GEDI AND TANDEM-X FUSION FOR 3D FOREST STRUCTURE PARAMETER RETRIEVAL

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Earth Ventures Instrument (EVI)

GEDI: Global Ecosystem Dynamics Investigation

- Selected in late 2014 for $94 M (Class C mission)
- Multi-beam waveform lidar instrument
  - NASA Goddard Spaceflight Center (GSFC)
- Deployed on International Space Station
  - Launch on SpaceX-17: Nov 2018
  - Observations between +/- 50°N/S
- Nominal 2 year mission length

GEDI is deployed on the JEM-EF (Japanese EXPERIMENT MODULE – EXPOSED FACILITY).
Mission Overview

High Resolution Laser Ranging of the Earth’s Forests and Topography

• GEDI produces high resolution laser ranging observations of the 3D structure of the Earth.

• GEDI makes precise measurements of forest canopy height, canopy vertical structure, and surface elevation.

• GEDI improves our ability to characterize important carbon and water cycling processes, biodiversity and habitat.

GEDI uses 3 lasers to produce 10 transects of lidar waveforms.
Science Questions and Objectives

GEDI Goal: Advance our ability to characterize the effects of changing climate and land use on ecosystem structure and dynamics.

- **Question**: What is the carbon balance of the Earth’s forests?
- **Quantify**: Forest Biomass

- **Question**: How will the land surface mitigate atmospheric CO2 in the future?
- **Quantify**: Disturbance and Recovery

- **Question**: How does forest structure affect habitat quality and biodiversity?
- **Quantify**: Carbon Sequestration Potential

- **Question**: What role does vertical forest structure play in biodiversity?
- **Quantify**: Vertical Forest Structure and its Relationship to Biodiversity

**Carbon Cycle**

**Biodiversity**
GEDI Lidar Measurements

GEDI’s sole observable is the lidar waveform which provides ground elevation, canopy height, cover and various profiles and metrics.

GEDI makes 12 billion observations of forest and land surface structure over its nominal two-year mission.
Science Approach and Data Products

<table>
<thead>
<tr>
<th>ATBD #</th>
<th>Data products</th>
<th>Product leads</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1A-2A</td>
<td>1A. Raw waveforms, 2A. Ground elevation, canopy top height, relative height (RH) metrics</td>
<td>Michelle Hofton, Bryan Blair</td>
<td>25 m (~82 ft) diameter</td>
</tr>
<tr>
<td>L1B</td>
<td>Geolocated waveforms</td>
<td>Scott Luthcke, Tim Rebold, Taylor Thomas, Teresa Pennington</td>
<td>25 m (~82 ft) diameter</td>
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<tr>
<td>L2B</td>
<td>Canopy Cover Fraction (CCF), CCF profile, Leaf Area Index (LAI), LAI profile</td>
<td>Hao Tang, John Armstrong</td>
<td>25 m (~82 ft) diameter</td>
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<tr>
<td>L3</td>
<td>Gridded Level 2 metrics</td>
<td>Scott Luthcke, Terence Sabaka, Sandra Preaux,</td>
<td>25 m (~82 ft) diameter</td>
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<tr>
<td>L4A</td>
<td>Footprint level above ground biomass</td>
<td>Jim Kellner, Laura Duncanson, John Armstrong</td>
<td>25 m (~82 ft) diameter</td>
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<tr>
<td>L4B</td>
<td>Gridded Above Ground Biomass Density (AGBD)</td>
<td>Sean Healey, Paul Patterson</td>
<td>1 km (~0.6 mi) grid</td>
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<tr>
<td>Demonstrative products</td>
<td>Prognostic ecosystem model outputs</td>
<td>George Hurtt</td>
<td>Grid size: Variable</td>
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<tr>
<td></td>
<td><strong>Demonstrative products</strong></td>
<td>Lola Fatoyinbo, Seung-Kuk Lee</td>
<td>Grid size: Variable</td>
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<tr>
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<td>Enhanced height/biomass using fusion with TanDEM-X</td>
<td>Matt Hansen, Chenquan Huang</td>
<td>Grid size: Variable</td>
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<td></td>
<td>Enhanced height/biomass and biomass change using fusion with Landsat</td>
<td>Scott Goetz, Patrick Jantz, Pat Burns</td>
<td>Grid size: Variable</td>
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<tr>
<td></td>
<td>Biodiversity/habitat model outputs</td>
<td>Scott Goetz, Patrick Jantz, Pat Burns</td>
<td>Grid size: Variable</td>
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</tbody>
</table>

GEDI Produces

GEDI Enables
GEDI & TanDEM-X Fusion

Can we fill in these gaps using fusion of TDX and GEDI?

- GEDI is sampling instrument
  - Gaps between ground tracks and adjacent swaths
- GEDI data combined with bistatic Interferometric SAR data from the TanDEM-X mission
  - Provide continuous mapping of forest structure and biomass while maintaining the fine resolution measurement of each footprint.
- **We focus on using the TDX product available globally (not dual polarization product) in RVoG**
Method 1: Extinction $\sigma$

- Using GEDI RH metrics, volume coherence is simulated on each GEDI footprint. → Optimization of the extinction
- Interpolation of $\sigma$ in a grid

Method 2: Ground Phase $\phi_0$

- GEDI ground-level DEM on each GEDI footprint → Interpolation
- Merging → GEDI DTM and TanDEM-X DEM

**Table:**

<table>
<thead>
<tr>
<th>Polarization</th>
<th>Independent Coherence</th>
<th>Assumption</th>
<th>Unknowns</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Pol.</td>
<td>$\tilde{\gamma}(\tilde{w}_1)$</td>
<td>$m_1 = 0$</td>
<td>$h_v, \sigma, \phi_0$</td>
<td>Underdetermined problem</td>
</tr>
</tbody>
</table>
Multi-Baseline TDX Inversion; Fusion DTM

- GEDI gridded CHM
- TDX height ($\sigma$, $\mu$)
- SRTM height

$\omega$ selection

TDX CoSSC$^1$
TDX CoSSC$^2$

InSAR Coherence

Volume Coherence$^1$
Volume Coherence$^2$
Volume Coherence$^i$

Forest Height Inversion

Forest Height

Biomass

<Lee et al. JSTARS 2018>
GEDI and TDX DEMs Merging; Wavelet

LVIS DTM (Airborne)

GEDI DTM (Spaceborne)

TanDEM-X DEM (Spaceborne)

GEDI + TDX DTM (Fusion)

- GEDI ground-track simulation
- Offsets are mitigated.
- Higher resolution

Wavelet Transform

\[
\Delta H = \begin{array}{c|c|c}
\text{Fusion DTM} & \text{GEDI DTM} & \text{TDX DEM} \\
\hline
\text{Mean} & 0.4 \text{ m} & 0.2 \text{ m} & 23.1 \text{ m} \\
\text{Std.} & 8.8 \text{ m} & 11.7 \text{ m} & 12.4 \text{ m}
\end{array}
\]
Forest Height Inversion Results

Lope, Gabon

DTM

TDX Forest Height

Validation

LVIS

R2 = 0.92
RMSE = 3.58 m

R2 = 0.81
RMSE = 5.47 m

LVIS CHM
Forest Height Inversion Results

Mondah, Gabon

LVIS RH95

Inversion using LVIS DTM

Pol-InSAR Inversion

R² = 0.870
RMSE = 2.886 m

Inversion using Fusion DTM

Pol-InSAR Inversion

R² = 0.755
RMSE = 3.717 m
Aboveground Biomass

Forest Height Map

Height-biomass allometric Eq. from GEDI waveform lidar data

Aboveground Carbon Map

0 700 Mg/ha
GEDI Webpage: https://gedi.umd.edu

Global Ecosystem Dynamics Investigation (GEDI)
High resolution laser ranging of Earth's forests and
topography from the International Space Station (ISS)

THE MISSION SCIENCE
GEDI will provide answers to how deforestation has
contributed to atmospheric CO₂ concentrations,
how much carbon forests will absorb in the future,
and how habitat degradation will affect global
biodiversity.
Thank you!