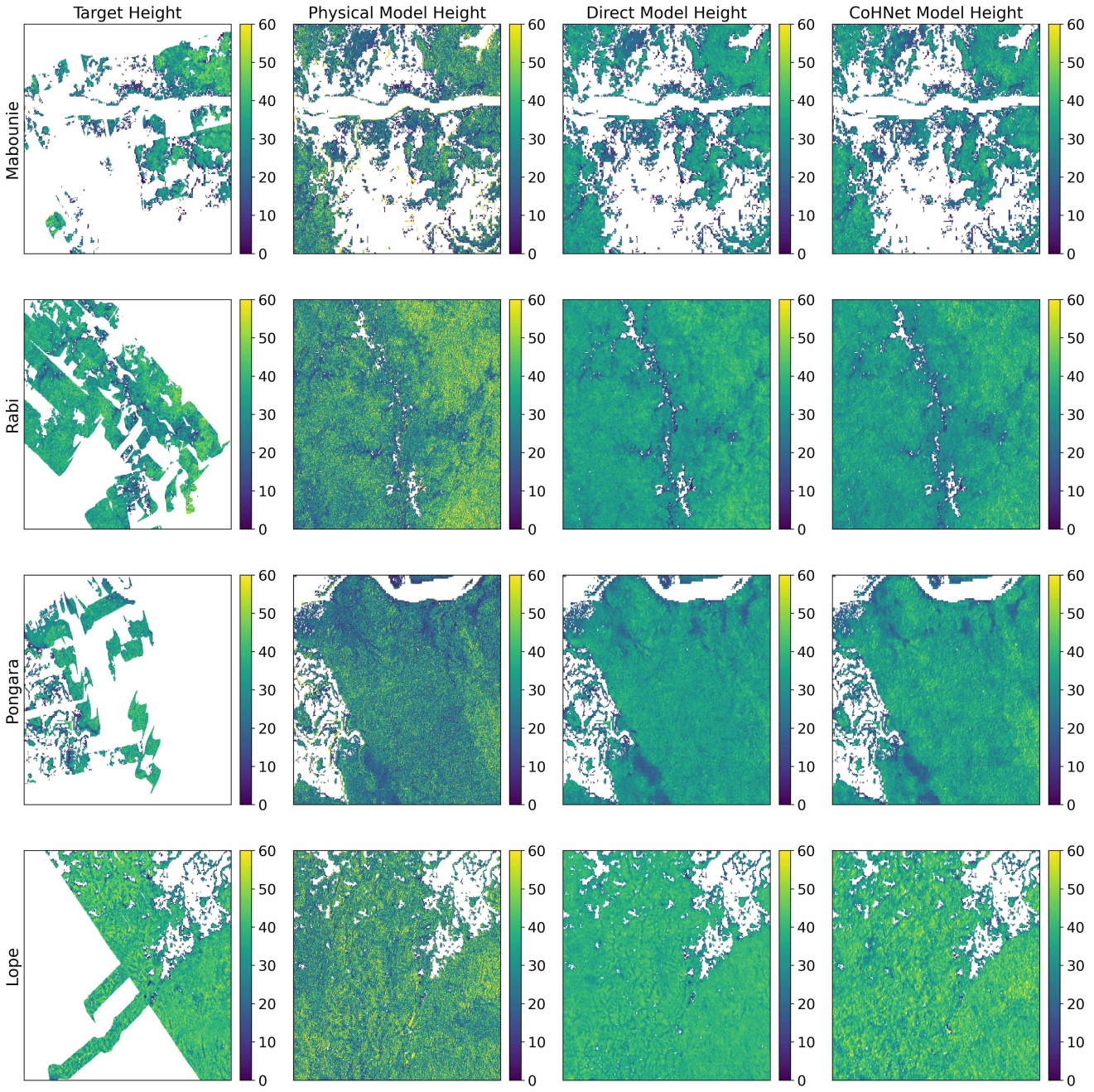


Figure 11. From left to right: Forest height as provided as reference value by LVIS and estimated by the physical model (RVoG), the direct model, and CoHNet for all used regions using the Gabon model. White regions in the reference data denote lack of LVIS measurements, while white regions in the model predictions denote non-forest areas for which the models are not applicable.

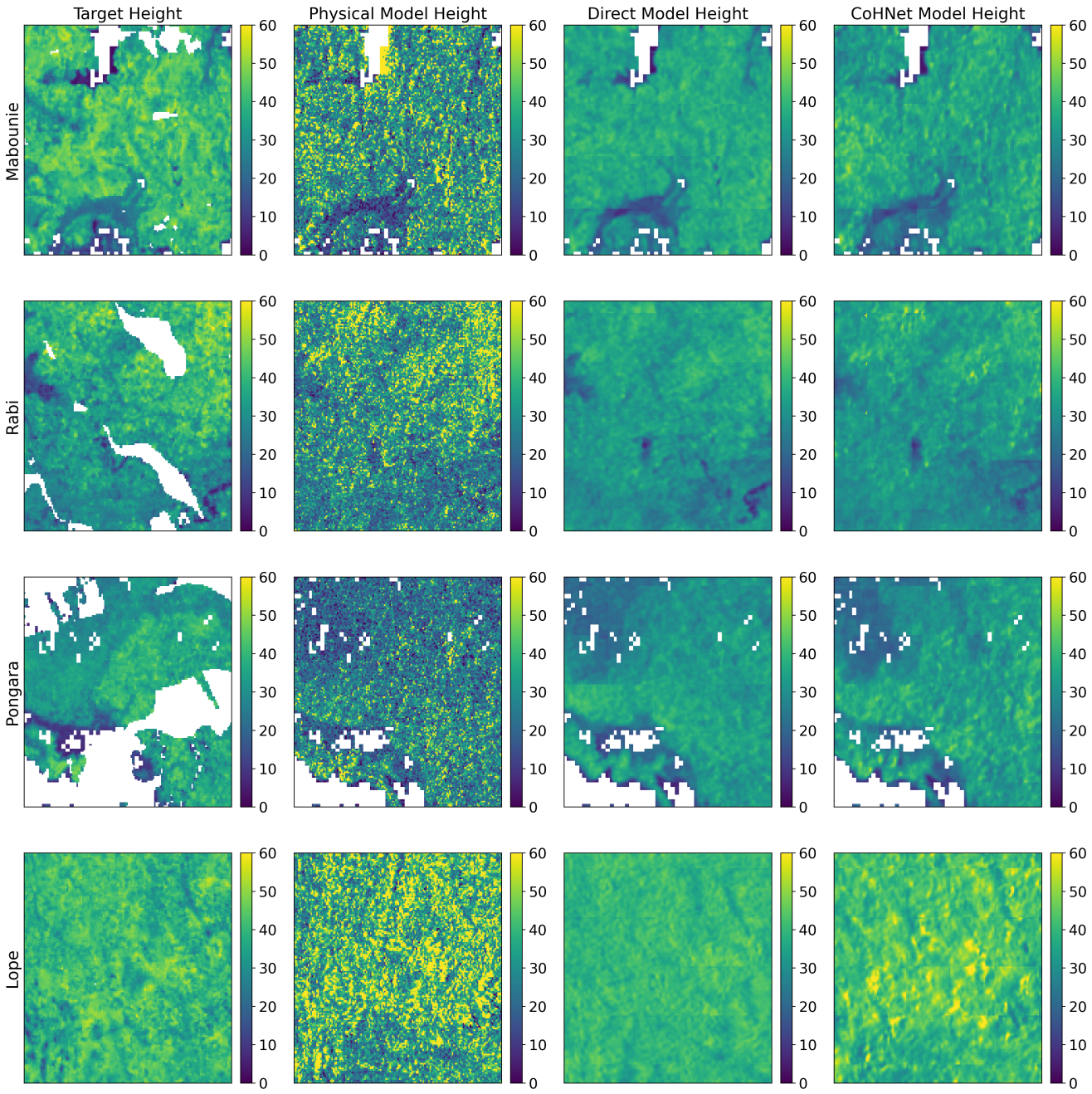


Figure 12. Zoomed in comparison, from left to right: Forest height as provided as reference value by LVIS and estimated by the physical model (RVoG), the direct model, and CoHNet for all used regions using the Gabon model. White regions in the reference data denote lack of LVIS measurements, while white regions in the model predictions denote non-forest areas for which the models are not applicable.

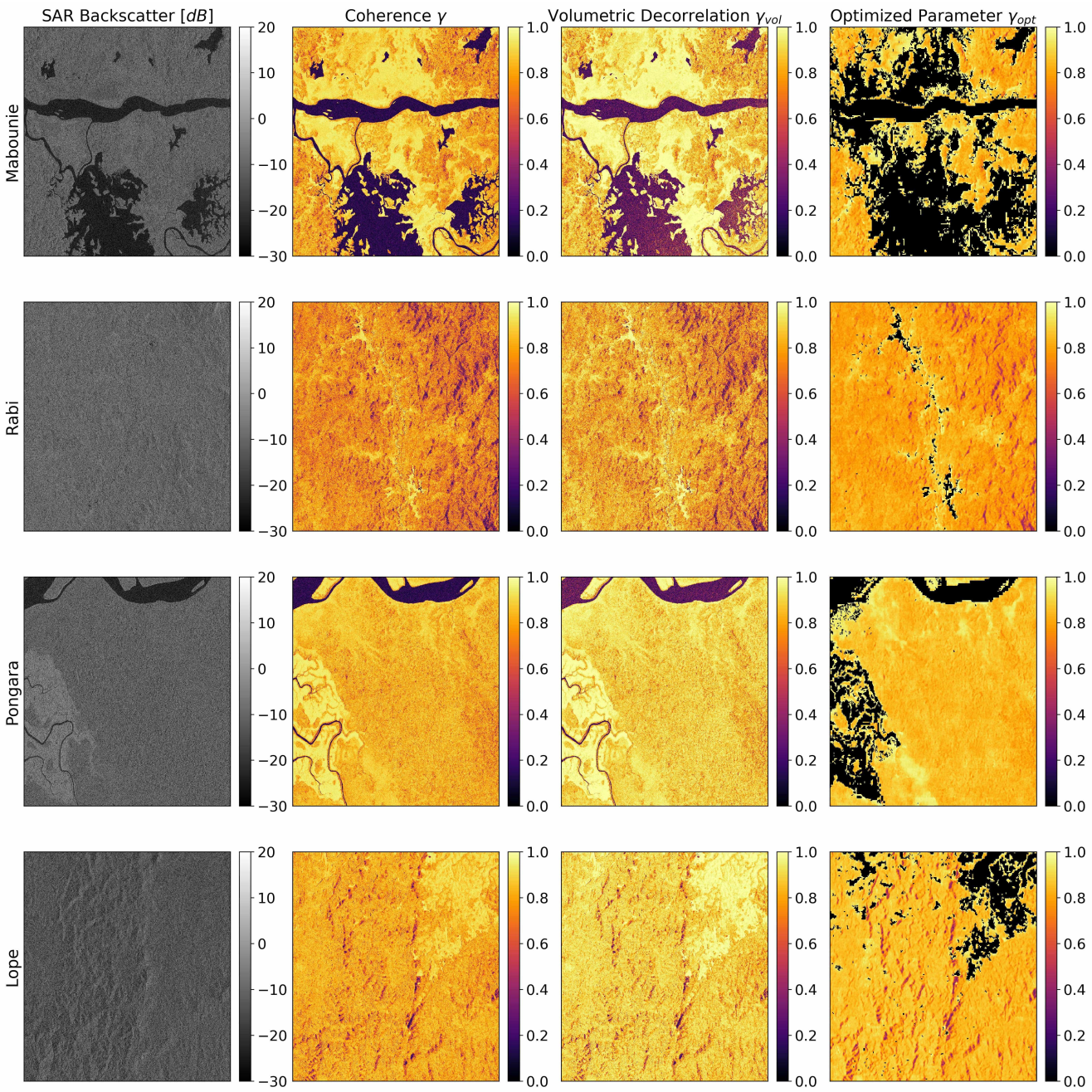


Figure 13. From left to right: SAR backscatter, input coherence γ, volumetric decorrelation γ_{Vol}, and optimized volume decorrlation $\hat{\gamma}_{\mathrm{Vol}}$ for all used regions. Black regions in the maps denote non-forest areas.

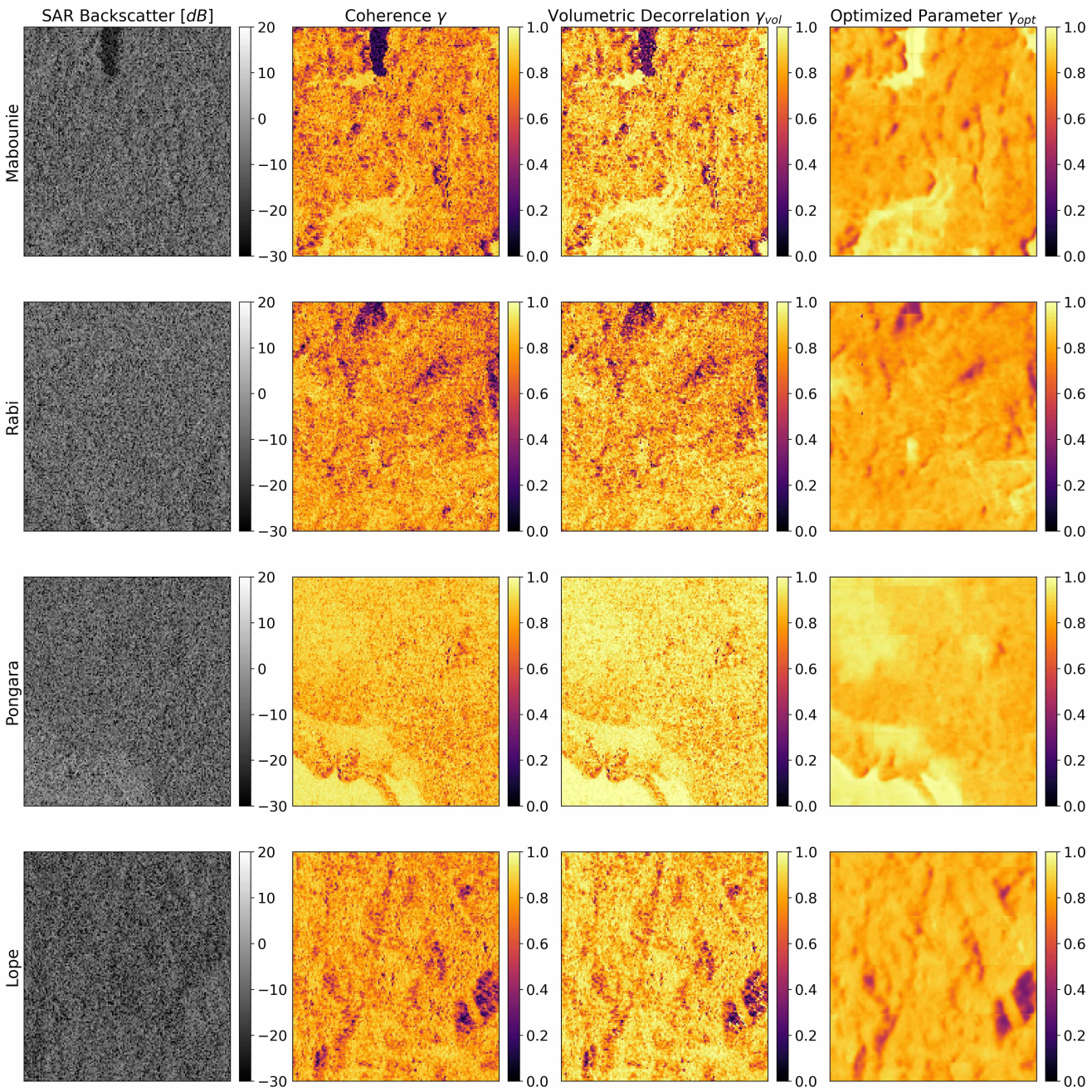


Figure 14. Zoomed in comparison, from left to right: SAR backscatter, input coherence γ, volumetric decorrelation γ_{Vol}, and optimized volume decorrlation $\hat{\gamma}_{\mathrm{Vol}}$ for all used regions.