
# Spaceborne Lidar for Monitoring Vegetation Structure and Biomass Using GEDI

## Session 1: Introduction to Full Waveform Lidar

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October 23, 2025

# About ARSET

# 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.

Spaceborne Lidar for Monitoring Vegetation Structure and Biomass Using GEDI

**Overview**

# What's happening beneath the canopy?


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, participants will be able to:

- Identify the fundamental physical principles of lidar remote sensing, including the uses and limitations for terrestrial applications.
- Access and retrieve full waveform lidar data from public NASA repositories to visualize vegetation structure.
- Identify key GEDI products, including elevation, canopy height, vegetation structure metrics, and biomass, across different processing levels and spatial resolutions.
- Access and visualize GEDI data related to elevation, height, vegetation structure, and biomass for specific areas of interest using openly available tools.
- Utilize GEDI standard biomass products at both footprint and 1 km scales to map forest resources.
- Access the open-source OBIWAN API to generate estimates of biomass change in areas of interest.
- Identify how OBIWAN can be used to create baseline scenarios for forest carbon accounting projects.

## Prerequisites

- ARSET - Fundamentals of Remote Sensing

## 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 | Session 2 | Session 3 |
|---|---|---|
| Introduction to Full Waveform Lidar | Introduction to the GEDI Mission and its Derived Products | Estimating Biomass Change with GEDI and the OBIWAN API |
| October 23, 2025 | October 30, 2025 | November 6, 2025 |
| 11 AM - 1 PM EDT | 11 AM - 1 PM EDT | 11 AM - 1 PM EDT |

Opens November 6 – Due November 20 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment(s) before the given due date.

Spaceborne Lidar for Monitoring Vegetation Structure and Biomass Using GEDI

**Session 1: Introduction to Full Waveform Lidar**

# Session 1 – Trainers

**Savannah Cooley**

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BAER/NASA Ames Research Center

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*Research Scientist*
NASA Jet Propulsion Laboratory

# ARSET Ecological Conservation Team

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**Justin Fain**
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**Savannah Cooley**
*Research Scientist*
BAER/NASA Ames Research Center

# Session 1 Learning Objectives

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

- Recognize essential physical principles of lidar remote sensing
- Identify different types of lidar sensors
- Assess the uses and limitations of full-waveform lidar technology for terrestrial ecosystem management and conservation applications
- Access public NASA repositories to retrieve full waveform lidar observations to visualize and quantify vegetation structure

# How to Ask Questions

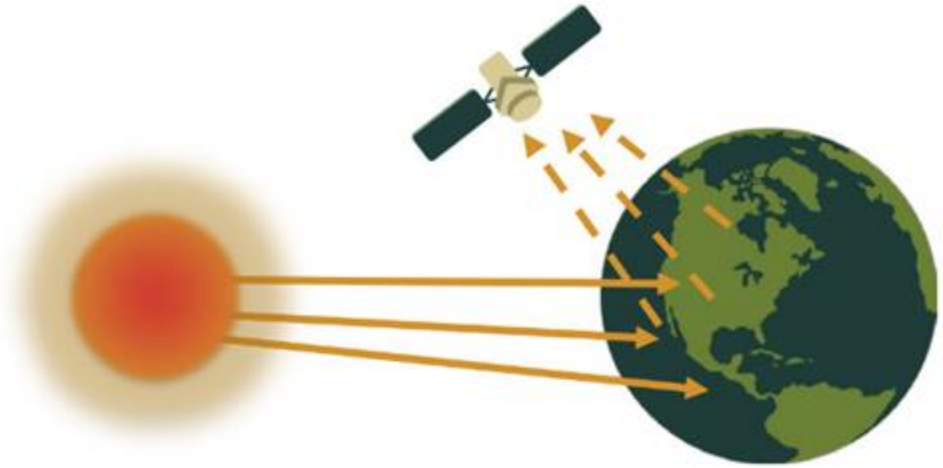
- Please write your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to answer all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

Session 1: Introduction to Full-Waveform Lidar

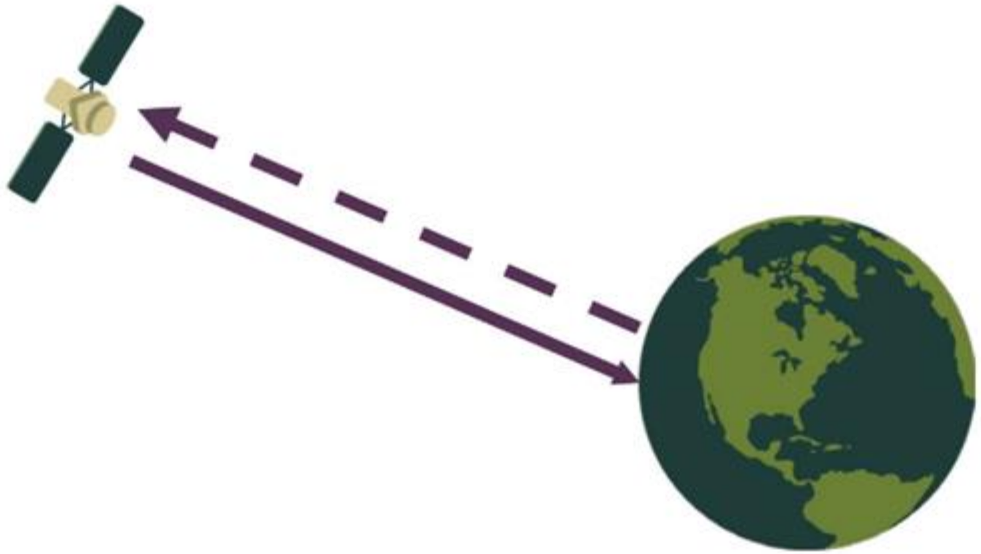
**Section 1: Fundamentals of Lidar Remote Sensing**

# Active vs. Passive Sensors

## Passive Sensors

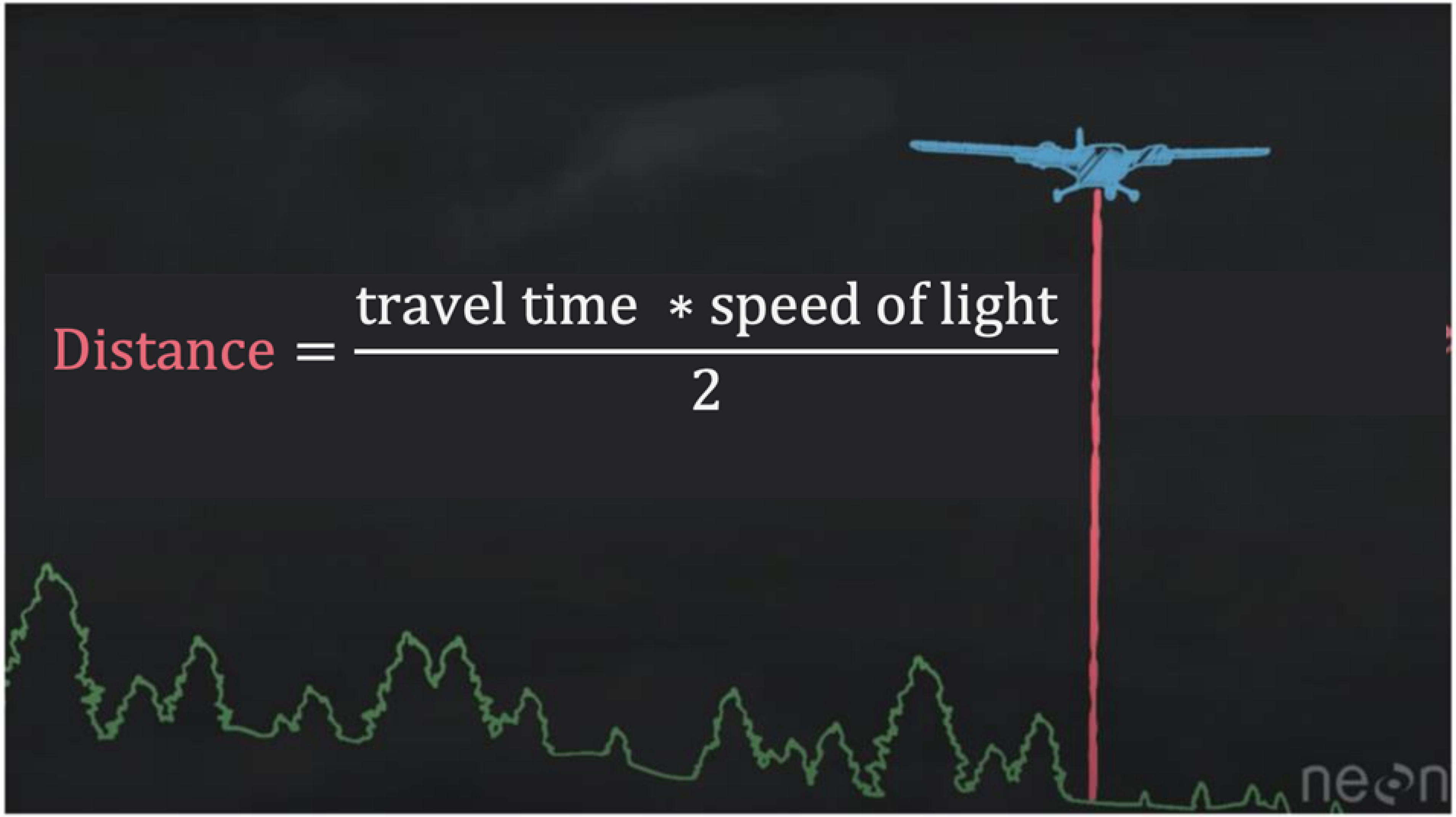


## Active Sensors



# Distance Measurement Principle

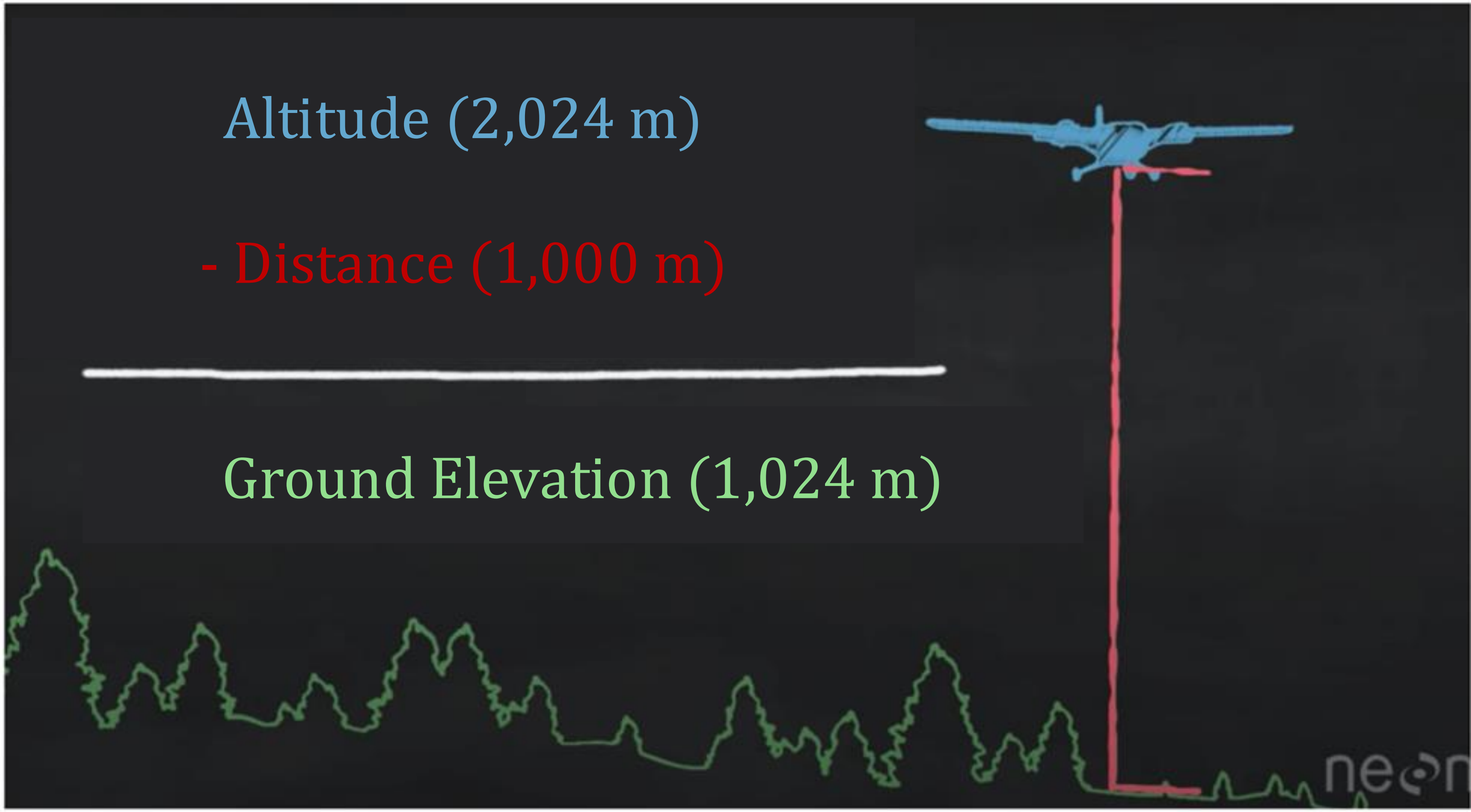
Lidar operates on the principle of **laser altimetry**—measuring the time it takes for a laser pulse to travel from the sensor to a target and back.




Source: NEON

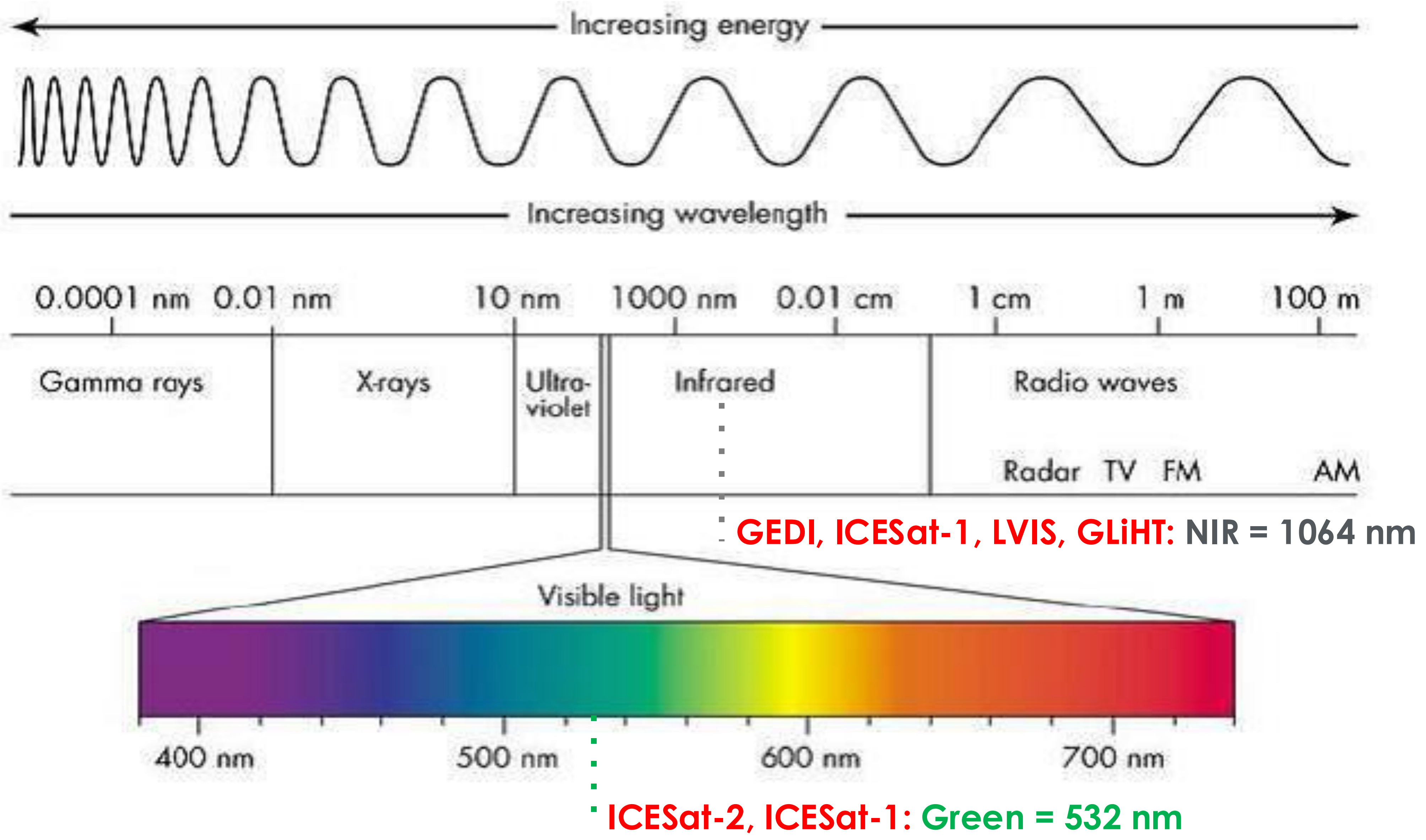
# Key Biophysical Parameters

- Elevation and Topography
- Canopy Height
- Vertical Vegetation Structure



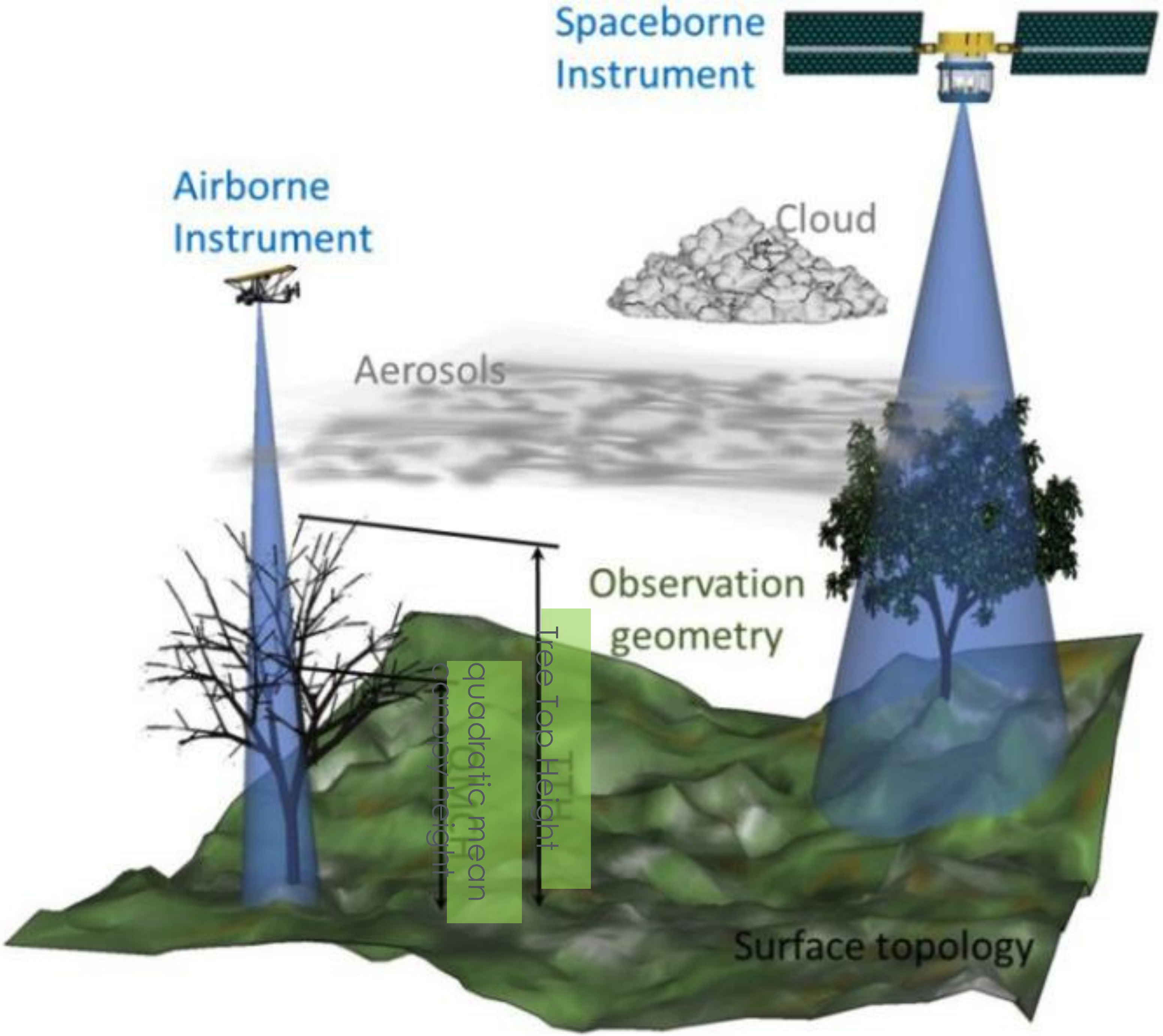

Source: NEON

# Lidar for Terrestrial Applications Operates in Green or NIR Wavelengths



# Lidar Platforms

- Terrestrial Lidar
- Airborne/UAV Lidar
- Spaceborne Lidar




Source: Shang and Chazette, 2015

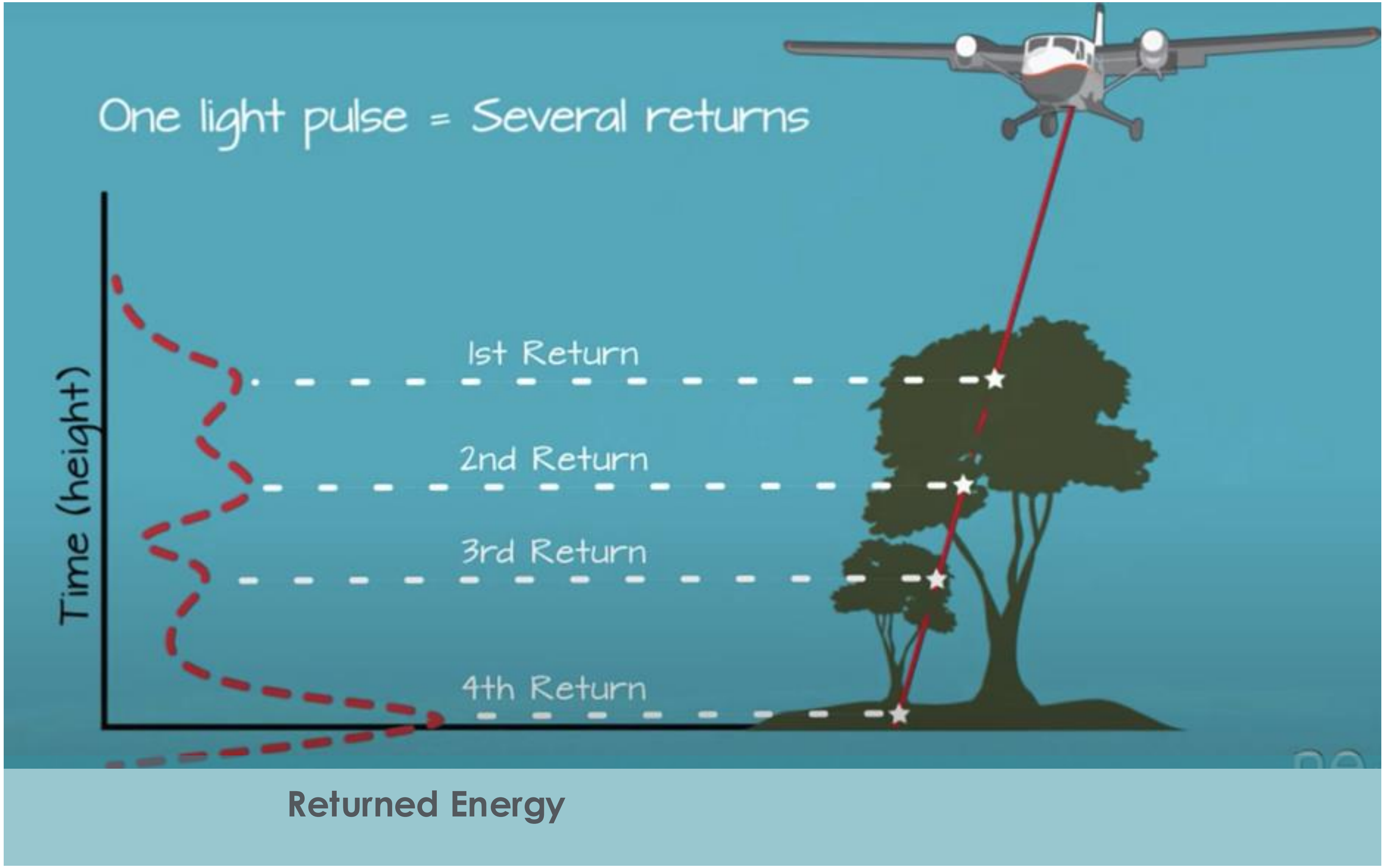
# Lidar Measurement Types

- **Discrete Return Lidar**: records individual return pulses when the laser encounters reflecting surfaces. Typically records 1-5 returns per pulse and are common in airborne applications.
  - Example: NEON AOP, NASA GLiHT

- **Single-Photon Counting Lidar**: detects individual photons rather than complete pulses. While providing less energy per measurement, these systems can operate from much higher altitudes and offer unique capabilities for ice sheet and vegetation studies.
  - Example: NASA ICESat-2

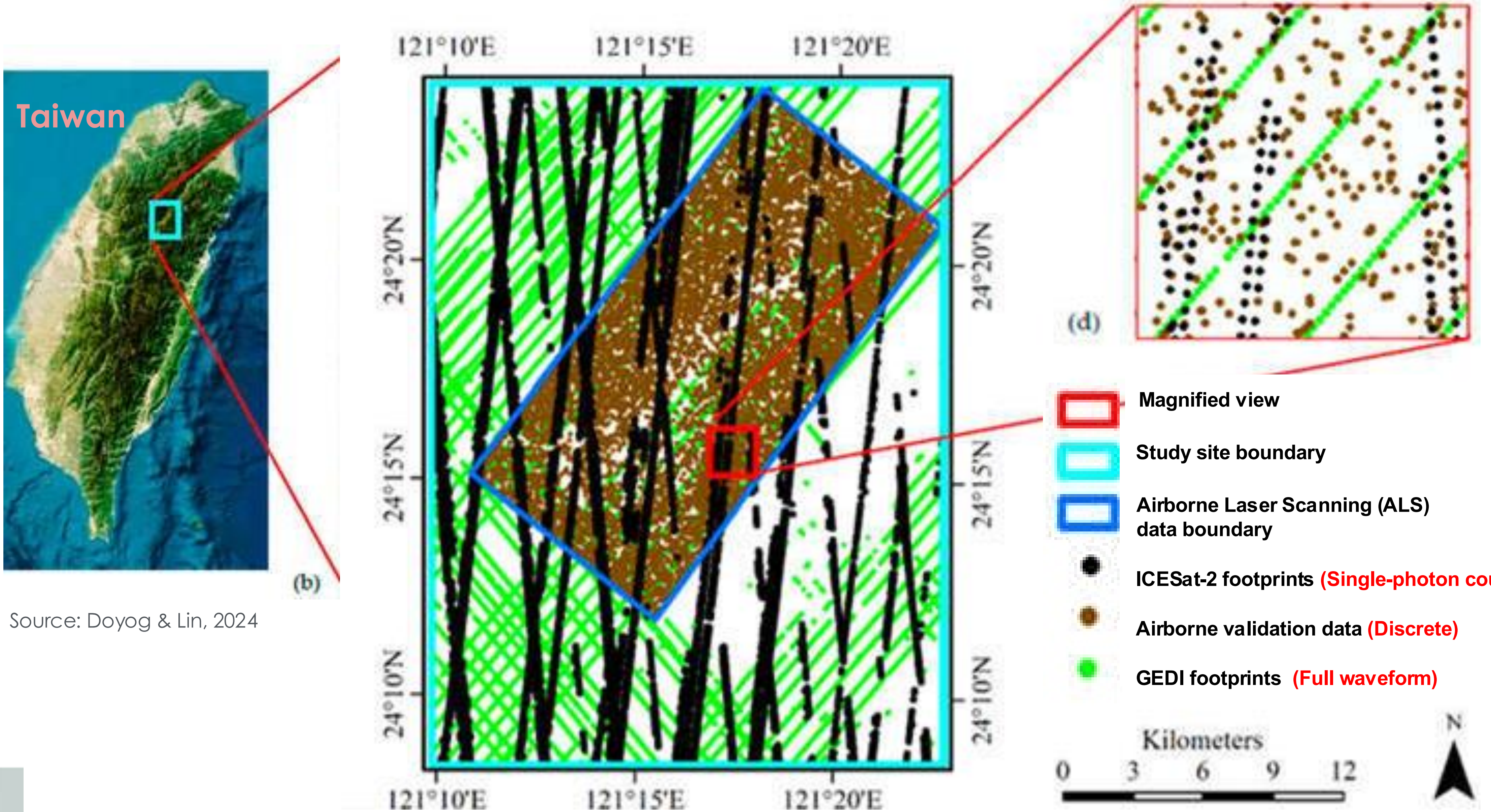
- **Full Waveform Lidar**: captures the complete energy profile ("waveform") of the returned laser pulse. This provides more detailed information about the vertical distribution of reflecting surfaces and is particularly valuable for vegetation studies. The entire waveform can be analyzed to extract multiple metrics describing canopy structure.
  - Example: ICESat/GLAS, LVIS, GEDI

# Discrete Lidar




Source: NEON

# Spatial Sampling Patterns of Discrete vs. Full Waveform Lidar

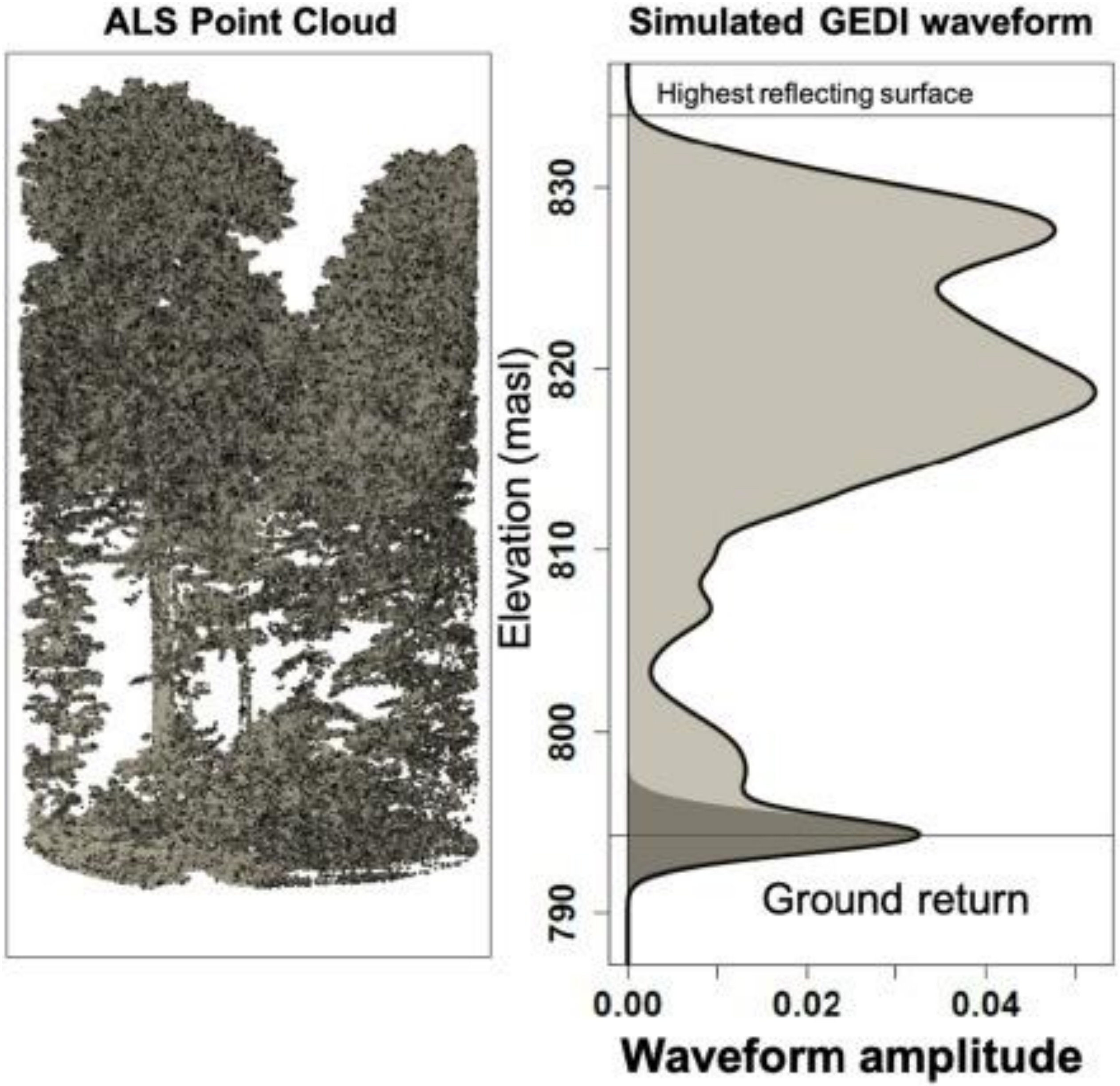



Source: Doyog & Lin, 2024

# Full Waveform Lidar

Full waveform Lidar captures the **entire profile** of the returned laser energy.

This results in a continuous **waveform** that represents the vertical distribution of all surfaces the laser pulse encountered.




Source: Duncanson et al., 2021

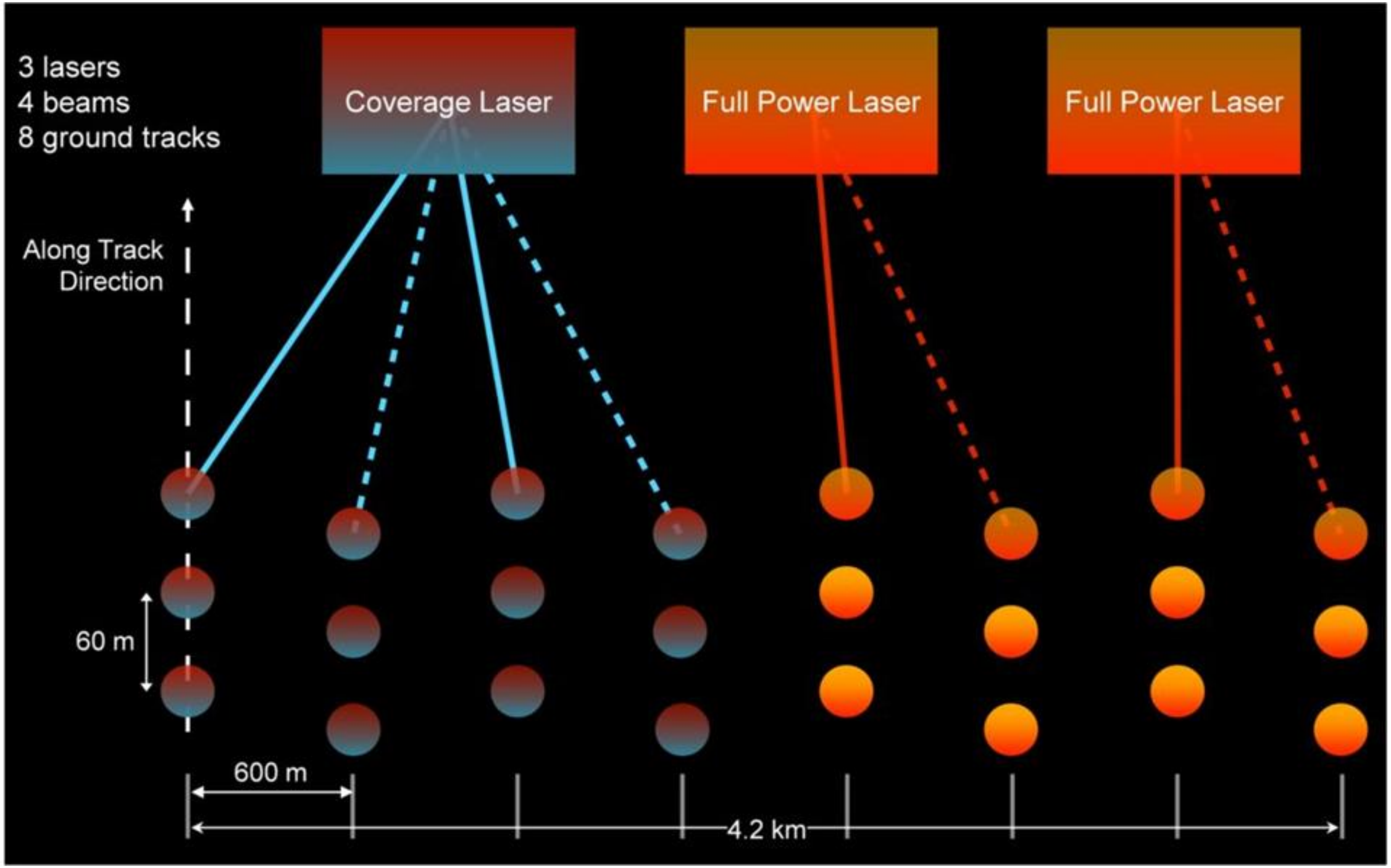
Session 1: Introduction to Full Waveform Lidar

**Section 2: Full Waveform Lidar from the GEDI Mission**

# GEDI Mission Overview

Source: GEDI Mission

# GEDI Laser System and Sampling Overview




Source:

GEDI Mission

# GEDI Data Products (Level 1 - Level 4)

| Level | ATBD name | Data Products | Resolution |
|---|---|---|---|
| **L1A-2A** | Transmit and Receive Waveform Interpretation and Generation of L1A and L2A products | 1A: Raw waveforms<br>2A: Ground elevation, canopy top height, relative height (RH) metrics | 25 m (~82 ft) diameter |
| **L1B** | Waveform Geolocation for L1 and L2 Products | Geolocated waveforms | 25 m (~82 ft) diameter |
| **L2B** | Footprint Canopy Cover and Vertical Profile Metrics | Canopy Cover Fraction (CCF), CCF profile, Leaf Area Index (LAI), LAI profile | 25 m (~82 ft) diameter |
| **L3** | Gridded Level 2 metrics | Including mean, median, and standard deviation for canopy height, surface elevation, and other biophysical features. | 1 km (~0.6 mi) grid |
| **L4A** | Footprint Above Ground Biomass Density | Footprint level above ground biomass | 25 m (~82 ft) diameter |
| **L4B** | Gridded Biomass Product | Gridded Above Ground Biomass Density (AGBD) | 1 km (~0.6 mi) grid |

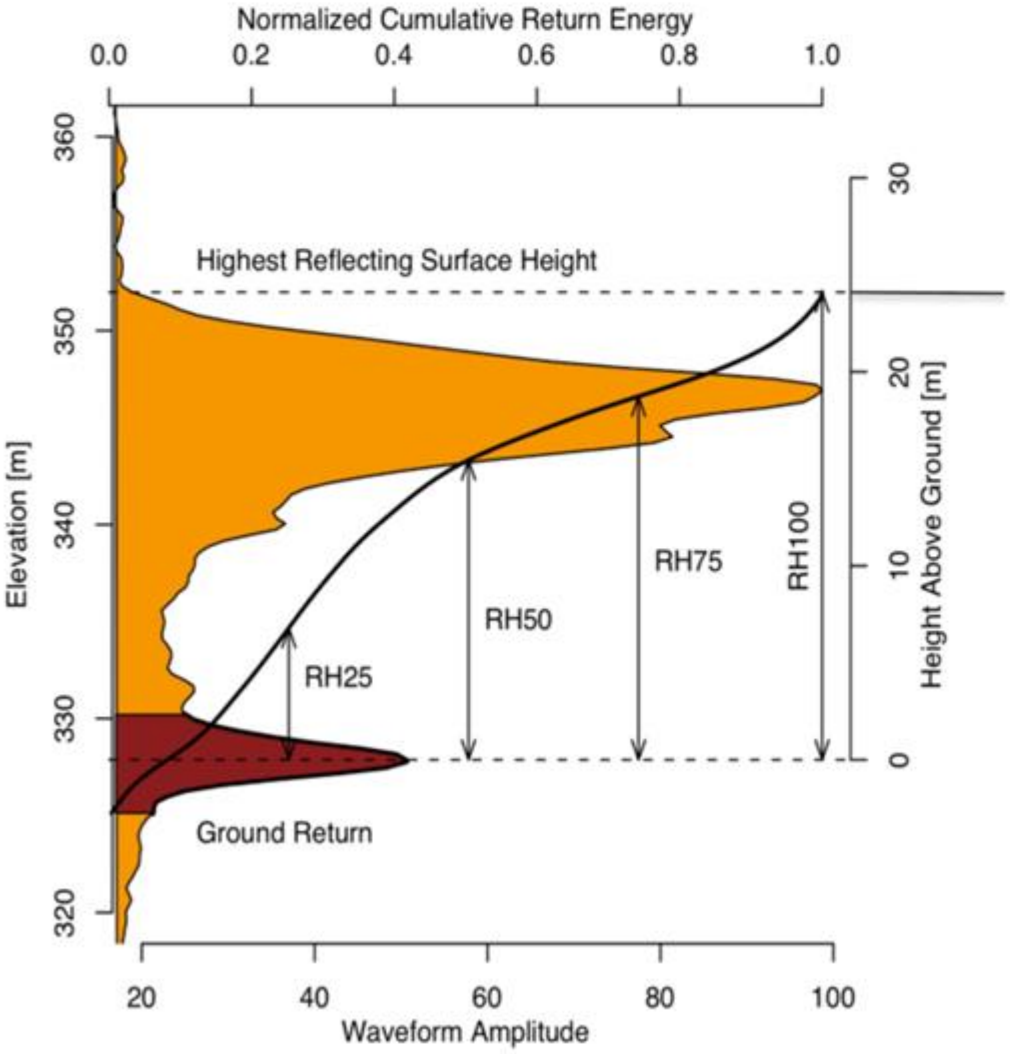
**Session 1 Training:**

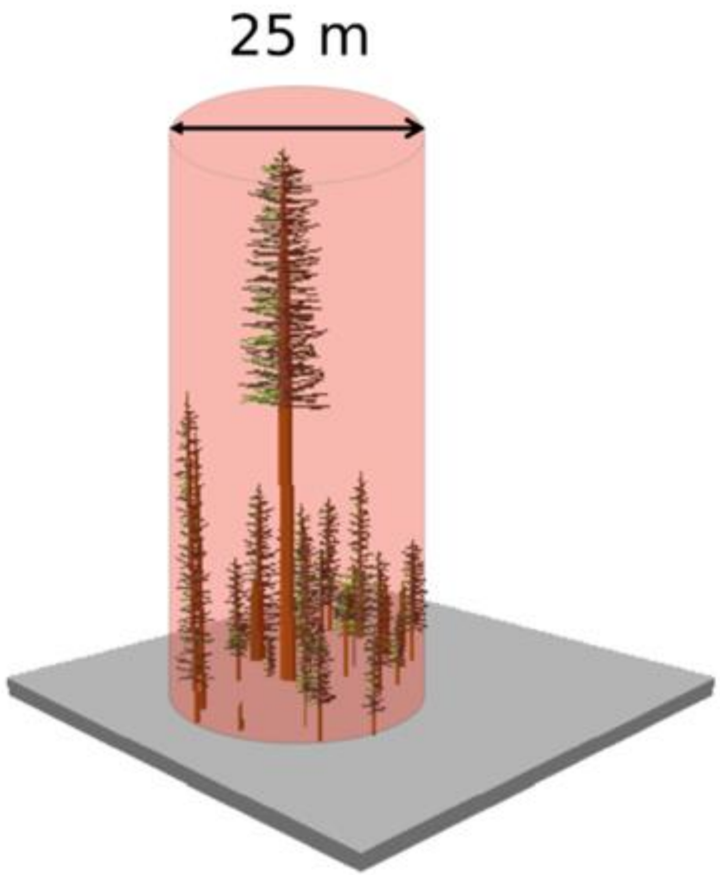
**Level 1B & Level 2A**

For more details on mathematical and modeling assumptions, access GEDI's Algorithm Theoretical Basis Documents (ATBDs).

# What information can we gain from a waveform?

**Relative Height (RH) Metrics** quantify the vertical structure of vegetation by calculating the height at which a specific percentage (quantile) of the total laser energy returned to the sensor is reached, relative to the ground surface.



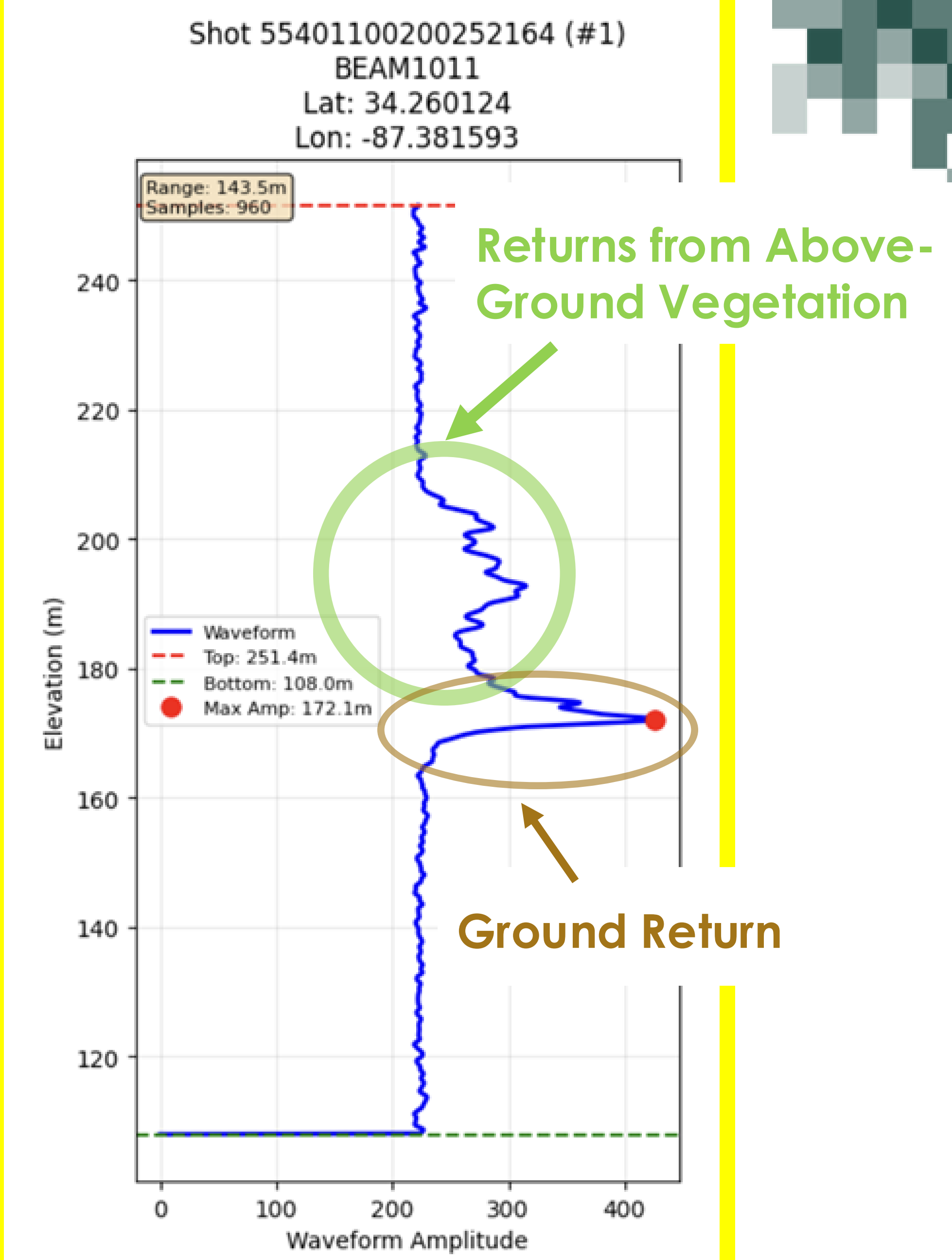




Source: GEDI mission

# GEDI Waveform – Example 1

Strong Above-Ground Return

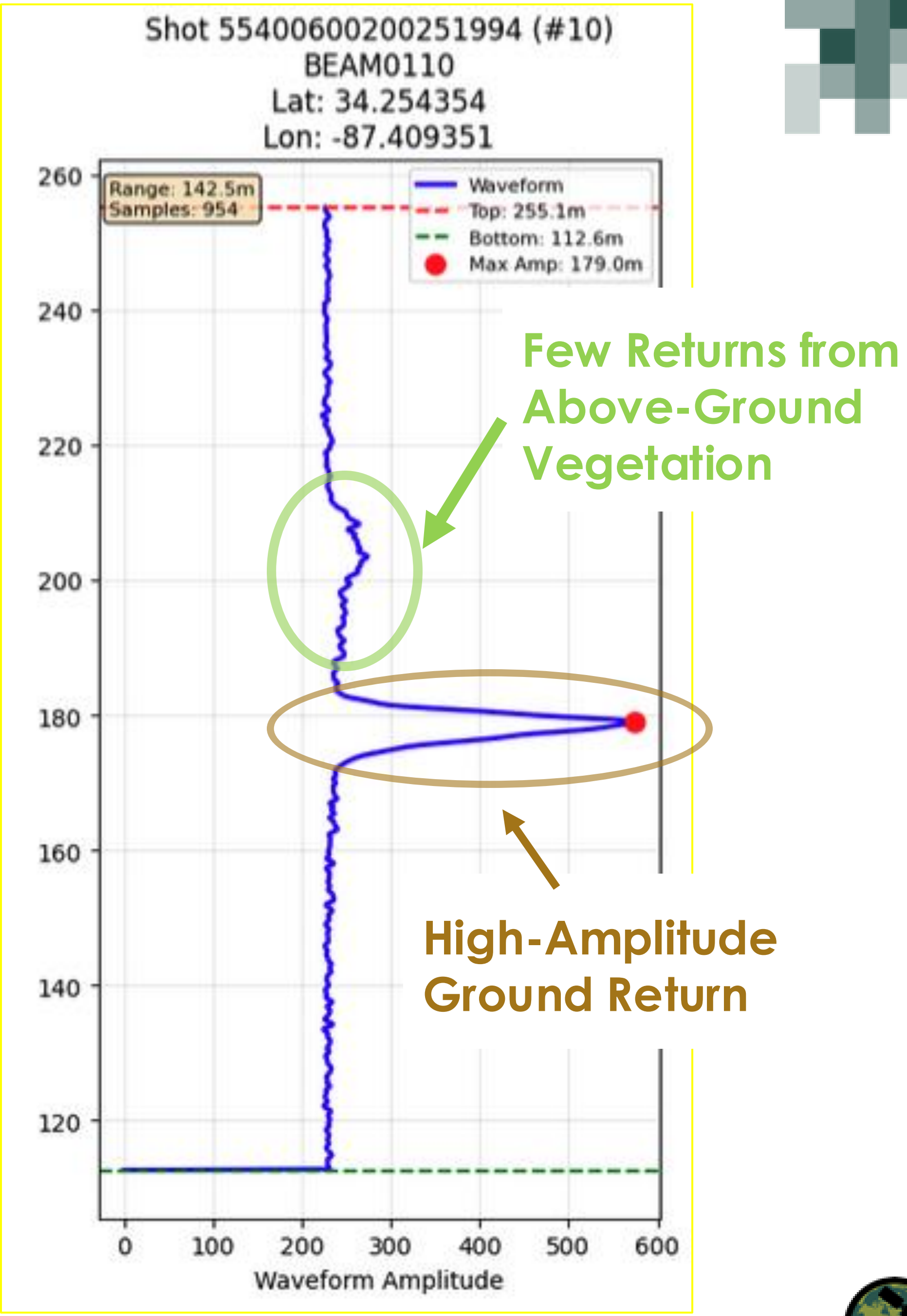
**Bankhead National Forest, Alabama, USA**

# GEDI Waveform – Example 2

Weaker Above-Ground Return, Strong Ground Return

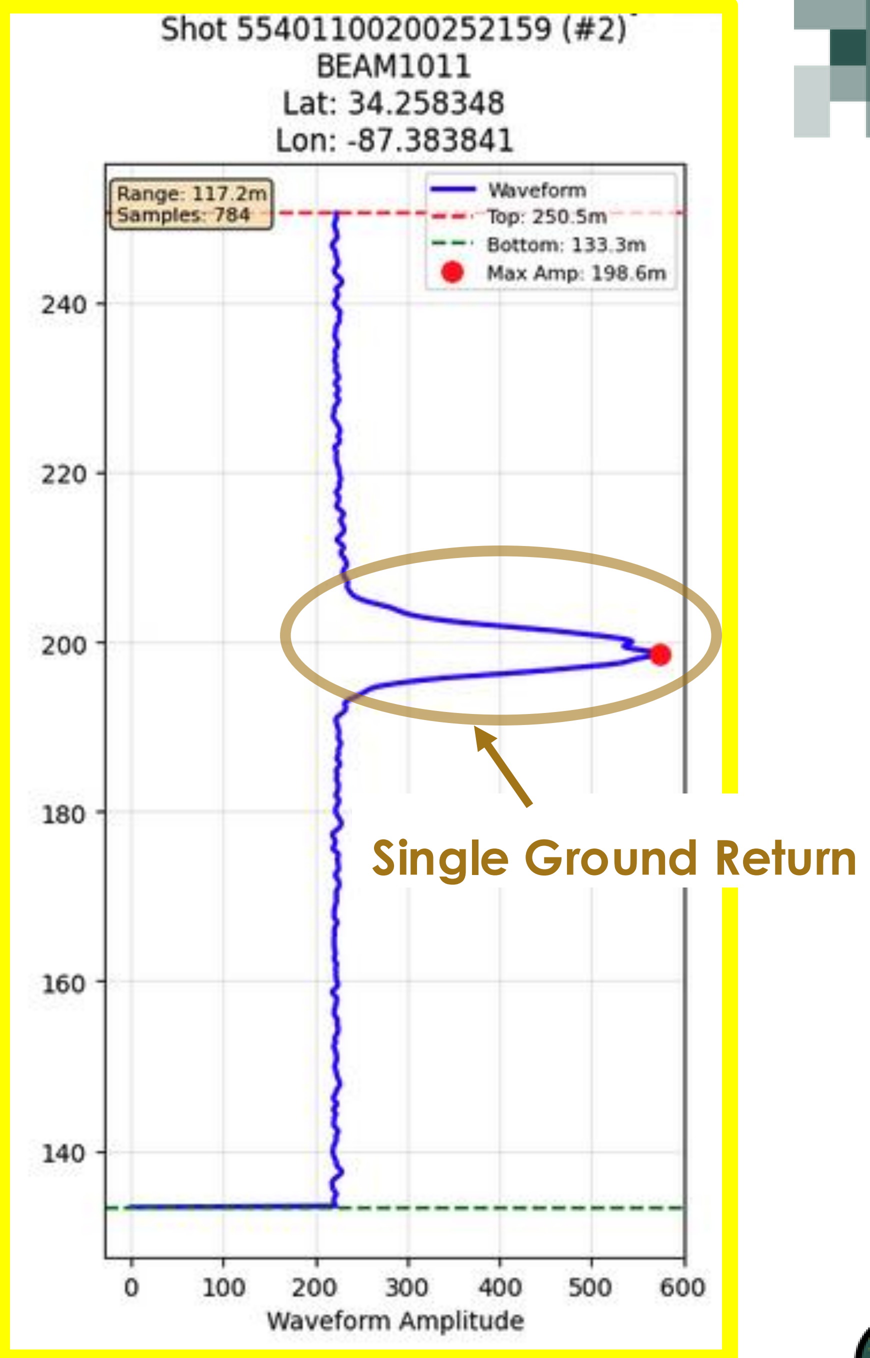
**Bankhead National Forest, Alabama, USA**

# GEDI Waveform – Example 3

No Above-Ground Return, Ground Return Only

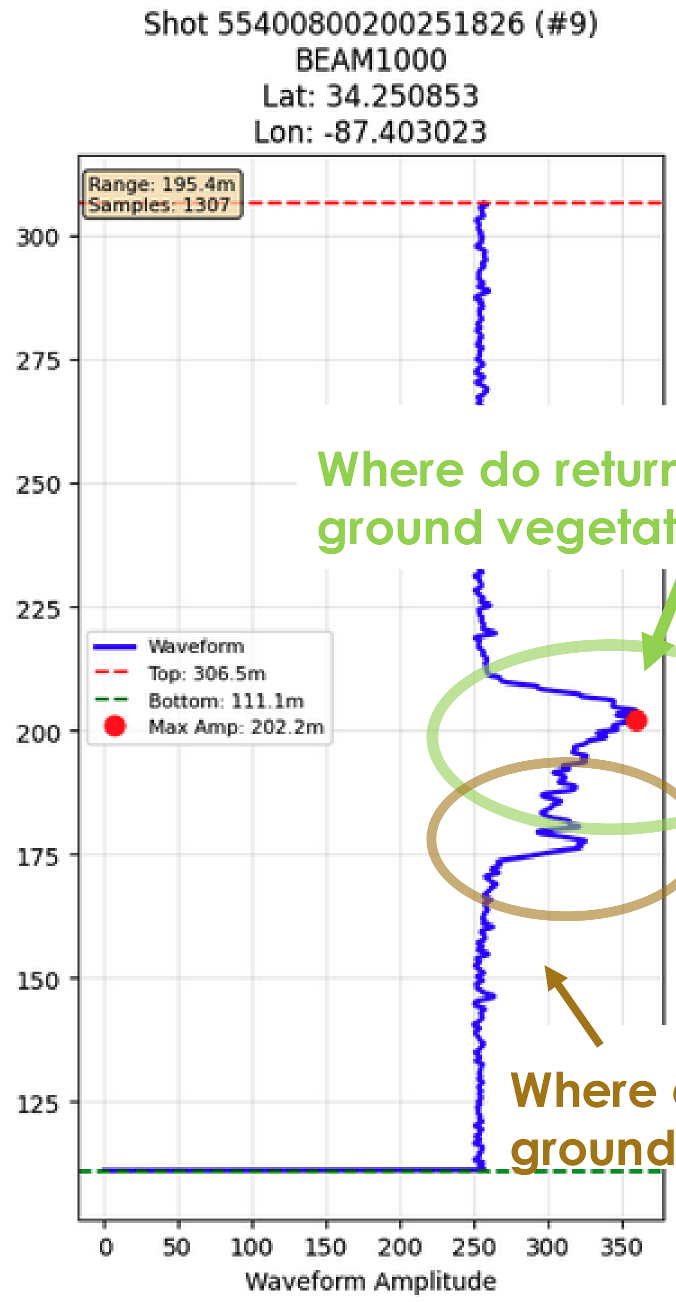
**Bankhead National Forest, Alabama, USA**

# GEDI Waveform – Example 4

Unclear if Above-Ground or Ground Return

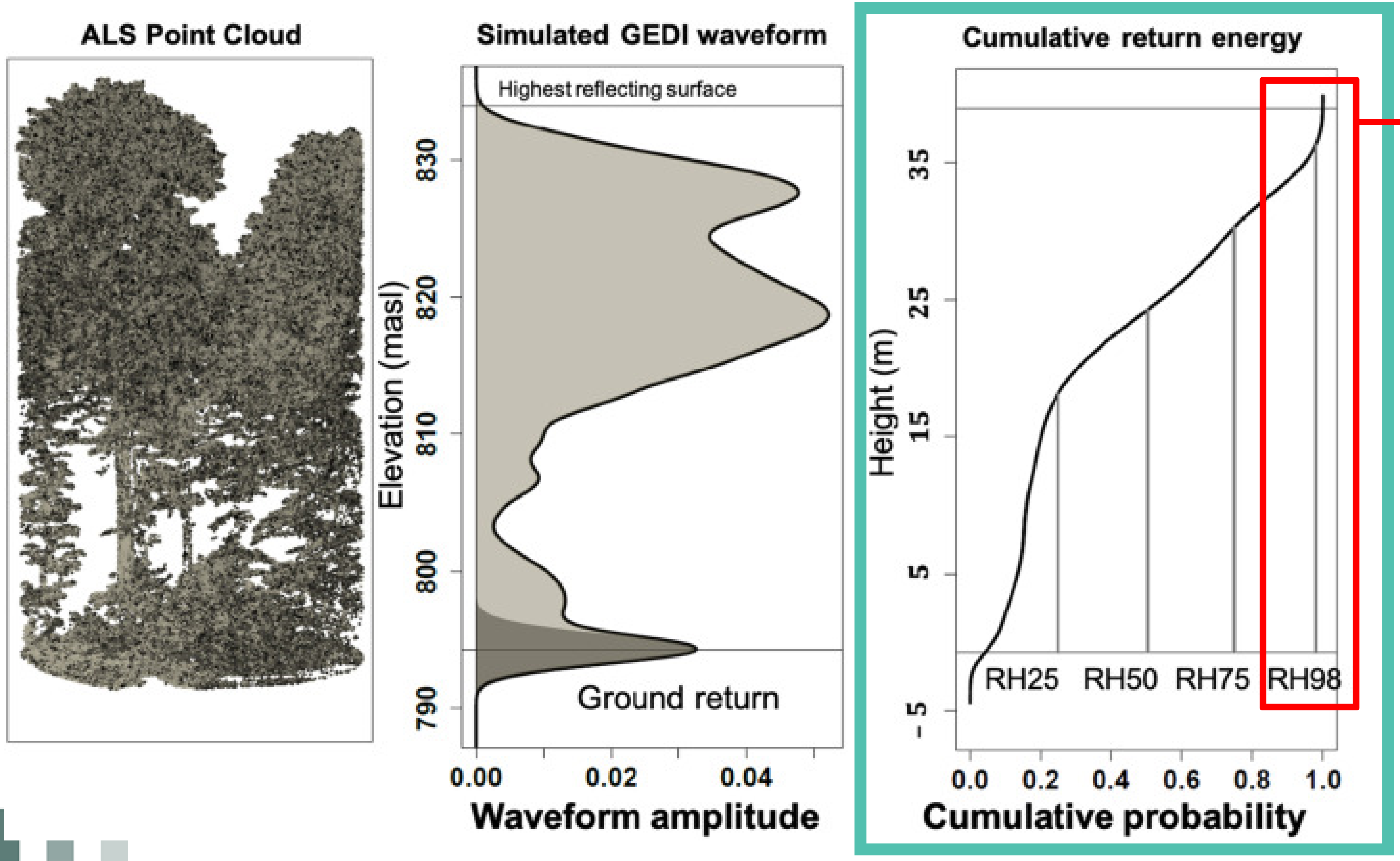
**Bankhead National Forest, Alabama, USA**


Where do returns from above-ground vegetation end?

Where does the ground return begin?

# Relative Height (RH) Metrics

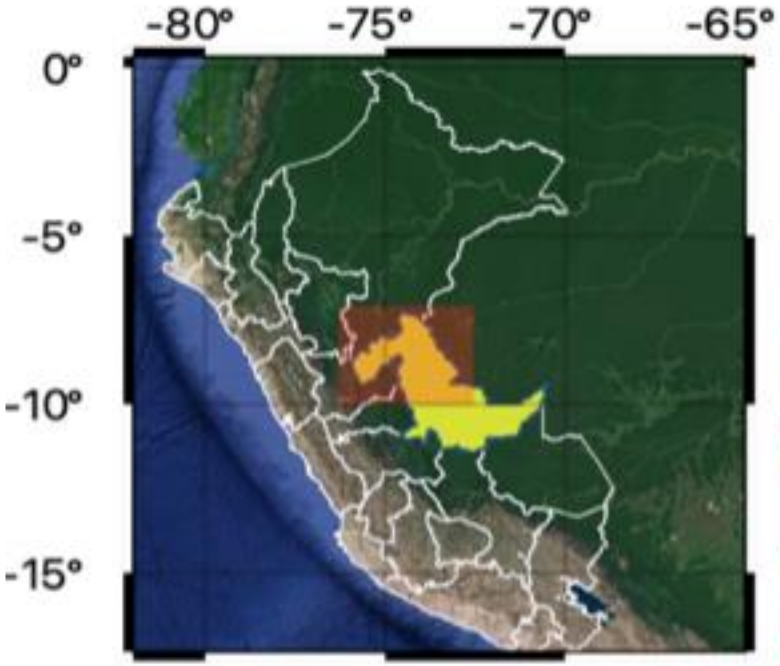


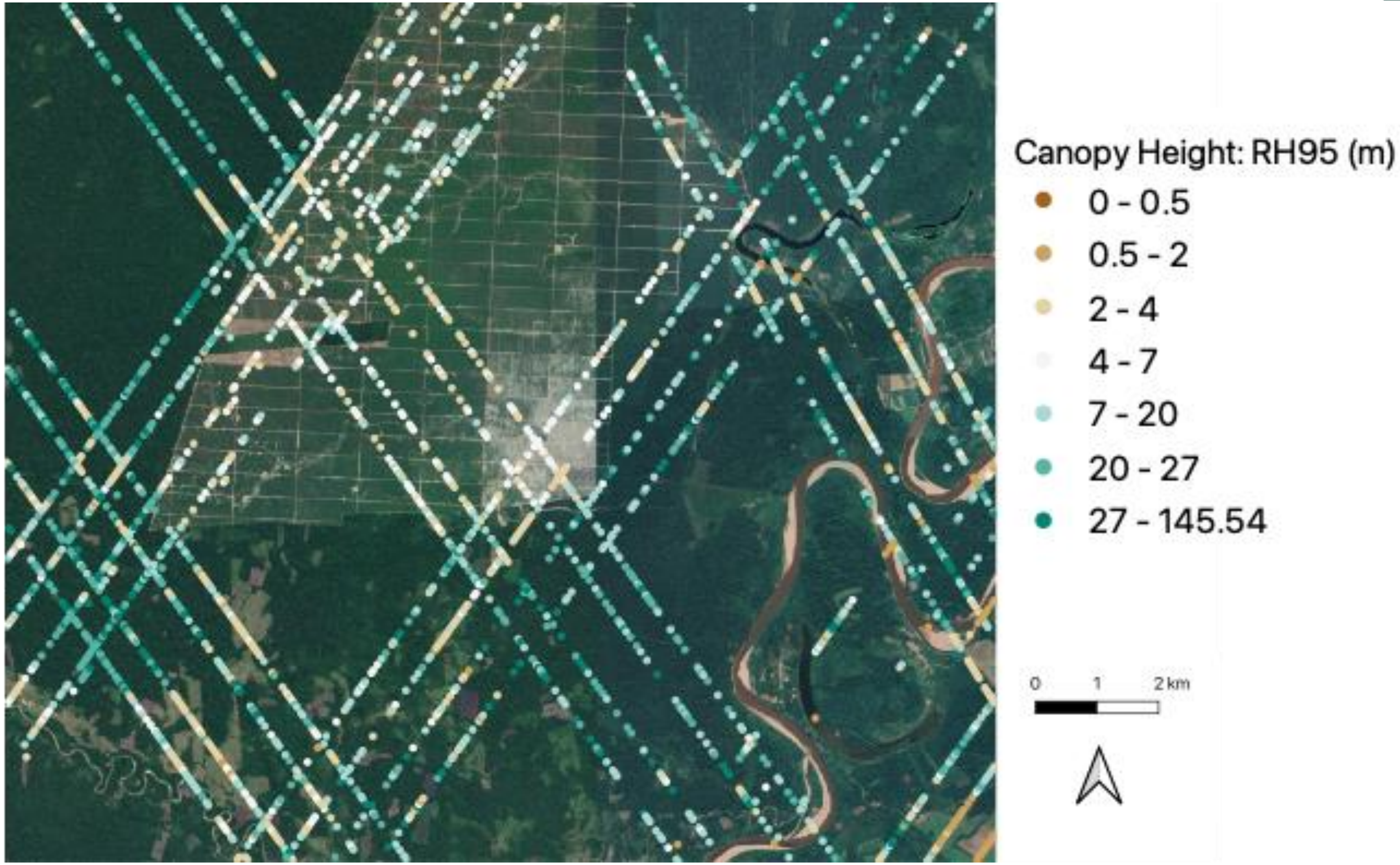

**Canopy Height**
(RH95-100)

**Summary:** RH metrics quantify the vertical structure of vegetation by calculating the height at which a specific percentage (quantile) of the total laser energy returned to the sensor is reached, relative to the ground surface.

Source: Duncanson et al., 2021

# Mapping Canopy Height: RH95

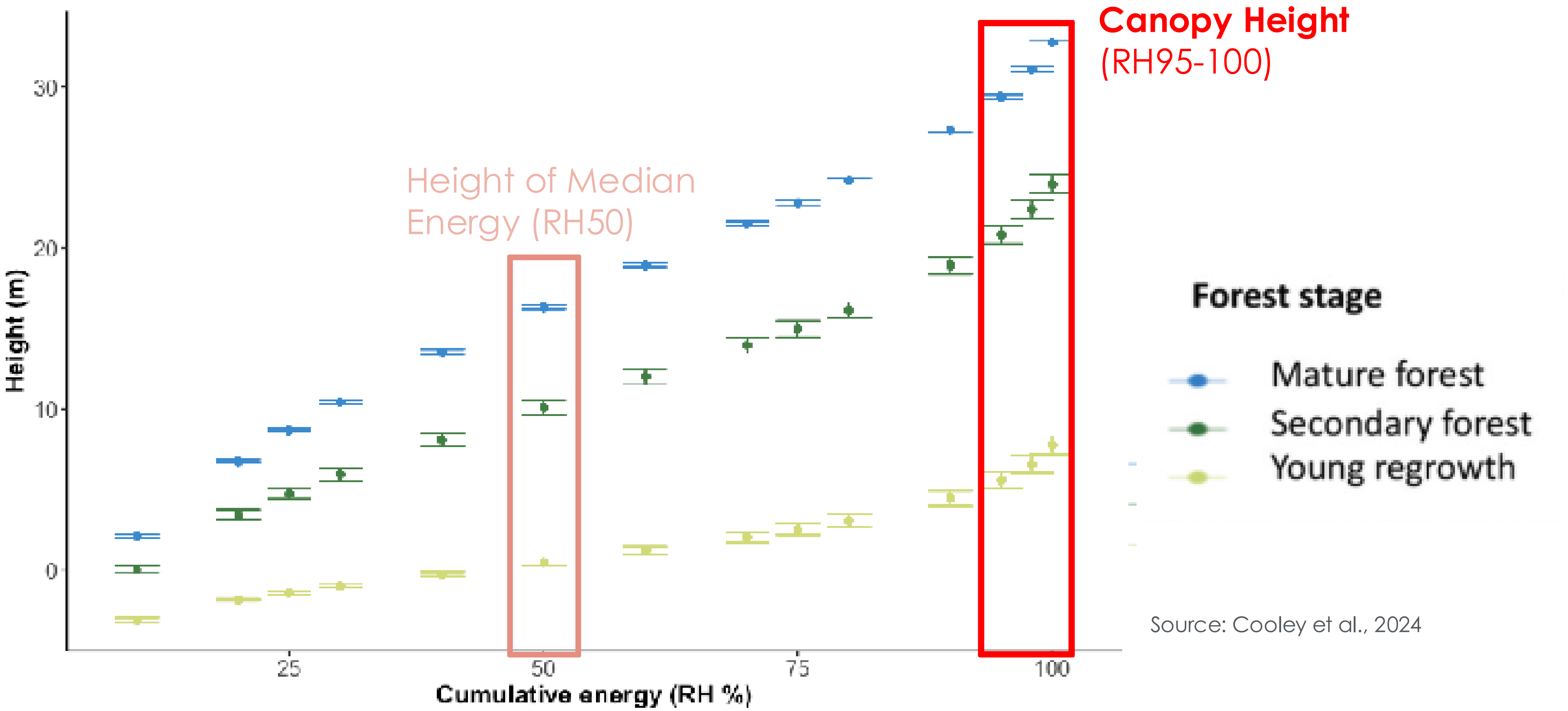



Source: Cooley et al., 2024

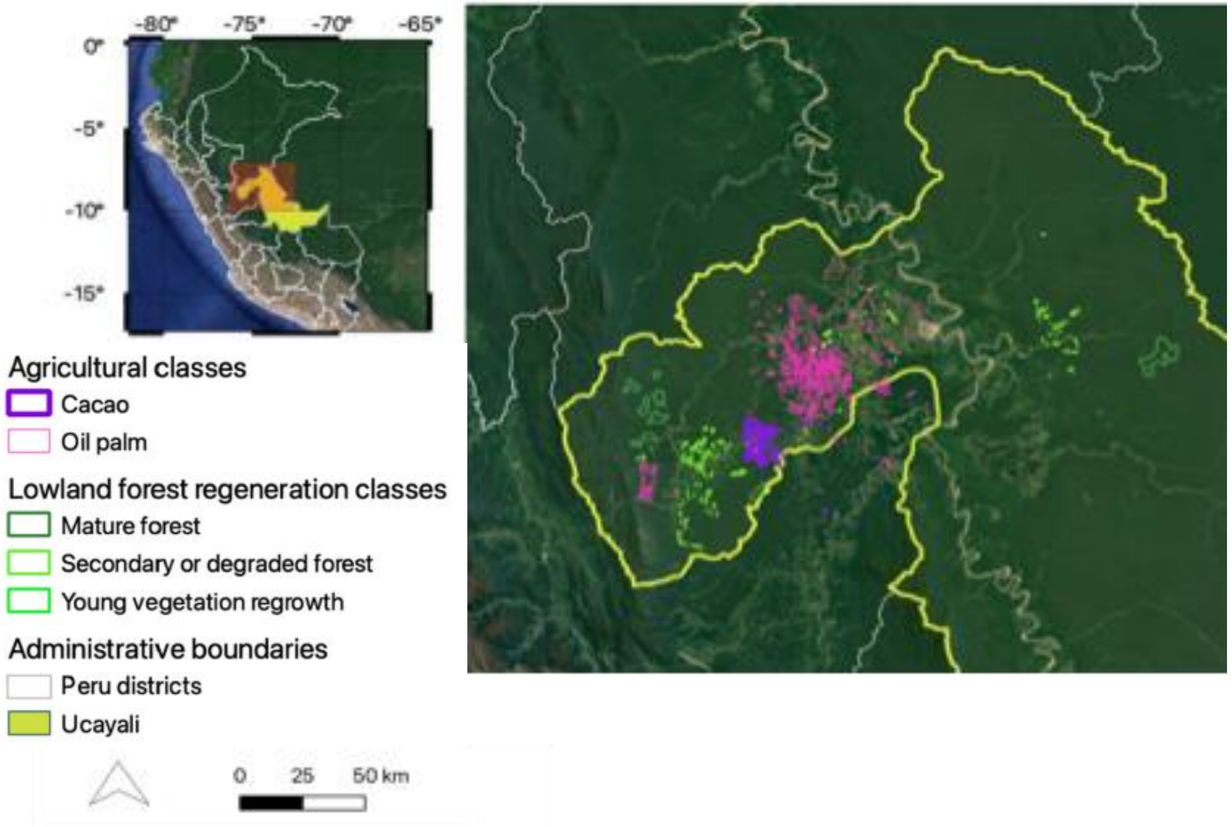
# Plotting Relative Height (RH) Metrics for Regenerating Forest Classes

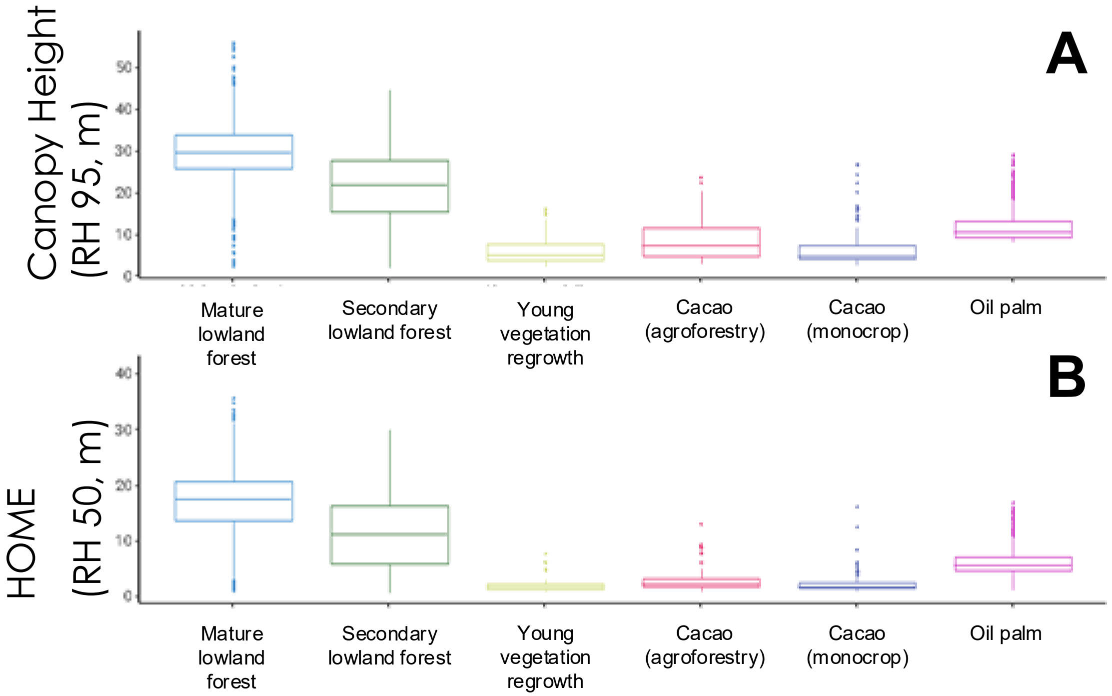
**Cumulative energy profiles with RH metrics from GEDI**
Reveals structural differences among forest classes in Ucayali, Peru




Source: Cooley et al., 2024

# Relative Height (RH) Metrics Compared Across Multiple Land Uses

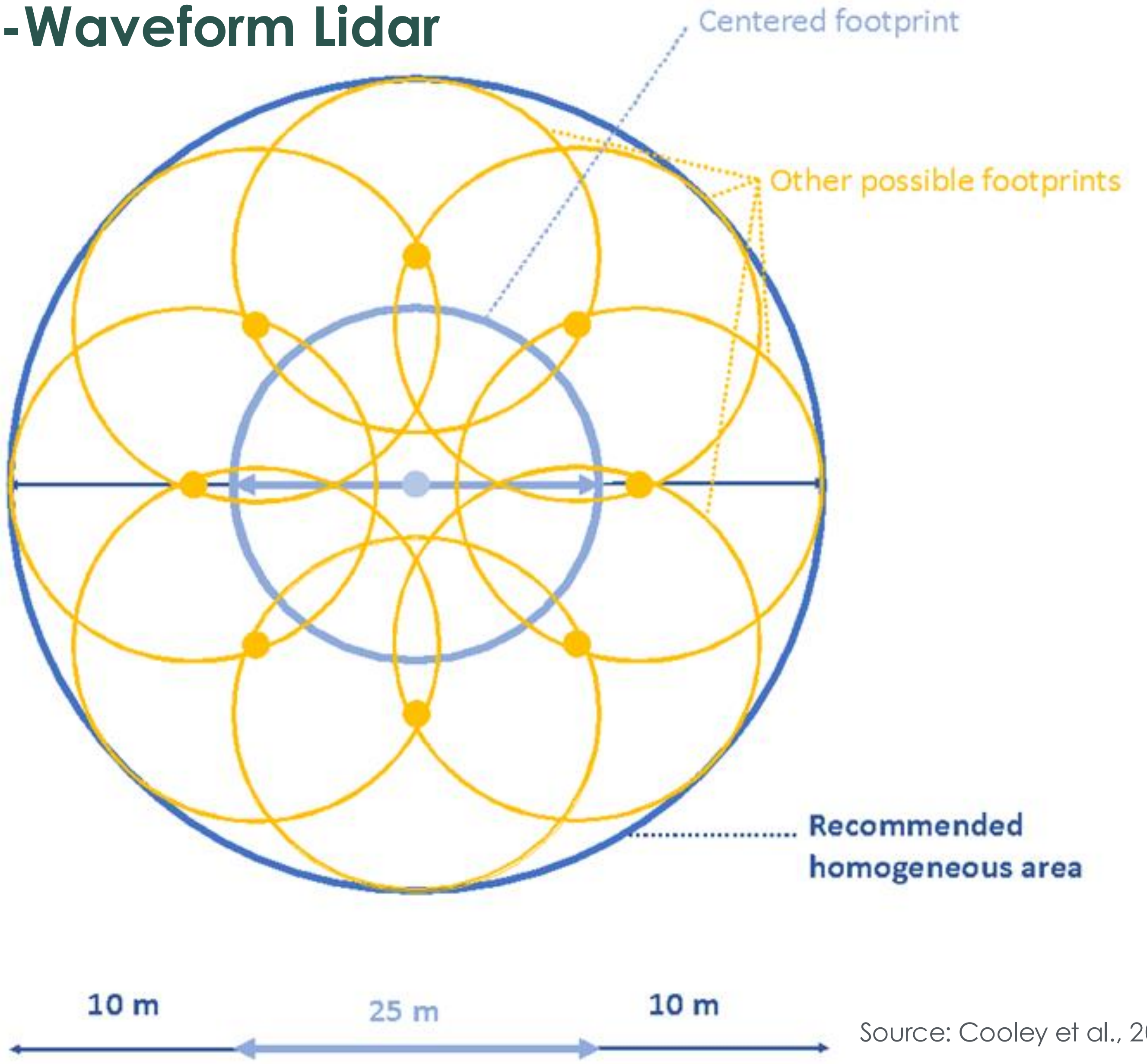



Source: Cooley et al., 2024

# Limitations of Spaceborne Full-Waveform Lidar

- Geolocation Error
- Inability to Penetrate Clouds
- Canopy Penetration Failure
- Sampling-Based Spatial Coverage
- Limited Temporal Resolution
- Slope-Induced Waveform Contamination




Source: Cooley et al., 2024

# First Round of Q&A (15 min)

Session 1: Introduction to Full Waveform Lidar

**Section 3: Practical Forest Ecosystem Applications with GEDI Full-Waveform Data**

# Exercise 1: Spatial Search GEDI L1B Files, Apply QA Filters & Plot Waveforms

Python notebook on Github

## Objective

- Access, filter, and visualize GEDI Level 1B full-waveform data using NASA Earthdata APIs
- Interpret waveform characteristics for vegetation structure analysis

## Activities

- Preparation Steps: 1) Clone the GitHub Repository, 2) Install Required Libraries, 3) Mount Your Google Drive
- Authenticate with NASA Earthdata Login credentials
- Search for GEDI Level 1B granules with earthaccess Python library
- Download the GEDI data into Google Colab cloud environment for the specified area of interest
- Apply quality assurance filtering using quality_flag and degrade_flag fields
- Plot raw waveforms for multiple footprints
- Identify and interpret ground return signals versus canopy returns

## Default Area of Interest (AOI)

- Bankhead National Forest, Alabama, USA
- The default lat/lon bounding box can be changed to your own AOI if you clone the Github repository and modify your local copy of the Colab .ipynb code!

## Time Frame

- start_date = "2019-04-01"
- end_date = "2025-10-3"

# Exercise 2: Search GEDI Data, Plot RH Metrics and RH Ratios

## Objective

- Access, filter, and visualize GEDI Level 2A relative Height (RH) metrics using NASA Earthdata APIs and the Harmony tool
- Interpret RH metrics for vegetation structure analysis

## Activities

We will use a google colab notebook to:

- Search GEDI L2A products
- Apply the Harmony tool to perform a spatial subsetting
- Select waveforms based on quality metrics
- Display results to visualize spatial trends in canopy height and RH metrics
- Assess differences in structure among mature forest sites and agricultural sites in the Brazilian Atlantic rainforest

## Default Area of Interest (AOI)

- Mature forest sites and agricultural sites in the Brazilian Atlantic rainforest
- The default lat/lon bounding box can be changed to your own AOI if you clone the Github repository and modify your local copy of the Colab .ipynb code!

## Time frame

- start_date = "2019-04-01"
- end_date = "2025-10-3"

Session 1: Introduction to Full-Waveform Lidar

**Summary**

# Summary

- **Lidar Fundamentals:** Active sensor measuring distance using laser time-of-flight; captures elevation, canopy height, and 3D vegetation structure
- **Full-Waveform Advantages:** Records complete energy profile (not just peaks), revealing vertical vegetation distribution within 25m footprints
- **GEDI Mission:** ISS-based spaceborne lidar with 8 parallel tracks covering ±51.6° latitude; produces footprint (25m) and gridded (1km) data products
- **Relative Height (RH) Metrics:** Quantify canopy structure—RH95 measures canopy height, RH50 captures understory characteristics, ratios reveal layering
- **Key Limitations:** ±10m geolocation uncertainty, cannot penetrate clouds, discrete track sampling (not wall-to-wall coverage), limited temporal revisits
- **Hands-On Skills:** Authenticated NASA Earthdata access, downloaded and filtered GEDI L1B/L2A data, plotted waveforms, interpreted vegetation structure from signal patterns

# Looking Ahead to Session 2

In Session 2, you will be able to:

- Describe the general characteristics, strengths and limitations of the GEDI mission and its data.
- Identify GEDI data products and their characteristics for elevation, canopy height, vegetation structure, and biomass.
- Access and visualize GEDI datasets—including elevation, canopy height, vegetation structure, and biomass—for an area of interest using openly available tools.

# Resources


- Cooley, S. S., Pinto, N., Becerra, M., Alvarado, J. W. V., Fahlen, J. C., Rivera, O., Fricker, G. A., Dantas, A. R. D. L. R., Aguilar-Amuchastegui, N., Reygadas, Y., Gan, J., DeFries, R., & Menge, D. N. L. (2024). Combining spaceborne lidar from the Global Ecosystem Dynamics Investigation with local knowledge for monitoring fragmented tropical landscapes: A case study in the forest–agriculture interface of Ucayali, Peru. Ecology and Evolution, 14, e70116. https://doi.org/10.1002/ece3.70116
- Doyog, N. D., & Lin, C. (2024). Generating Wall-to-Wall Canopy Height Information from Discrete Data Provided by Spaceborne LiDAR System. Forests, 15(3), 482.
- Dubayah, R., Blair, J. B., Goetz, S., Fatoyinbo, L., Hansen, M., Healey, S., Hofton, M., Hurtt, G., Kellner, J., Luthcke, S., Armston, J., Tang, H., Duncanson, L., Hancock, S., Jantz, P., Marselis, S., Patterson, P. L., Qi, W., & Silva, C. (2020). The global ecosystem dynamics investigation: High-resolution laser ranging of the Earth's forests and topography. Science of Remote Sensing, 1, 100002.
- Kellner, J. R., Armston, J., & Duncanson, L. (2021). Algorithm theoretical basis document (ATBD) for GEDI level-4A (L4A) footprint level aboveground biomass density. University of Maryland.
- Potapov, P., Li, X., Hernandez-Serna, A., Tyukavina, A., Hansen, M. C., Kommareddy, A., Pickens, A., Turubanova, S., Tang, H., Silva, C. E., Armston, J., Dubayah, R., Blair, J. B., & Hofton, M. (2021). Mapping global forest canopy height through integration of GEDI and Landsat data. Remote Sensing of Environment, 253, 112165.
- Wulder, M. A., White, J. C., Nelson, R. F., Næsset, E., Ørka, H. O., Coops, N. C., Hilker, T., Bater, C. W., & Gobakken, T. (2012). Lidar sampling for large-area forest characterization: A review. Remote Sensing of Environment, 121, 196-209.

# Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 11/06/2025
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 11/20/2025**

- **Certificate of Completion:**
  - Attend all three 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

Trainers:

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- Naiara Pinto
  - naiara.printo@jpl.nasa.gov

- ARSET Website
- ARSET YouTube

# Thank You!

# Second Round of Q&A (15 min)