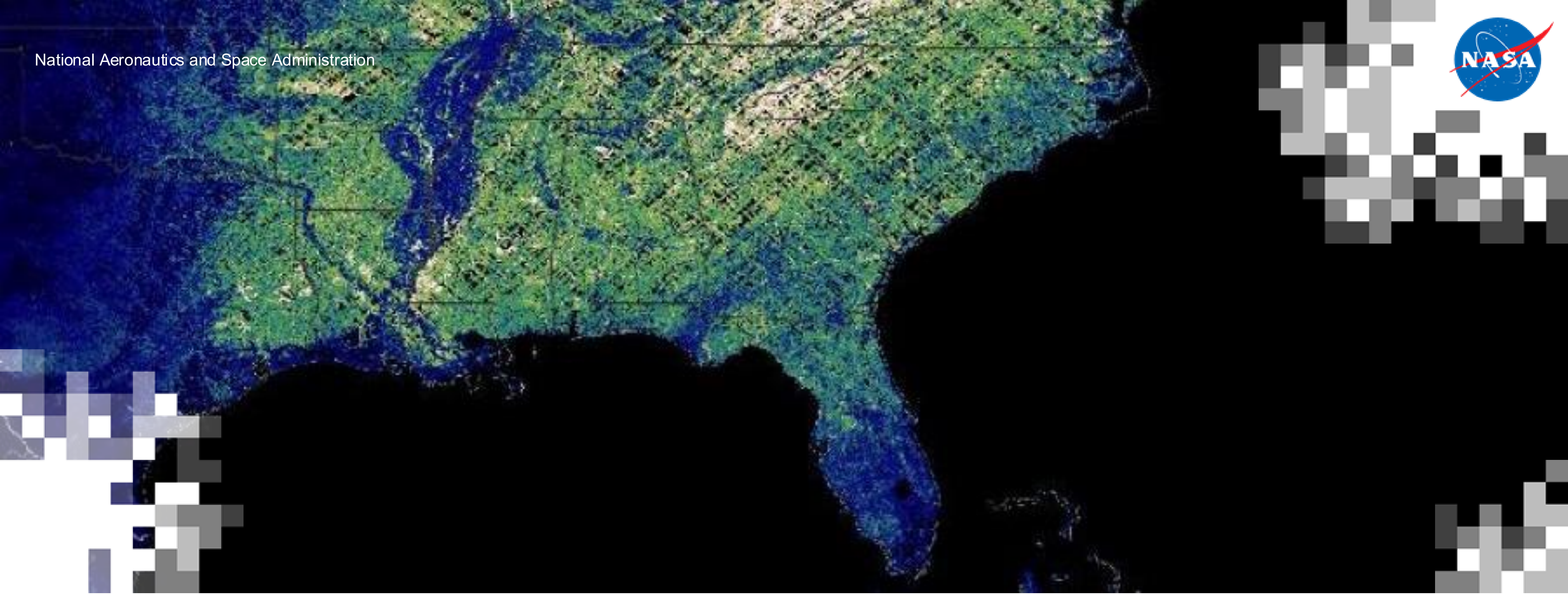
National Aeronautics and Space Administration

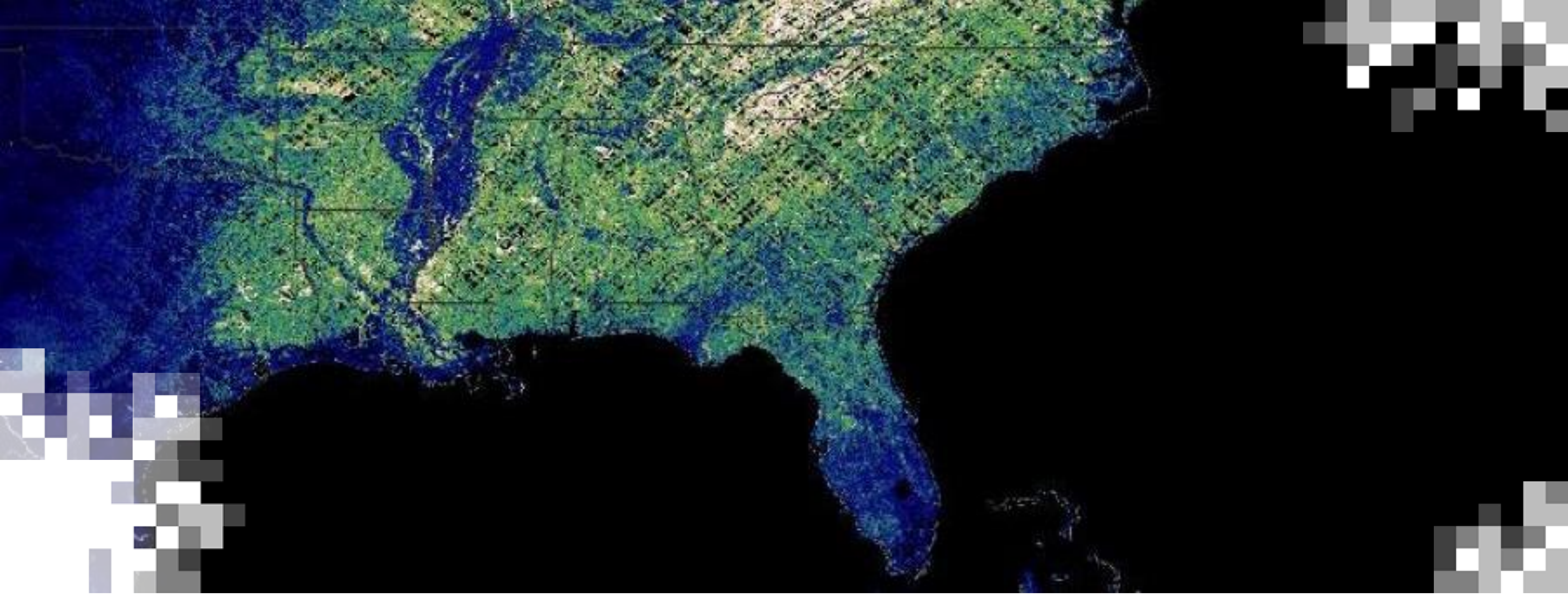


Estimating Biomass and Change with GEDI and the OBIWAN API

Session 1: Estimating Biomass using GEDI

Sean Healey, Ph.D., U.S. Forest Service (USFS) / U.S. Department of Agriculture (USDA)
Erika Podest, Ph.D., Jet Propulsion Laboratory/Caltech

May 21, 2026



About ARSET

OBI-WAN
Forest Carbon Reporting

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**
- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE

CLIMATE & RESILIENCE

DISASTERS

ECOLOGICAL CONSERVATION

HEALTH & AIR QUALITY

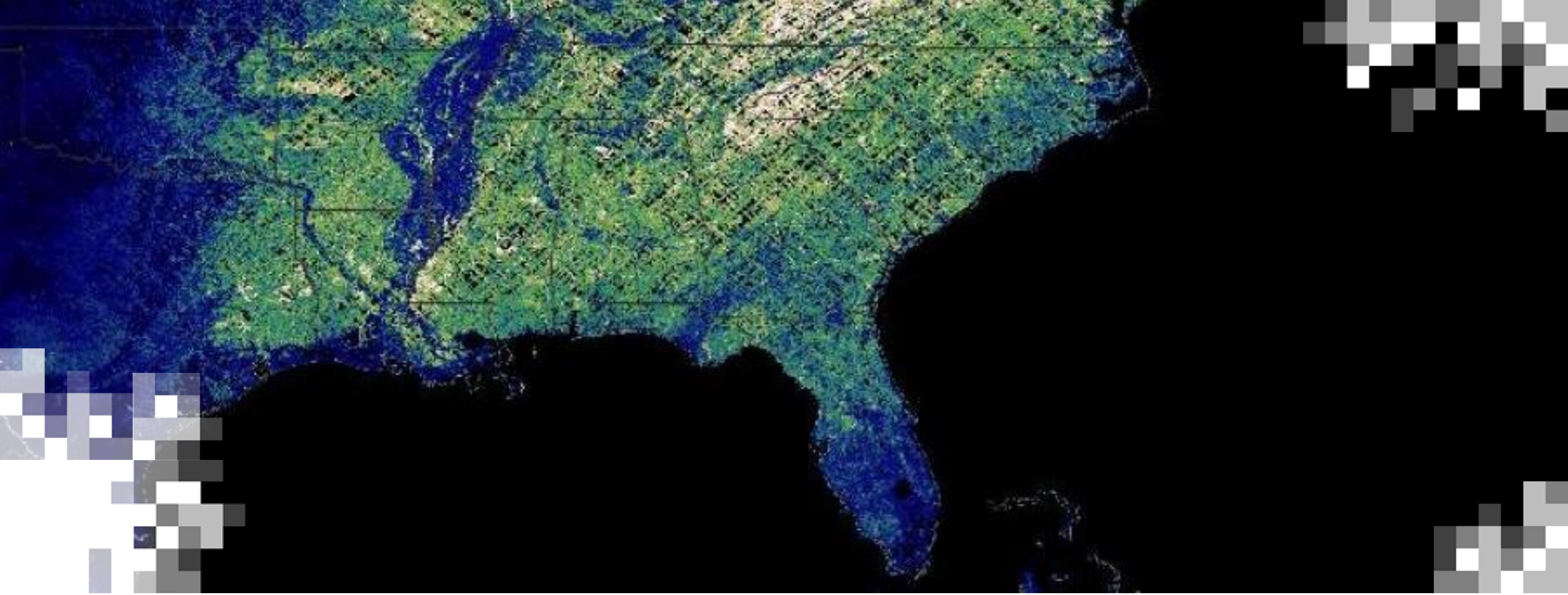
WATER RESOURCES

WILDLAND FIRES

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.



Estimating Biomass and Change with GEDI and the OBIWAN API

Overview

OBI-WAN
Forest Carbon Reporting

What's happening beneath the canopy?

Traditional satellites can't tell us.
Spaceborne lidar can.

Description: AmeriFlux BR-Sa1 Santarem Primary Forest site

Source: DOE, Lawrence Berkeley National Laboratory

Description: NASA's Global Ecosystems Dynamics Investigation (known as GEDI) onboard the International Space Station is the first spaceborne lidar optimized for measuring ecosystem structure.

Source: NASA

Training Learning Objectives

By the end of this training attendees will be able to:

- Identify fundamental characteristics of GEDI data and carbon monitoring, including data structure, uncertainty and system requirements.
- Apply methods for estimating biomass and biomass change, including the integration of GEDI with Landsat time series and calibration with forest inventory data.
- Evaluate the accuracy and uncertainty of biomass estimates using validation data.
- Use OBIWAN tools and APIs to generate and analyze biomass change products, including visualizing results for user-defined areas and comparing carbon gains to different climate scenarios.
- Evaluate advantages and disadvantages of the footprint level versus gridded level GEDI biomass products to determine which data are appropriate for a given use case.

Prerequisites

- ARSET – Fundamentals of Remote Sensing
- Spaceborne Lidar for Monitoring Vegetation Structure and Biomass using GEDI (or equivalent knowledge)

Suggested Trainings

- For intro to lidar and basics of accessing GEDI and ICESat data:
  - ARSET – Use of Solar Induced Fluorescence and LIDAR to Assess Vegetation Change and Vulnerability
- For interpretation of lidar imagery from past and current spaceborne lidars, including the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), the Cloud-Aerosol Transport System (CATS), the Ice, Cloud, and Elevation Satellite, version 2 (ICESat-2), and the Earth Cloud Aerosol Radiation Experiment (EarthCARE):
  - ARSET – LiDAR Profiling Satellite Observations for Air Quality Applications
- For familiarity on LVIS airborne laser altimeter:
  - ARSET – Biodiversity Applications for Airborne Imaging Systems
- LPDAAC access GEDI data tutorials

Training Outline

Session 1

Estimating Biomass using GEDI

May 21, 2026

11 AM - 12 PM EDT

Session 2

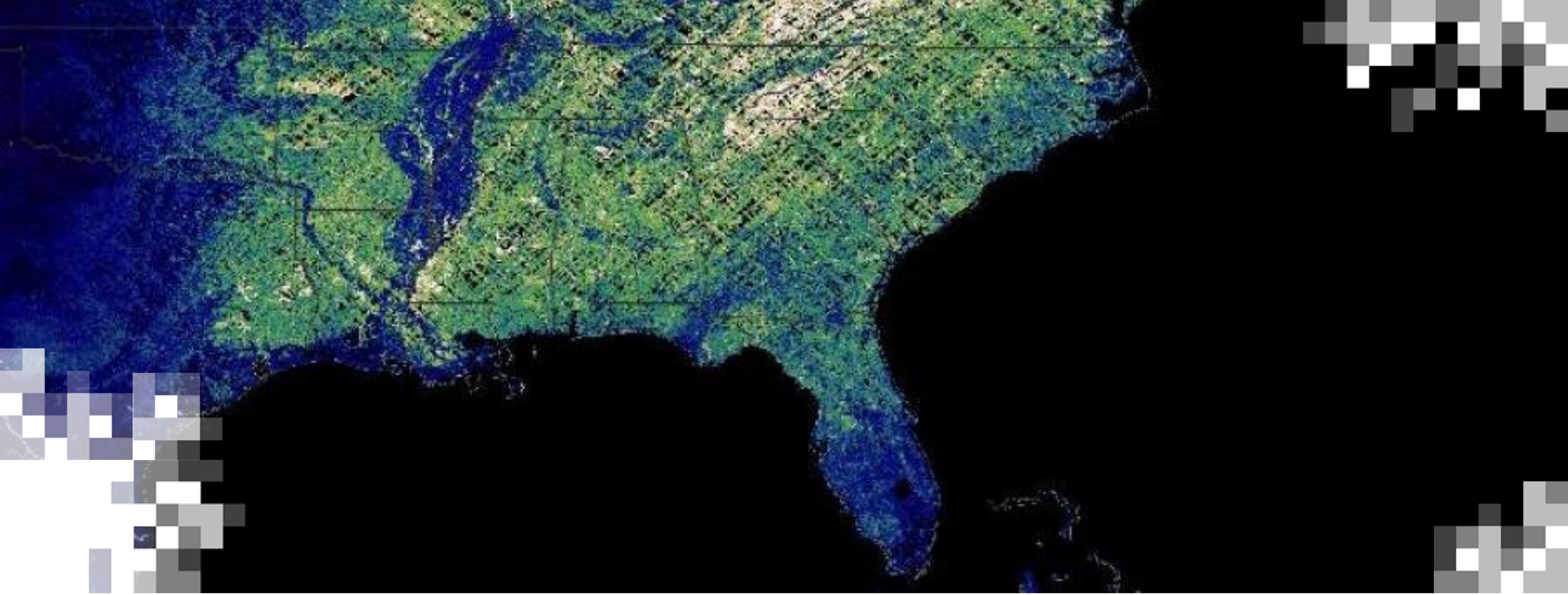
Estimating Biomass Change with GEDI and the OBIWAN API

May 28, 2026

11 AM - 12 PM EDT

Homework opens on May 28 – Due June 18 – Posted on the training Webpage

A certificate of completion will be awarded to participants who attend all live sessions and complete the homework assignment by the due date.



Estimating Biomass and Change with GEDI and the OBIWAN API

Session 1: Estimating Biomass using GEDI

OBI-WAN
Forest Carbon Reporting

Session 1 – Trainers

Sean Healey

Research Ecologist
USFS/USDA

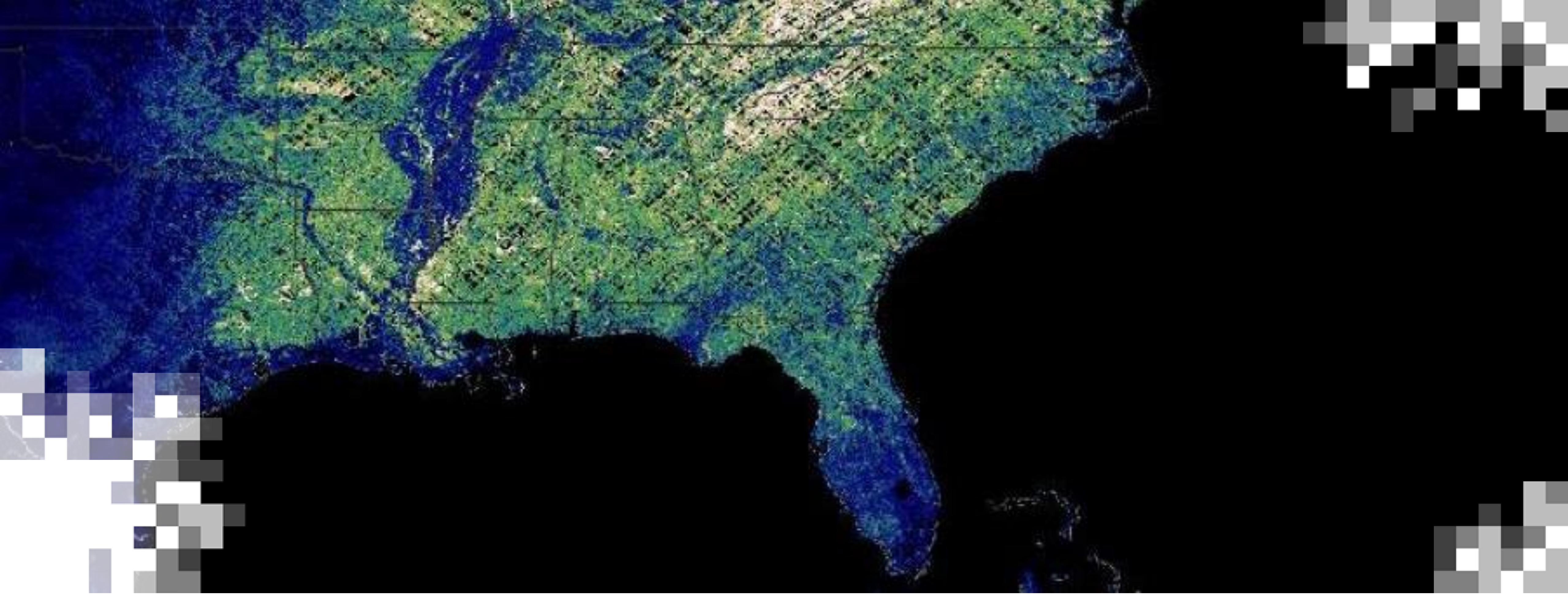
Session 1 Learning Objectives

By the end of this session, participants will be able to:

- Identify fundamental characteristics of GEDI data and carbon monitoring, including data structure, uncertainty and system requirements.
- Explain GEDI data structure and how uncertainty is characterized.
- Demonstrate how GEDI data are fused with Landsat time series and calibrated with forest inventory data to estimate biomass change.
- Apply GEDI estimation methods to visualize and generate biomass products for given user-defined areas of interest.

How to Ask Questions

- Please write your questions in the Questions box and we will address them at the end of the webinar.
- Please feel free to submit your questions throughout the webinar. We will do our best to address as many questions as possible during the live Q&A session following the presentation.
- Any remaining questions will be answered in a Q&A document, which will be posted on the training website approximately one week after the training.



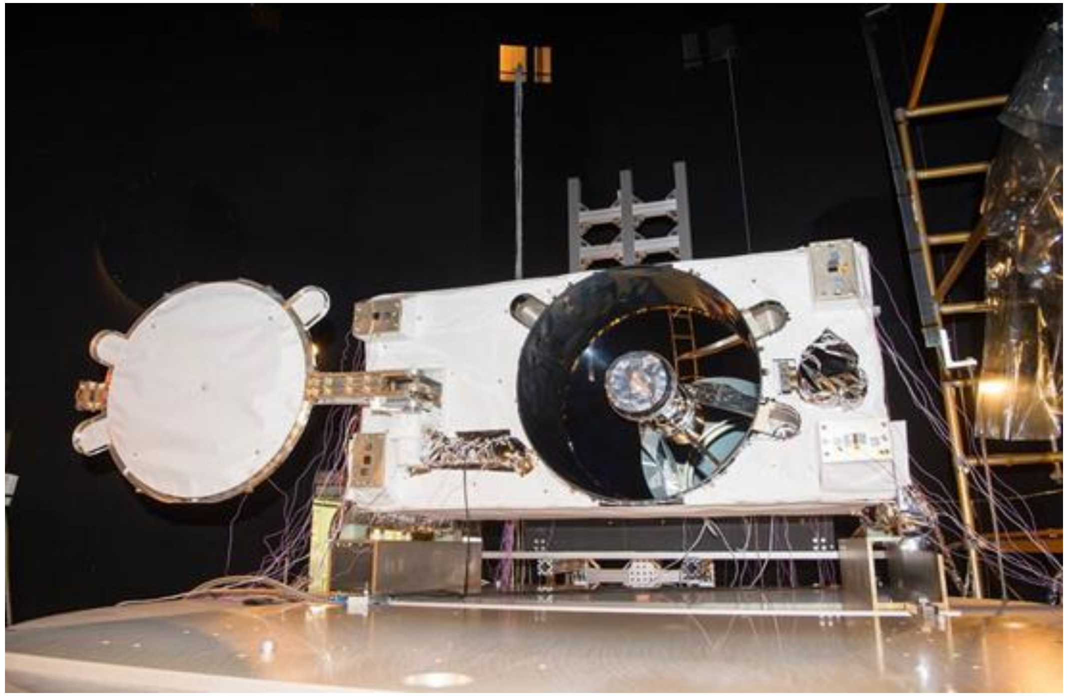
Estimating Biomass with GEDI

Sean P. Healey and Zhiqiang Yang
USDA Forest Service Forest Inventory and Monitoring Program

OBI-WAN
Forest Carbon Reporting

GEDI: NASA Earth Ventures Instrument

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

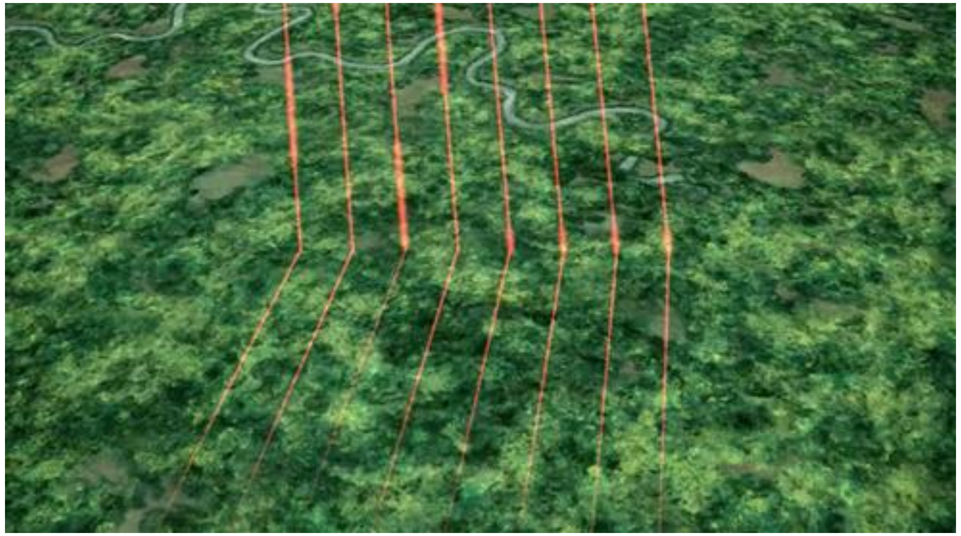


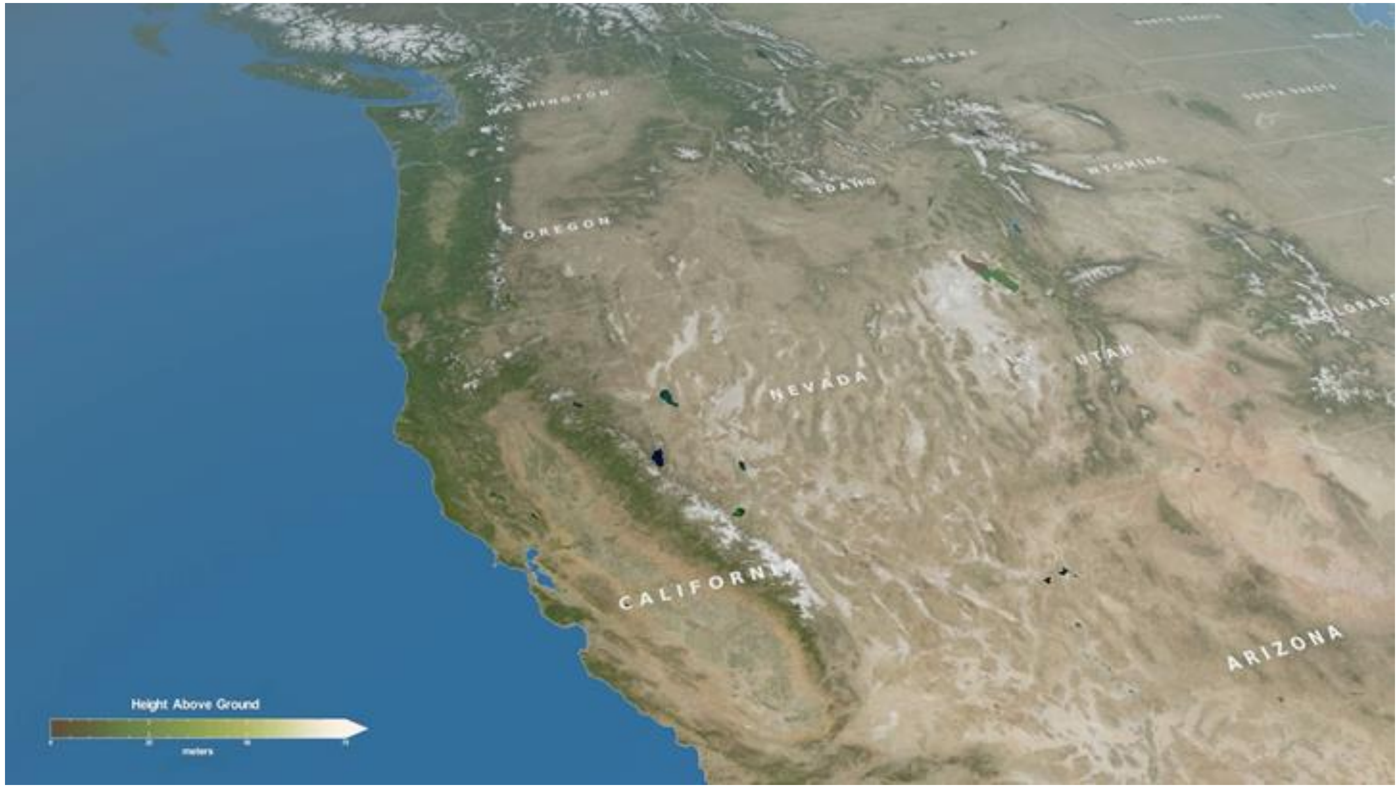
Key Facts:

- Joint project of University of Maryland and NASA Goddard Space Flight Center
- Operational on ISS (JEM-EF) from April 2019 to March 2023
- Hibernation from March 2023 to April 2024
- Operations resumed April 2024

GEDI Lidar Measurements

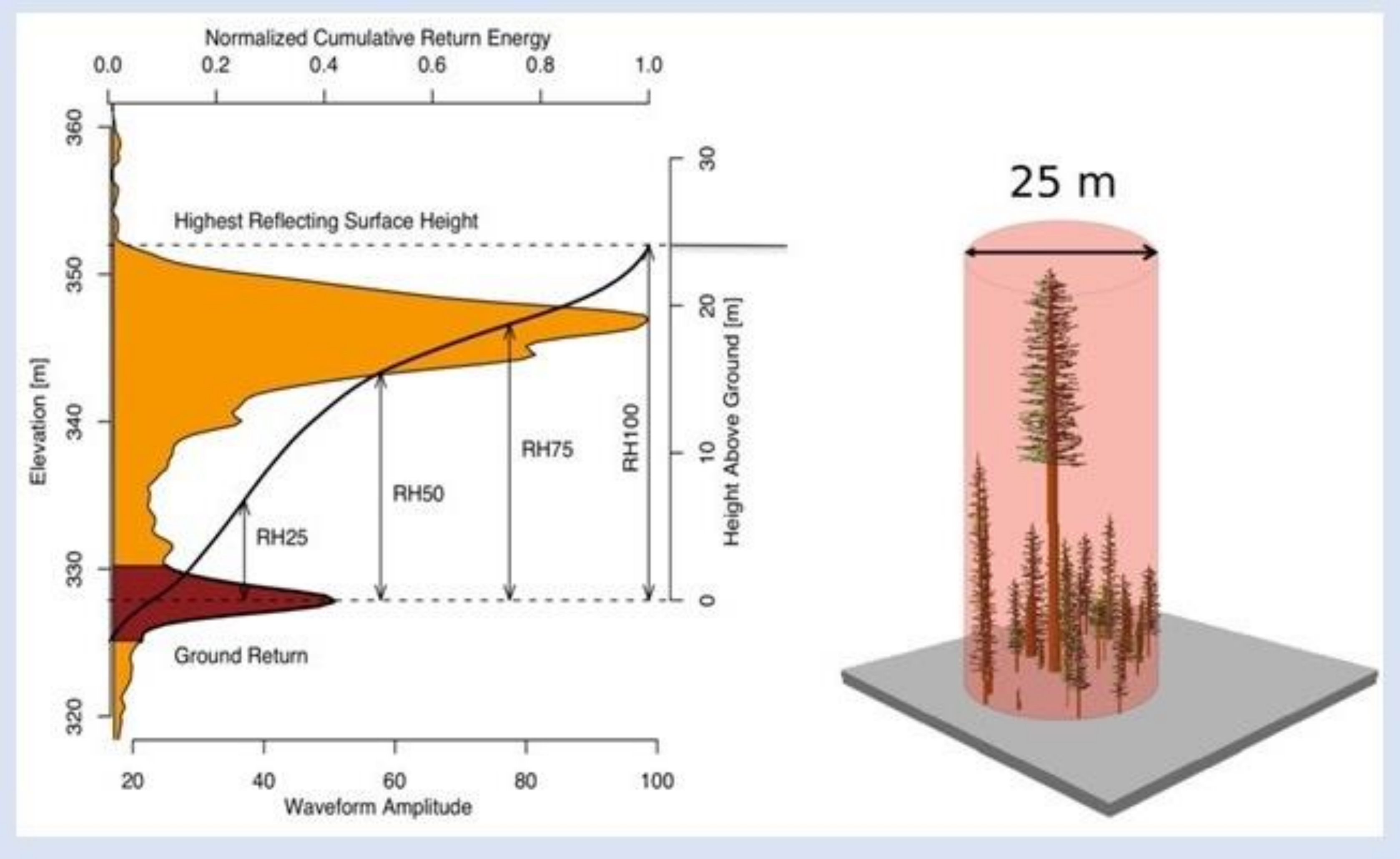
- GEDI uses 3 lasers to produce 8 transects of lidar waveforms.
- Each footprint provides the complete vertical structure of the canopy.





GEDI's Main Observable: The Waveform

- Different fractions of laser energy are returned from different heights above the ground, resulting in the profile to the right.
- Relative Heights (RH) are a property of the waveform that can be plugged into a biomass model.



GEDI Science Products

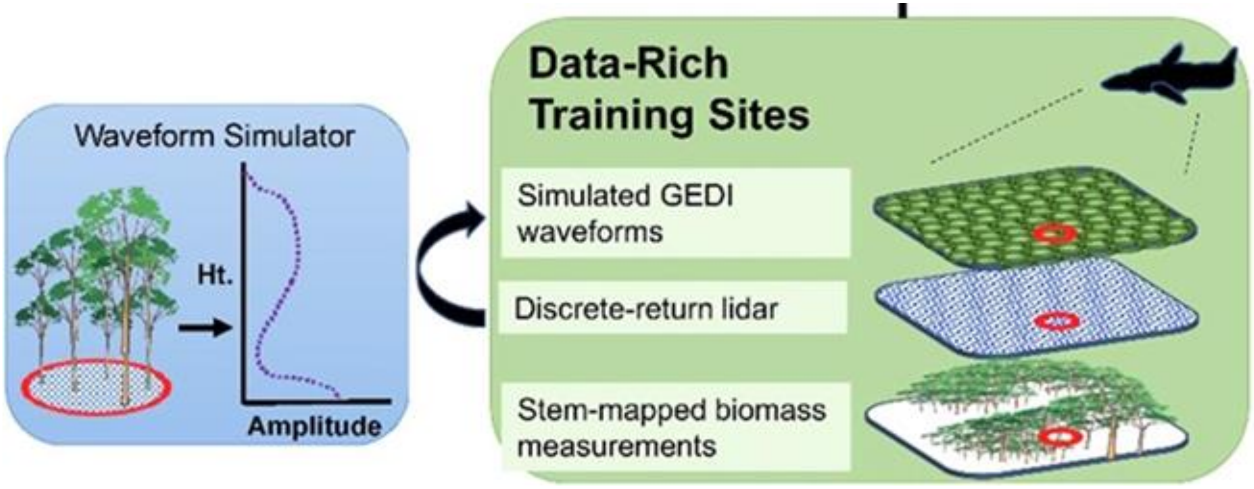
	Data Level Product	Description	DAAC Location
Level 1: Waveforms/Geolocated Waveforms Raw GEDI waveforms collected by the GEDI system and waveforms geolocated by the GEDI science team. **Format: HDF5**	Level 1B	Geolocated waveforms	LP DAAC
Level 2: Footprint level canopy height and profile metrics The waveforms are processed to provide canopy height and profile metrics, which provide easy-to-use and interpret information about the vertical distribution of the canopy material. **Format: HDF5**	Level 2A	Ground elevation, canopy top height, and Relative Height (RH) metrics	LP DAAC
	Level 2B	Canopy Cover Fraction (CCF), CCF profile, Leaf Area Index (LAI), and LAI profile	LP DAAC
Level 3: Gridded canopy height metrics and variability Gridded by spatially interpolating Level 2 footprint estimates of canopy cover, canopy height, LAI, vertical foliage profile and their uncertainties. **Format: GeoTIFF**	Level 3	Gridded canopy cover, canopy height, LAI, and uncertainty	ORNL DAAC
Level 4: Footprint and Gridded Above Ground Carbon Estimates Level 4 data are model output. Footprint metrics derived from Level 2 data products are converted to footprint estimates of aboveground biomass density using calibration equations. These footprints are used to produce mean biomass and its uncertainty in cells of 1 km using statistical theory. **Format: GeoTIFF**	Level 4A	Footprint level aboveground biomass	ORNL DAAC
	Level 4B	Gridded aboveground biomass density [AGBD]	ORNL DAAC

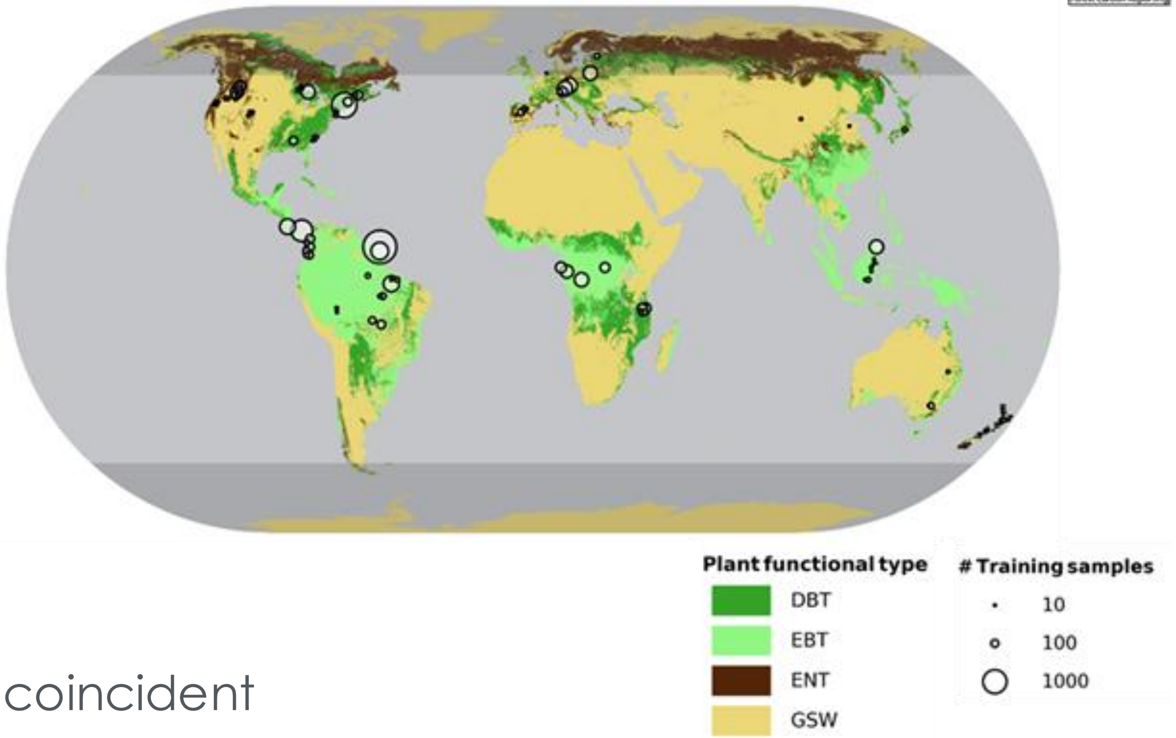
Image by Felix Mittermeier from Pixabay

We will focus on Level 4.

- **Level 4A** – Biomass density predicted for individual footprints
- **Level 4B** – Statistical estimates of mean biomass for 1-km grid cells using GEDI's sample of L4A biomass predictions

GEDI Level 4A – Footprint-Level Biomass





- Global collaborators contribute field biomass and coincident airborne lidar
- GEDI waveforms simulated from airborne data
- **We save uncertainty information for these biomass models, which we later use in L4B statistical estimates.**

Duncanson et al. 2022, Rem. Sens. Env. 270: 112845

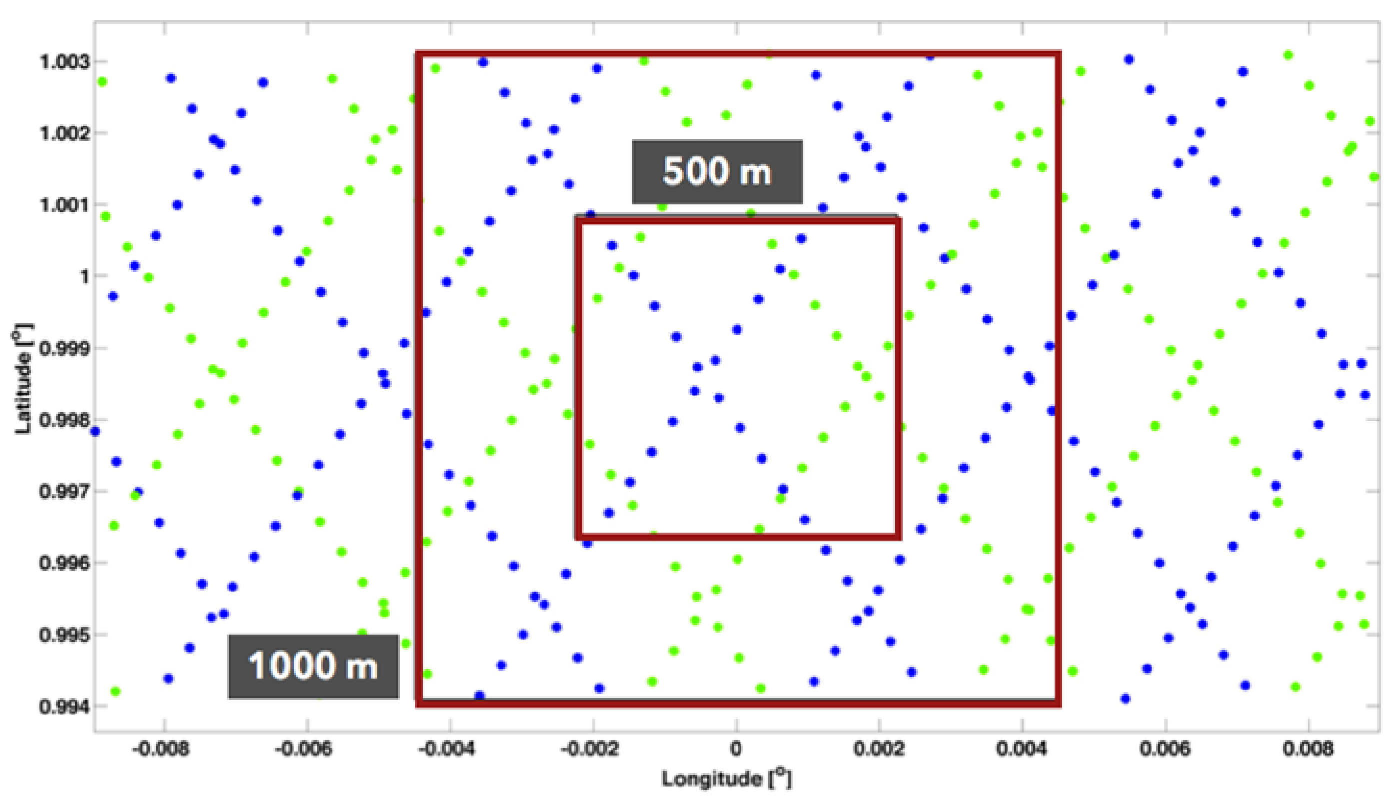
GEDI uses sampling theory to estimate mean biomass and uncertainty.

How do we get mean biomass?

- It ends up being close to the mean L4A prediction.

How do we get uncertainty around mean biomass?

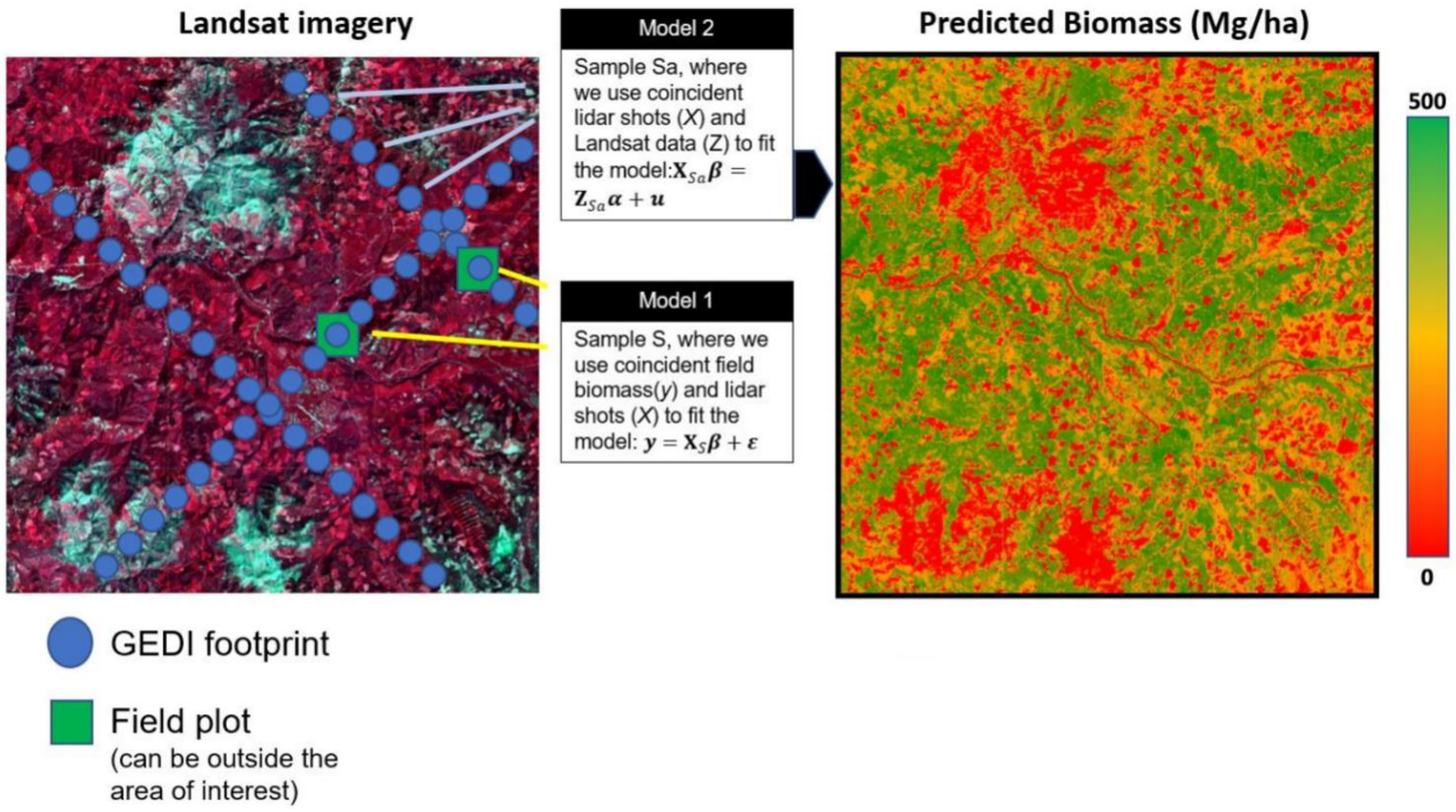
- Hybrid model-based inference, meaning:
  1. There is a sampling variance component (function of sample number and variability); and,
  2. A model covariance term, integrating what we know about how wrong the model could be with the math of how model error might propagate across the whole population of predictions.



Patterson et al. (2019) "Statistical properties of hybrid estimators proposed for GEDI—NASA's global ecosystem dynamics investigation." *Environmental Research Letters* 14, no. 6: 065007.

Patterson et al. 2019, Env. Res. Letters . 14, no. 6: 065007.

GHMB – Generalized Hierarchical Model-Based Inference



How do we get mean biomass?

- Use GEDI predictions to train a local biomass model based on Landsat imagery. The mean Landsat prediction is our estimated mean.

How do we get uncertainty around mean biomass?

- Hierarchical Model-based inference, meaning:
  - Propagate the error covariance across the population (either analytically or through simulation) for two levels of model.

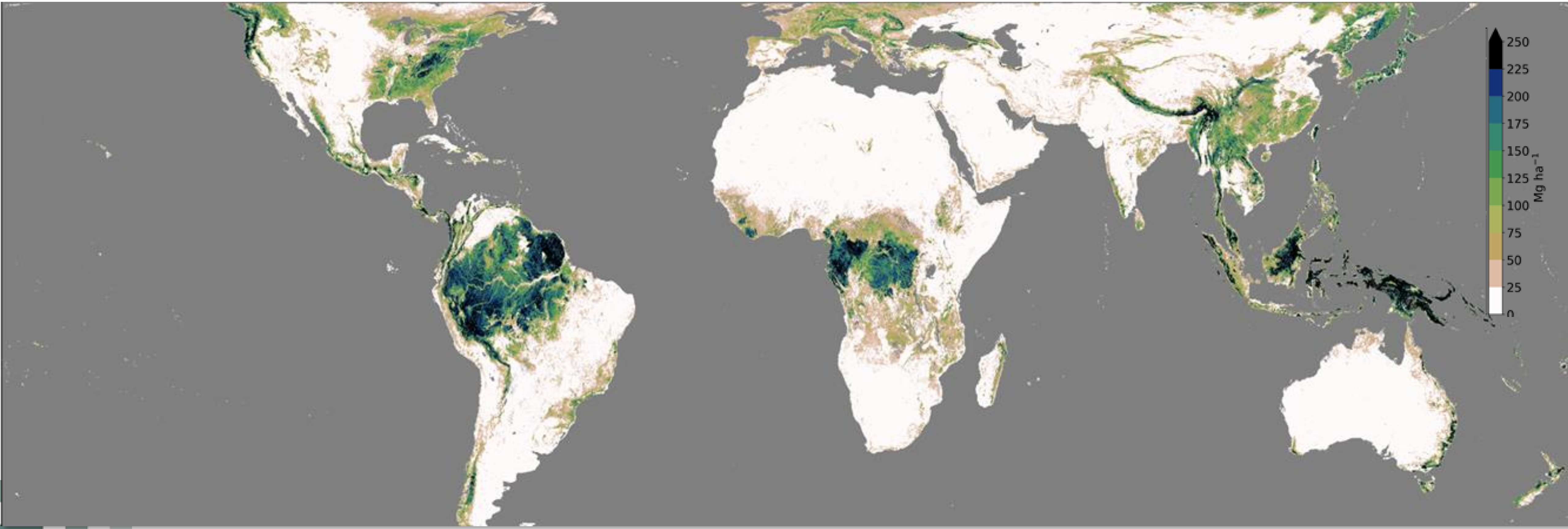
When does GEDI use this algorithm?

- It is used in 1-km cells when there aren't enough clear shots to support hybrid inference (the no-Landsat option described before).

Saarela et al., 2018

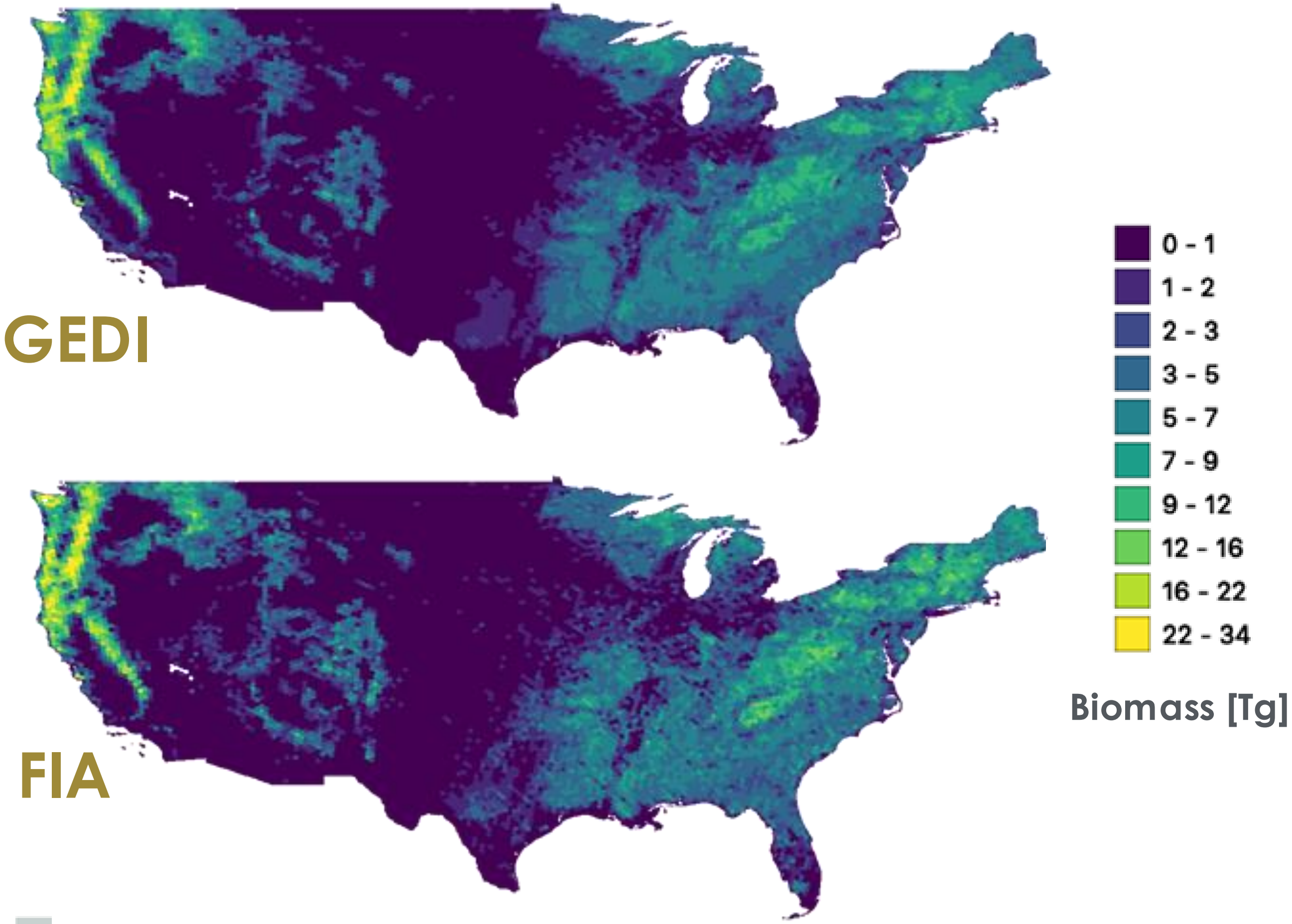
GEDI L4B Gridded Biomass Estimates

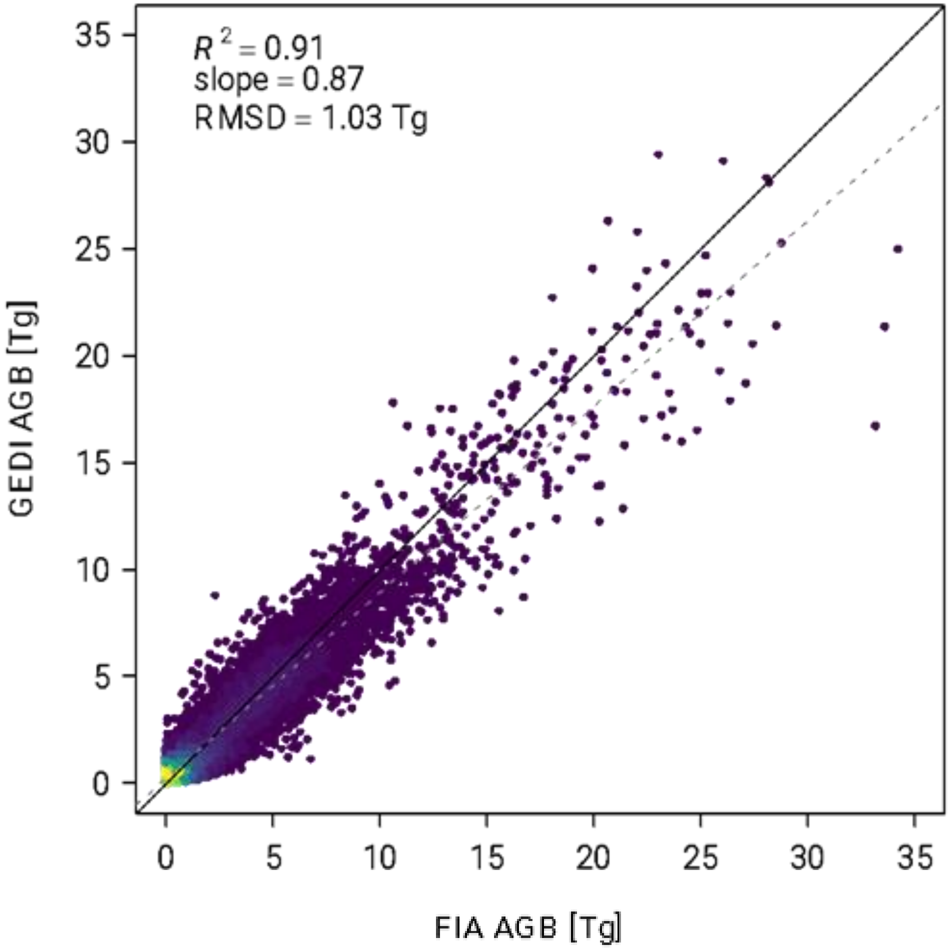
- GEDI's map of biomass density is the benchmark for the current epoch and the first produced using observations from a single instrument within a consistent statistical framework.



GEDI Biomass Estimation Beyond 1-km Grid Cells

Validation of GEDI Estimates with Forest Service Inventory Data (FIA)

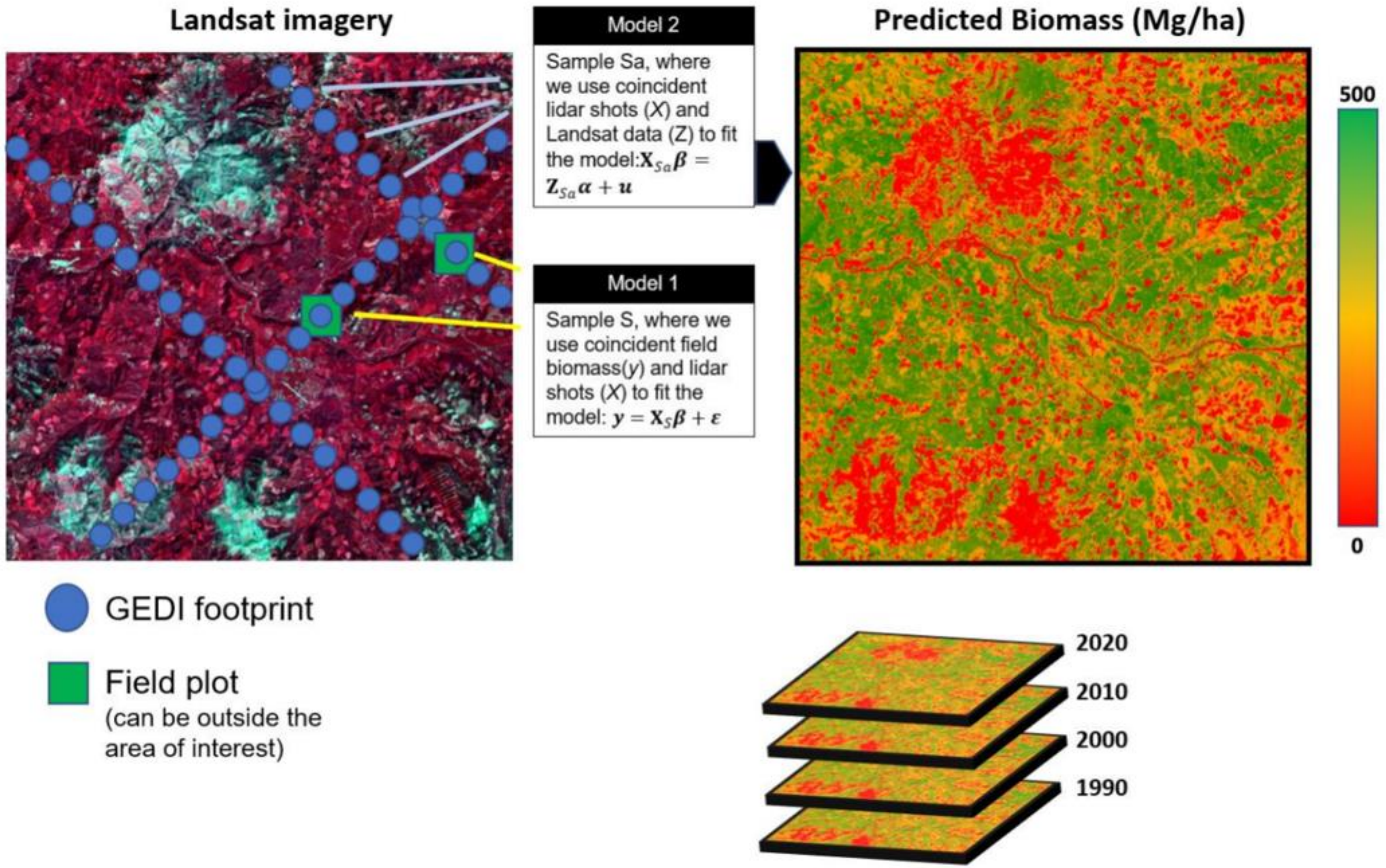




Dubayah et al. 2012, Env. Res. Letters . 17, no. 9: 095001.

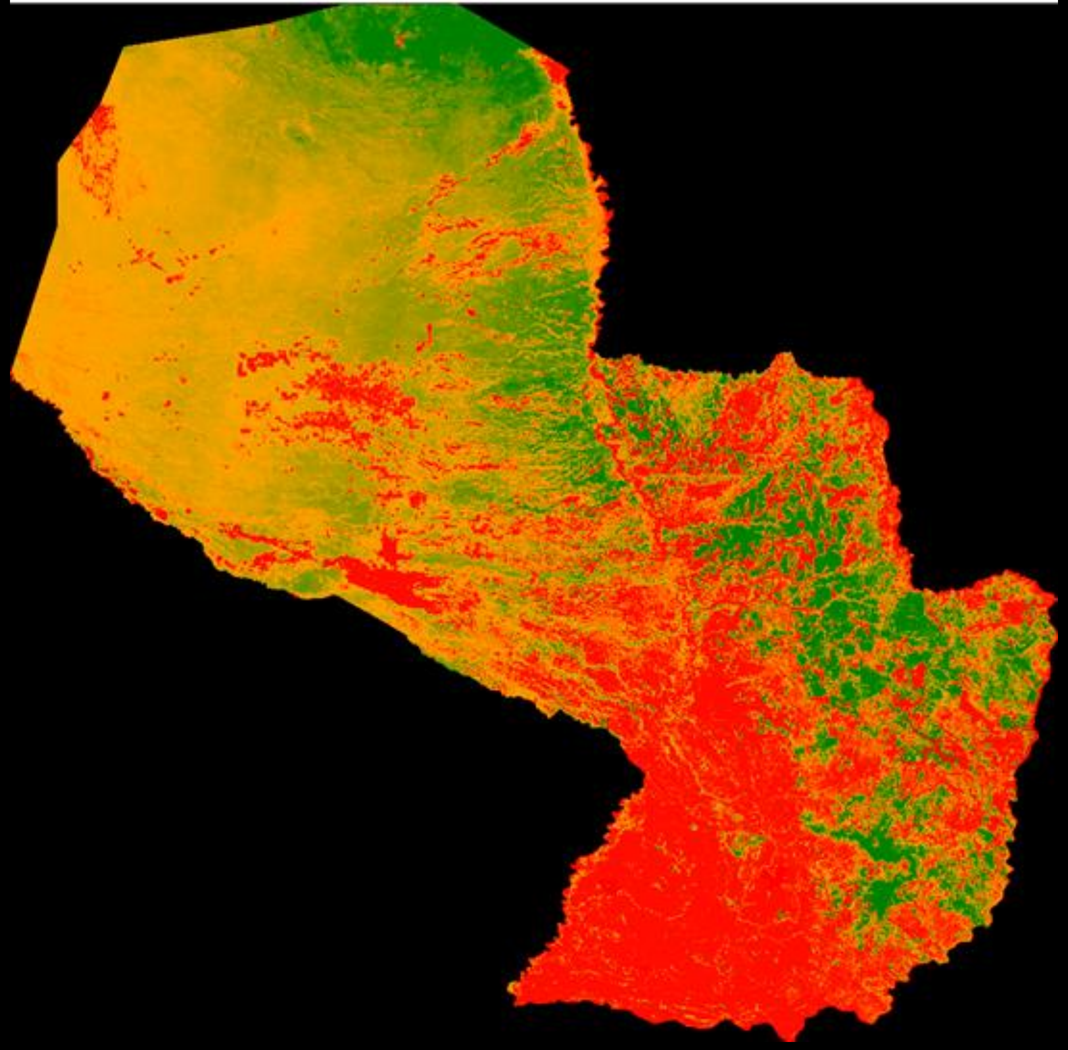
OBIWAN: Estimates of Biomass Change in Customized Areas

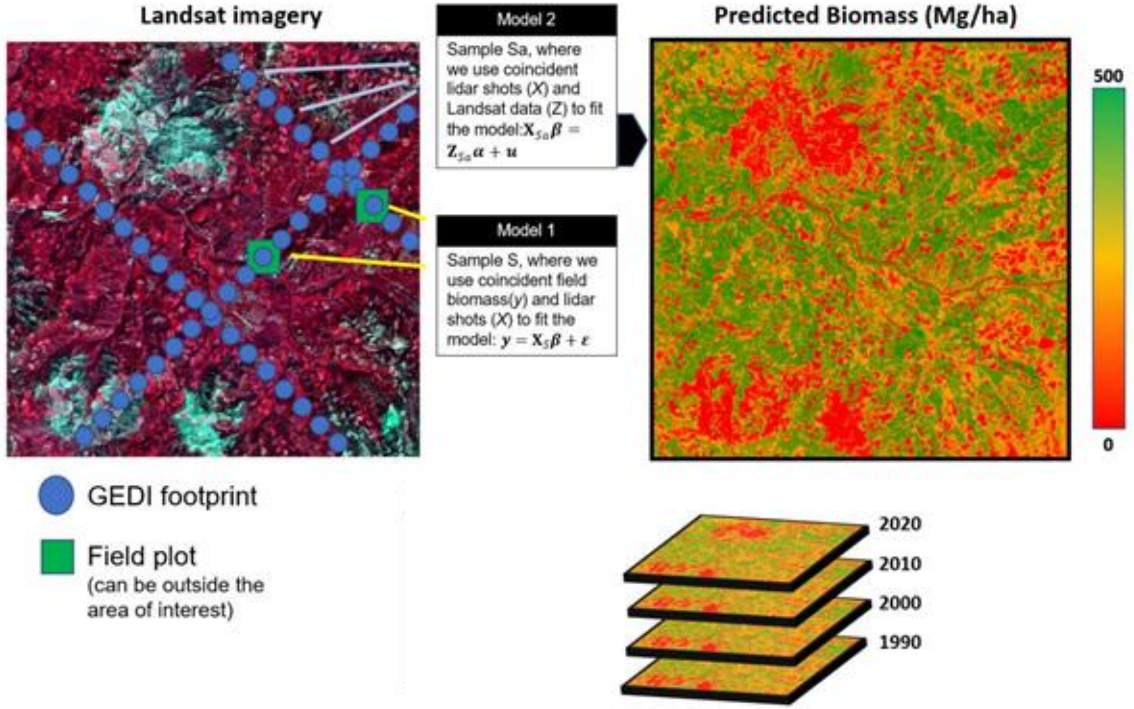
OBIWAN is built upon an extension of hierarchical model-based estimation.



Applying the GEDI-calibrated Landsat model through time allows evaluation of apparent change.

1985



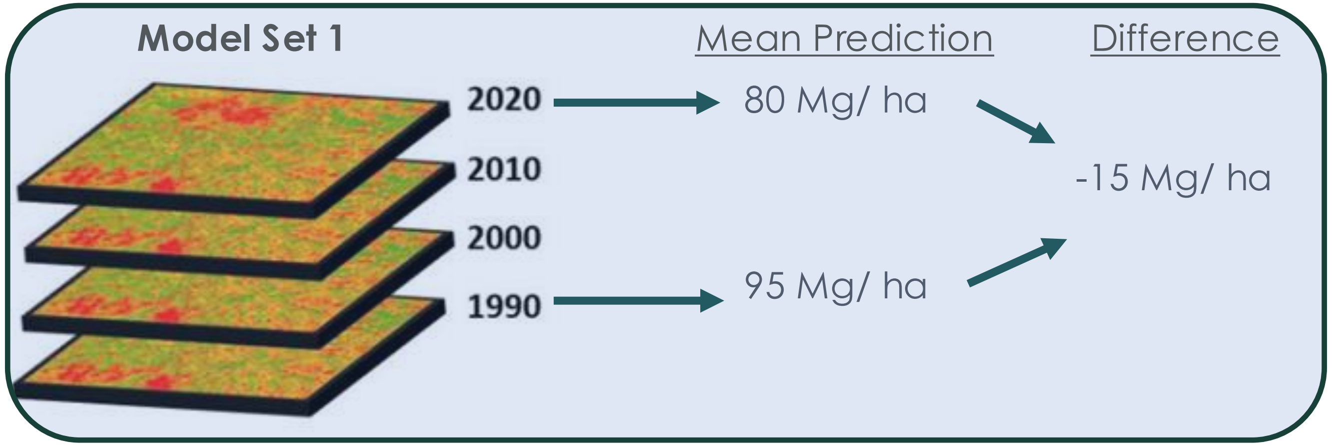


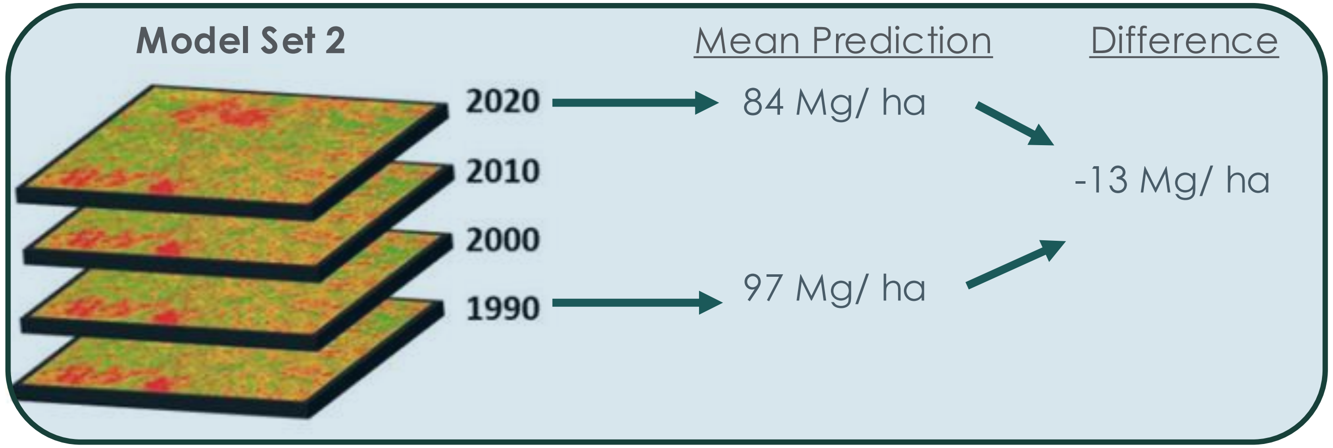
Above-Ground Biomass, Paraguay 1987-2021

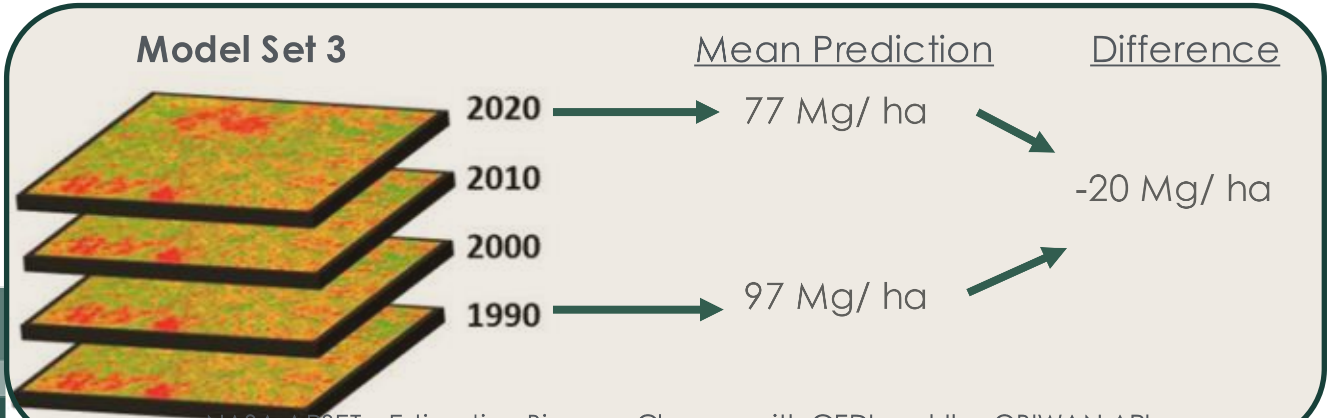
Low Biomass

High Biomass

Bootstrapping time series of predictions produces a probability distribution around the estimate of change.







What does “bootstrapping” mean?

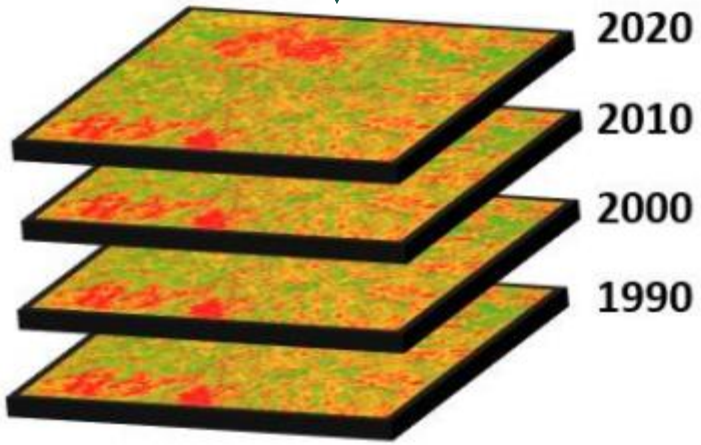
10x10 km Tile

Represent Field to GEDI model Uncertainty

Resample parameters of the GEDI L4A biomass models to get new biomass values at GEDI footprints

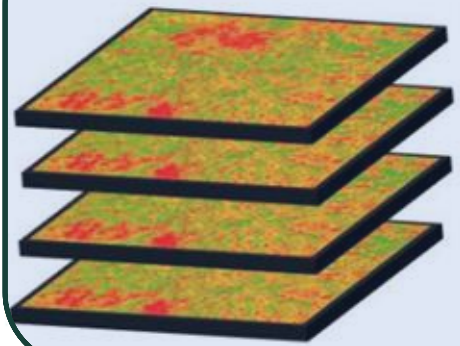
Represent GEDI to Landsat Model Uncertainty

Resample GEDI shots with replacement (use 2000 shots to make Random Forests model)



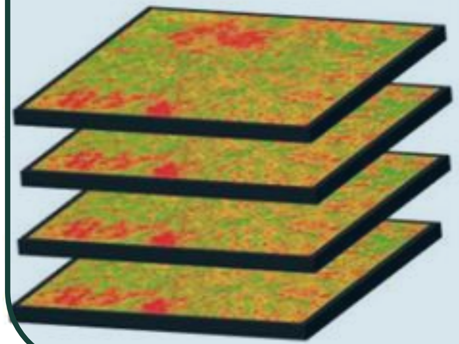
Landsat imagery does not offer great discrimination of different levels of biomass, even if models are made very locally. If Landsat mistakes both high and low biomass values for more average conditions, big gains or losses will be **systematically** underestimated. This is a challenge OBIWAN addresses through calibration.

Model Set 1



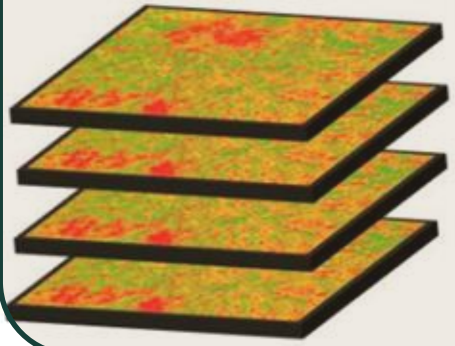
Year	Mean Prediction	Calibrated Mean Prediction	Difference
2020	80 Mg/ ha	78 Mg/ ha	-19 Mg/ ha
1990	95 Mg/ ha	97 Mg/ ha	

Model Set 2



Year	Mean Prediction	Calibrated Mean Prediction	Difference
2020	84 Mg/ ha	84 Mg/ ha	-21 Mg/ ha
1990	97 Mg/ ha	105 Mg/ ha	

Model Set 3

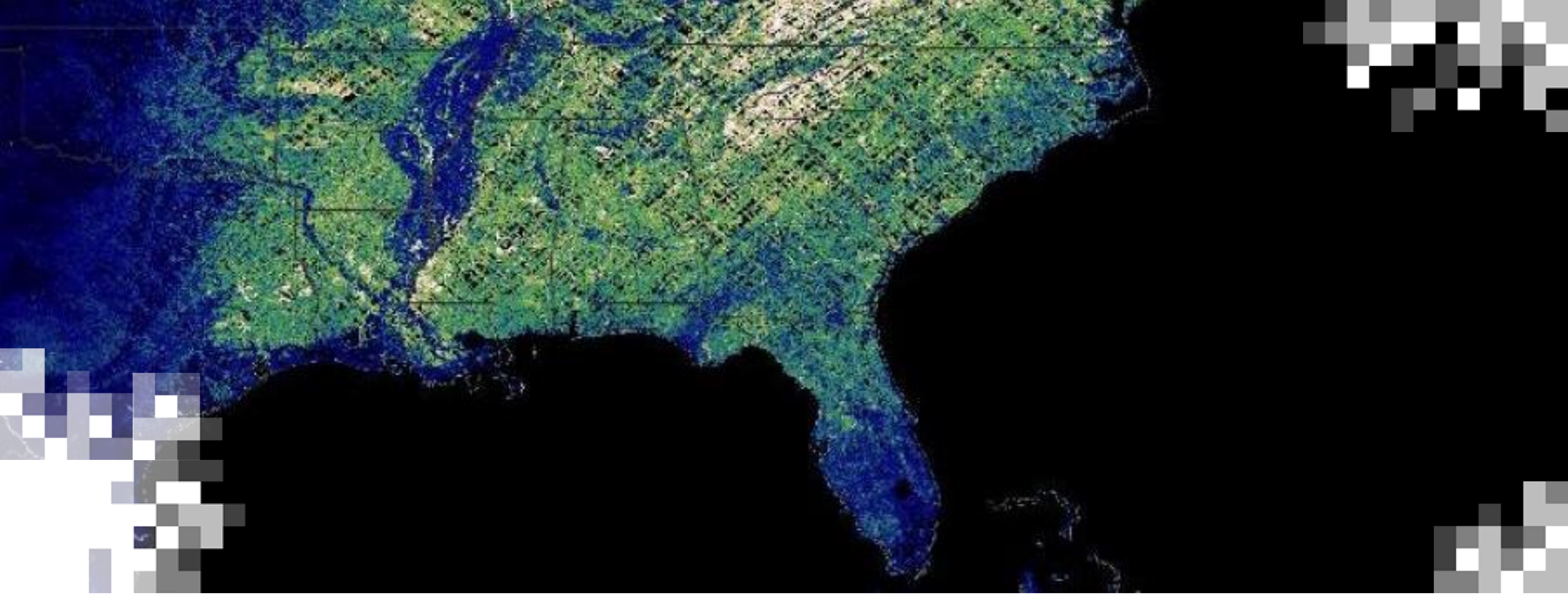


Year	Mean Prediction	Calibrated Mean Prediction	Difference
2020	77 Mg/ ha	72 Mg/ ha	-26 Mg/ ha
1990	97 Mg/ ha	98 Mg/ ha	

- Calibration with either forest **inventory data** or **GEDI shots** not used in making the Landsat model reduces prediction bias with very little additional computing.

Resources

- Spaceborne Lidar for Monitoring Vegetation Structure and Biomass using GEDI
- LiDAR Profiling Satellite Observations for Air Quality Applications
- For Intro to Lidar and Basics of Accessing GEDI and ICESat Data:
  - ARSET Use of Solar Induced Fluorescence and LIDAR to Assess Vegetation Change and Vulnerability
- For Familiarity on LVIS Airborne Laser Altimeter:
  - ARSET Biodiversity Applications for Airborne Imaging Systems
- LPDAAC Access GEDI Data Tutorials
- https://www.youtube.com/watch?v=UlrCC1Xp-wk



Hands-On Activity

OBI-WAN
Forest Carbon Reporting

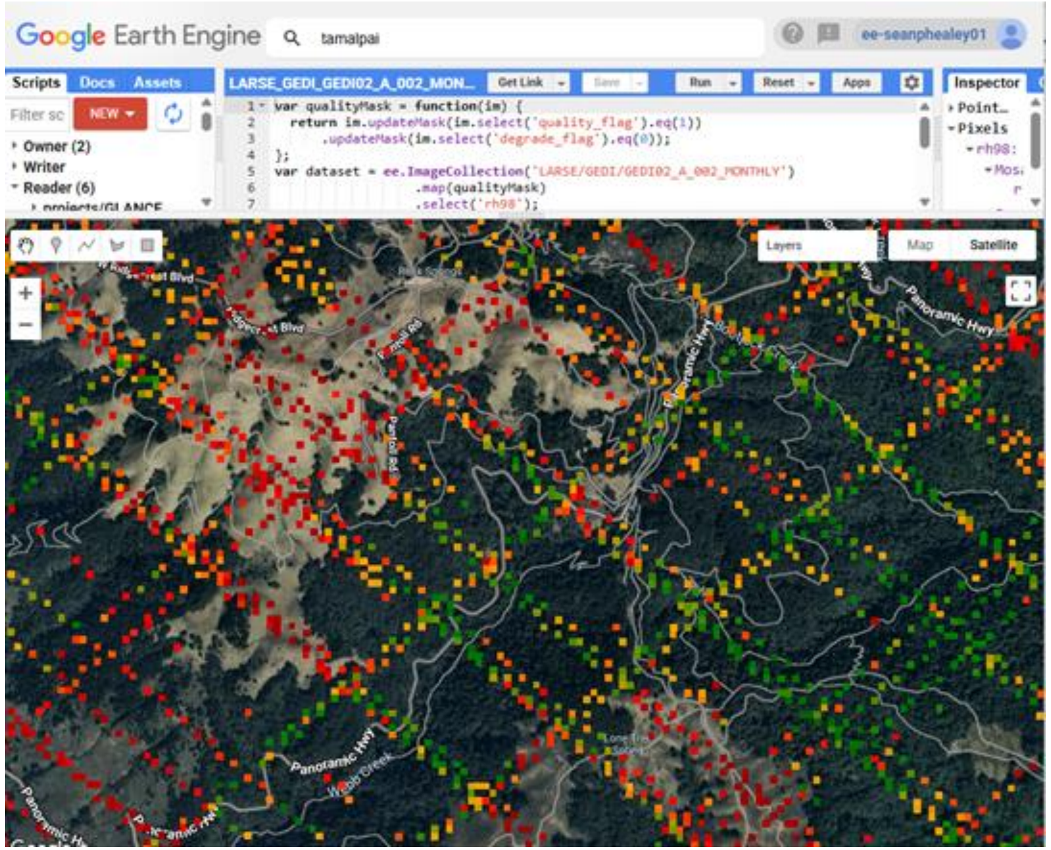
In this hands-on session, we will use an Earth Engine app to…

- Explore the distribution of GEDI shots
- Query properties of shots falling in places of interest
- Visualize the distribution of GEDI L4A Footprint biomass predictions
- Explore the GEDI L4B Gridded Mean biomass product (with uncertainties)
- Apply hybrid inference (the algorithm behind L4B) to areas of interest

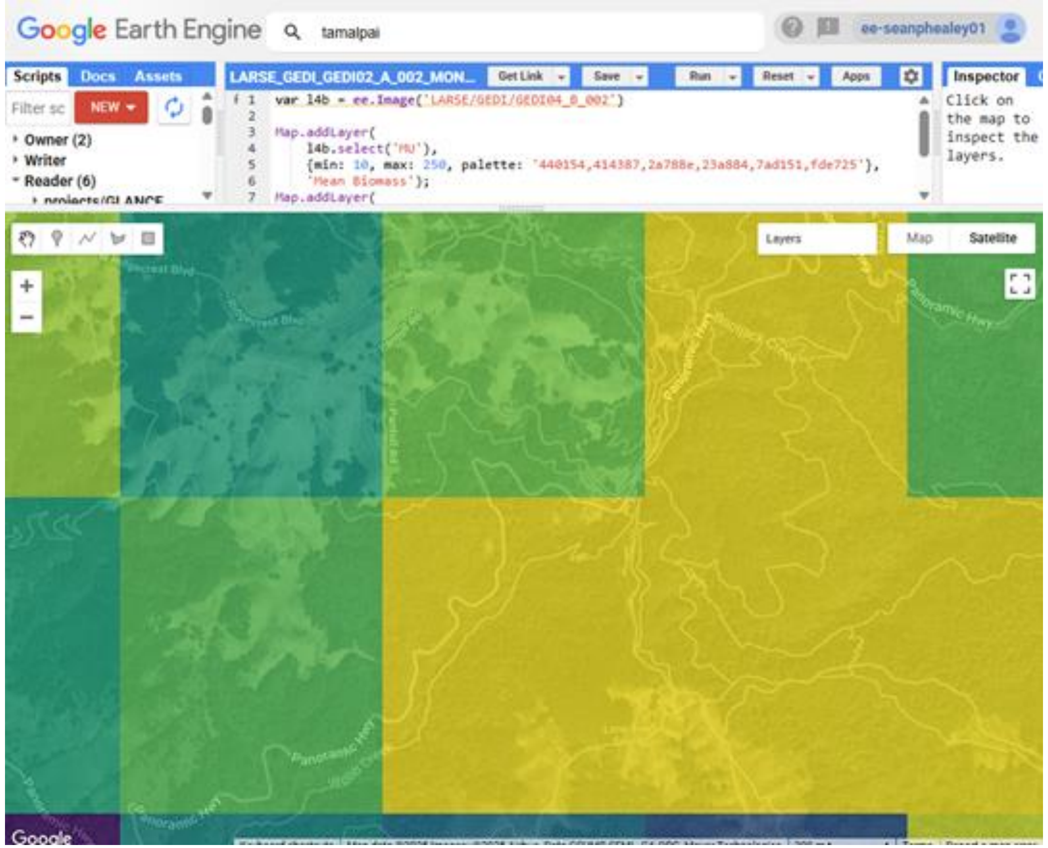
In Part 2 of this training, we will see practical applications and validation of OBIWAN in operational forest carbon accounting.

OBIWAN uses GEDI assets on Google Earth Engine.

`ee.ImageCollection("LARSE/GEDI/GEDI02_A_002_MONTHLY")`



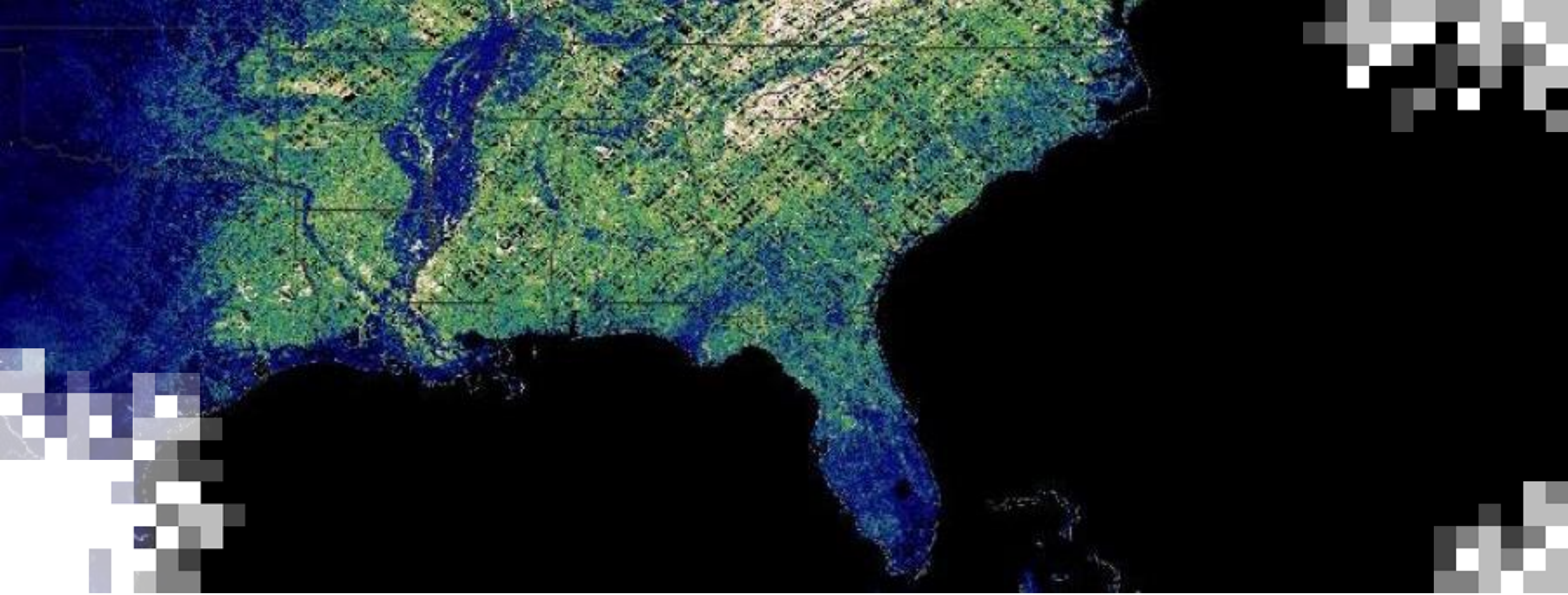
`ee.Image("LARSE/GEDI/GEDI04_B_002")`



Healey, S. P., Yang, Z., Gorelick, N., & Ilyushchenko, S. (2020). Highly local model calibration with a new GEDI LiDAR asset on Google Earth Engine reduces Landsat forest height signal saturation. *Remote Sensing*, *12*(17), 2840.

GEDI Exploration App

bit.ly/gediv01



Session 1: Estimating Biomass Using GEDI

Summary

Summary

- Each footprint provides the complete vertical structure of the canopy.
- Different fractions of laser energy are returned from different heights above the ground, resulting in the profile to the right.
- Relative Heights (RH) are a property of the waveform that can be plugged into a biomass model.
  - Level 4A – Biomass density predicted for individual footprints

  - Level 4B – Statistical estimates of mean biomass for 1-km grid cells using GEDI's sample of L4A biomass predictions
  - GEDI uses sampling theory to estimate mean biomass and uncertainty.
  - OBIWAN is a forest carbon analysis application that uses GEDI lidar observations together with forest inventory data to estimate biomass and monitor changes in forest carbon over time.

Looking Ahead to Session 2

In Session 2, you will be able to:

- Identify key concepts in carbon monitoring, including system requirements, decision-making needs, and the concept of additionality.
- Recognize how OBIWAN estimates biomass change, including its use of GEDI, Landsat time series, and underlying data infrastructure.
- Evaluate uncertainty and validation, using Forest Service inventory data to assess the accuracy and precision of OBIWAN change estimates.
- Access the open-source OBIWAN API to generate estimates of biomass change in areas of interest.
- Apply OBIWAN tools and APIs to visualize biomass change and compare carbon gains against different climate scenarios.

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 05/28/2026
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by June 18, 2026**

- **Certificate of Completion:**
  - Attend both live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

Sean Healey: sean.healey@usda.gov

- ARSET Website
- Follow us on Twitter!
  - @NASAARSET
- ARSET YouTube

Thank You!