


**Journal:** Remote Sensing of Environment

**Title:** Achieving accuracy requirements for forest biomass mapping: a data fusion method for estimating forest biomass and LiDAR sampling error with spaceborne data

**Authors:** Montesano, P.M.<sup>1,2,3,\*</sup>, Cook, B.D.<sup>2</sup>, Sun, G.<sup>3</sup>, Simard, M.<sup>4</sup>, Nelson, R.F.<sup>2</sup>, Ranson, K.J.<sup>2</sup>, Zhang, Z.<sup>3</sup>, Luthcke, S.<sup>2</sup>, Blair, J.B.<sup>2</sup>

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<sup>3</sup> University of Maryland, Department of Geographical Sciences, College Park, MD 20742

<sup>4</sup> Radar and Engineering Section, Caltech-Jet Propulsion Laboratory, Pasadena, CA, USA

### Popular Summary

Maps of both the extent and mass of terrestrial vegetation are needed to characterize Earth's rapidly changing forest cover, monitor disturbance, and assess biodiversity. Satellites can provide global scale measurements of forest cover with sufficient detail to map land surface changes. The accuracy of these maps determines how well we can understand the location and size of terrestrial sources and sinks of carbon. The need for accurate measurements of forests at or near the scale of forest disturbance drives global map accuracy requirements.

One control over the accuracy of biomass maps is the way in which LiDAR sample measurements are fused, or, used in concert, with multispectral and synthetic aperture radar (SAR) imagery, and the error associated with fusion estimates. Furthermore, the effect of this data fusion technique on map accuracy at different map scales is important for understanding the trade-offs between biomass map accuracy and spatial detail. This work aggregates LiDAR forest biomass measurements for spatially coincident forest patches, estimates forest biomass with multispectral and SAR imagery, and evaluates biomass and biomass errors associated with LiDAR sampling across the study area using three biomass estimation methods at 4 spatial scales ranging from 100m to 1km. The goal was to understand biomass estimates and LiDAR sampling errors at various scales that can be expected from near-term spaceborne LiDAR missions, and determine whether biomass estimates can meet spaceborne global biomass map accuracy requirements.

Our data fusion results demonstrate that incorporating forest patches into the biomass mapping framework can provide sub-grid forest information for coarser grid-level biomass reporting, and that combining LiDAR with SAR and multispectral data are most useful for estimating biomass when measurements from LiDAR are limited. Furthermore, spaceborne global scale accuracy requirements were achieved at each grid scale when all data types were used within a machine-learning decision tree routine for estimating biomass.

### Abstract

The synergistic use of active and passive remote sensing (i.e., data fusion) demonstrates the ability of spaceborne light detection and ranging (LiDAR), synthetic aperture radar (SAR) and multispectral imagery for achieving the accuracy requirements of a global

forest biomass mapping mission. This data fusion approach also provides a means to extend 3D information from discrete spaceborne LiDAR measurements of forest structure across scales much larger than that of the LiDAR footprint. For estimating biomass, these measurements mix a number of errors including those associated with LiDAR footprint sampling over regional - global extents. A general framework for mapping above ground live forest biomass (AGB) with a data fusion approach is presented and verified using data from NASA field campaigns near Howland, ME, USA, to assess AGB and LiDAR sampling errors across a regionally representative landscape. We combined SAR and Landsat-derived optical (passive optical) image data to identify forest patches, and used image and simulated spaceborne LiDAR data to compute AGB and estimate LiDAR sampling error for forest patches and 100m, 250m, 500m, and 1km grid cells. Forest patches were delineated with Landsat-derived data and airborne SAR imagery, and simulated spaceborne LiDAR (SSL) data were derived from orbit and cloud cover simulations and airborne data from NASA's Laser Vegetation Imaging Sensor (LVIS). At both the patch and grid scales, we evaluated differences in AGB estimation and sampling error from the combined use of LiDAR with both SAR and passive optical and with either SAR or passive optical alone. This data fusion approach demonstrates that incorporating forest patches into the AGB mapping framework can provide sub-grid forest information for coarser grid-level AGB reporting, and that combining simulated spaceborne LiDAR with SAR and passive optical data are most useful for estimating AGB when measurements from LiDAR are limited because they minimized forest AGB sampling errors by 15 – 38%. Furthermore, spaceborne global scale accuracy requirements were achieved. At least 80% of the grid cells at 100m, 250m, 500m, and 1km grid levels met AGB density accuracy requirements using a combination of passive optical and SAR along with machine learning methods to predict vegetation structure metrics for forested areas without LiDAR samples. Finally, using either passive optical or SAR, accuracy requirements were met at the 500m and 250m grid level, respectively.

**Keywords**

Data fusion; lidar; radar; sar; biomass; sampling error