NASA's Global Ecosystem Dynamics Investigation (GEDI): Progress towards global mapping of aboveground biomass

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1. Introduction

The Global Ecosystem Dynamics Investigation (GEDI) was proposed and selected as part of NASAs Earth System Science Pathfinder (ESSP) Earth Ventures 2 (EV-2) competition. The GEDI mission represents the culmination of almost 30 years of effort on the part of the terrestrial ecology community to provide critical data on the structure of the Earth's forests towards key science questions regarding the aboveground carbon balance of the Earth's land surface, the role of the land surface with regards to atmospheric CO_2 concentrations, and the impact of ecosystem structure on habitat quality and biodiversity.

The GEDI instrument was successfully launched in December of 2018 and subsequently installed on the Japanese Experiment Module-Exposed Facility (JEM-EF) on board the International Space Station (ISS). GEDI became fully operational in April 2019, when it began its two-year prime science mission and as of June 2021 has publicly released more than 18 months of on-orbit data over the Earth's tropical and temperate forests. The key driving factor that has determined mission operations during its prime mission is the GEDI Level 1 science requirements. All measurement requirements trace back towards achieving these. In terms of aboveground biomass density (AGBD), the GEDI mission is designed to acquire lidar canopy vertical profile data required to estimate AGBD for the Earth's global tropical and temperate forests at $\leq$ 1 km resolution. At the end of a two-year mission, AGBD of at least 80% of the 1 km cells is expected be estimated with a precision (standard error of the mean) of the larger of ±20 Mg / ha or 20% of the estimate, whichever is greater.

Here we present the status of GEDI's progress towards global mapping of AGBD and will discuss the major successes and challenges in achieving the measurement performance required for input to this mapping, as well as the outlook for an extended mission through to 2023.

2. Key results

In collaboration with the forest remote sensing and terrestrial ecology communities, GEDI has developed the Forest Structure and Biomass Database (FSBD), which is comprised of 31,414 simulated waveforms that are collocated with footprint level estimates of aboveground biomass. These have provided the means to train models representative of the entire GEDI observation domain (Hancock et al., 2019; Dubayah et al., 2020). Selected Level 4A models used to predict footprint AGBD from Level 2A canopy height metrics have % RMSE that range

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from 28.66% (evergreen broadleaf trees in Australia) to 66.89% (evergreen broadleaf trees in Africa), with a mean %RMSE of 51.34% across all selected models.

Between April 2019 and September 2020, over 5.7 billion science quality land surface shots were acquired, which has quantified spatial variation in canopy height, cover and vertical profile metrics at unprecedented spatial resolution. Evaluation of Level 2A estimates of canopy height collocated with the GEDI FSBD over evergreen broadleaf forests has shown an overall RMSE of 2.09 m to date, which is approaching the mission design precision of 2 m. Similarly, evaluation of on-orbit Level 2B canopy cover estimates using NASA Land, Vegetation and Ice Sensor (LVIS) data has shown an overall RMSE of 13%, which is within the mission design accuracy of minimum 10-20% (Bergen et al., 2009).

GEDI uses hybrid model-based statistical estimators to infer the mean AGBD and its uncertainty within each grid cell from the Level 4A models and predictions of AGBD (Patterson et al. 2019). GEDI ground tracks are treated as cluster samples under the hybrid inference paradigm, and at least two clusters are required to create a valid estimate. The output of this process is the Level 4B product, for which preliminary 1 km maps of AGBD and uncertainty estimated from quality waveforms acquired under leaf-on conditions between April 2019 and September 2020 are shown in Figure 1. Estimates are aggregated over larger areas for comparison with independent estimates from national forest inventory data (e.g., Menlov & Healey, 2020), accounting for dependencies between grid cells due to the same Level 4A models being applied and the same GEDI tracks intersecting multiple grid cells.

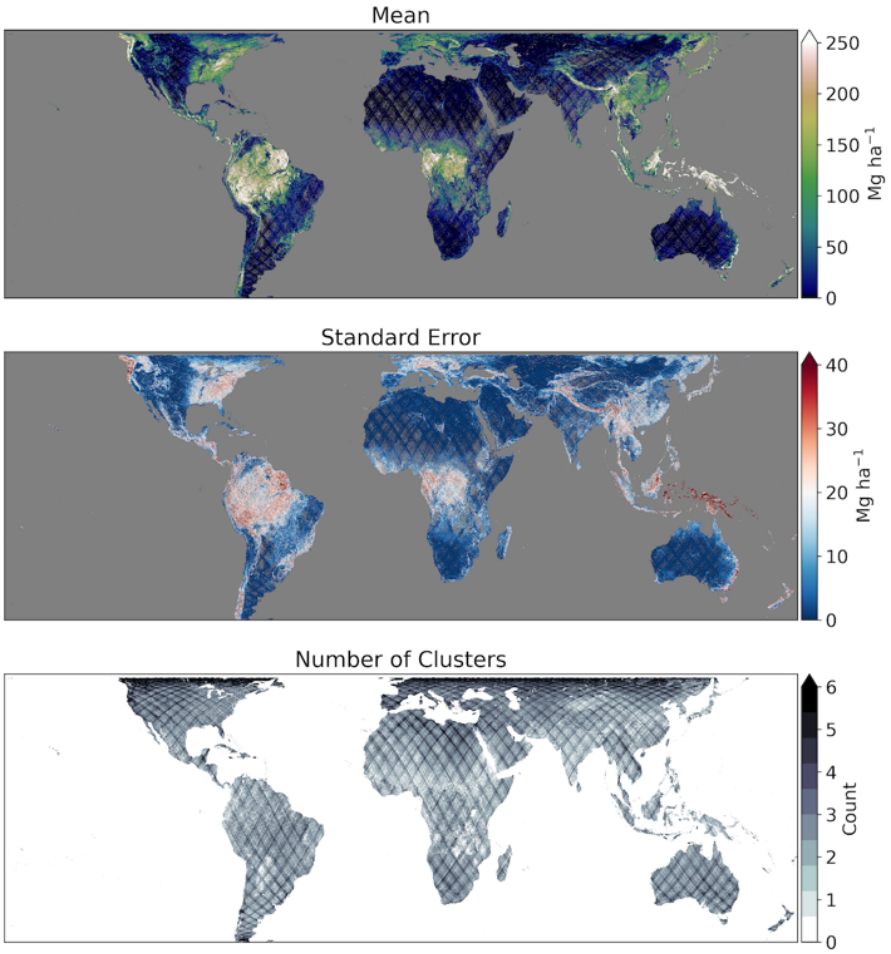

Figure 1. Preliminary Level 4B maps of 1 km estimates of the mean aboveground biomass density (top), standard error of the mean (middle), and the number of clusters (tracks) with quality waveforms acquired under leaf-on conditions used for estimation (bottom). These maps are based on 18 months of on-orbit data acquired between April 2019 and September 2020.

3. Status and outlook

GEDI has met or exceeded expectations with regards to the quality and quantity of its observations, derived canopy height, cover and vertical profile metrics, and how these are applied to advance GEDI science questions. GEDI is the first mission to design and implement a formal inference framework for the estimation of AGBD, enabling comparison with independent estimation of AGBD at multiple scales and unprecedented insights into the global quantity and distribution of carbon stocks. GEDI's prime mission was two-years, ending on-orbit acquisitions on 30 March 2021. New challenges introduced by unplanned change in the ISS altitude has recently limited GEDI's ability to uniformly sample the Earth's surface. Therefore, a longer time on orbit is now required to fully meet mission science requirements, with estimates ranging from 2-4 years depending on whether the ISS changes its orbital altitude.

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