Global Ecosystem Dynamics Investigation

Mission Status

Ralph Dubayah

University of Maryland

GEDI ECOSYSTEM LIDAR

Outline

- Science Goals and Objectives
- Mission and Instrument Specifications
- Science Approach and Data Products
- Calibration and Validation Activities
- Fusion with Tandem-X and Other Missions

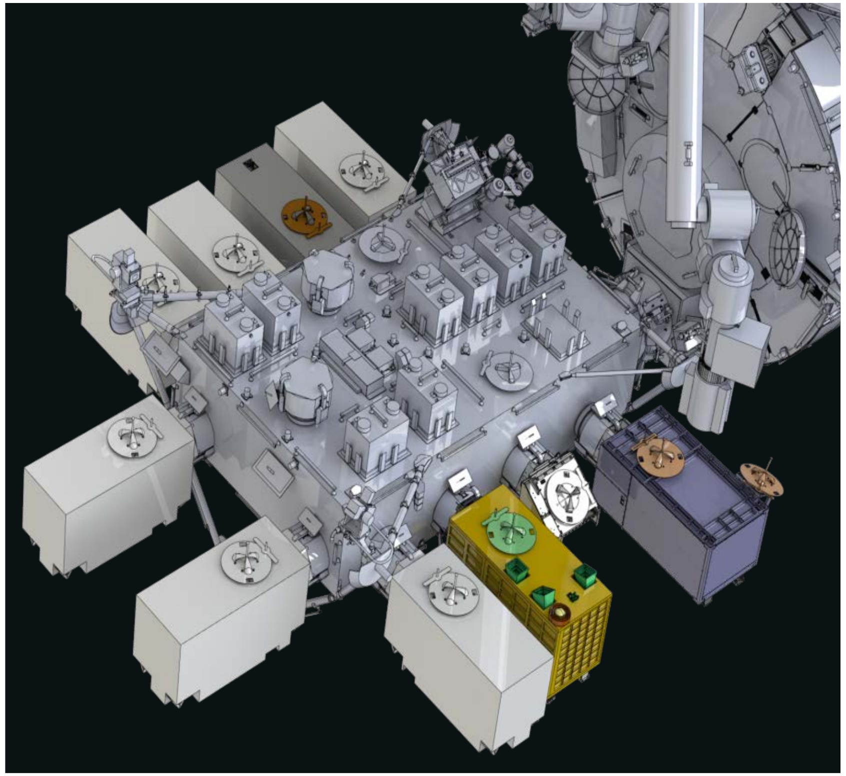
Earth Ventures Instrument (EVI)

- 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-18: 31 December 2018
  - Observations between +/- 50º N &
- Nominal 2 year mission length

Mission Overview

High Resolution Laser Ranging of the Earth's Forests and

- **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 is deployed on the JEM-EF

Science Questions and Objectives

Quantify

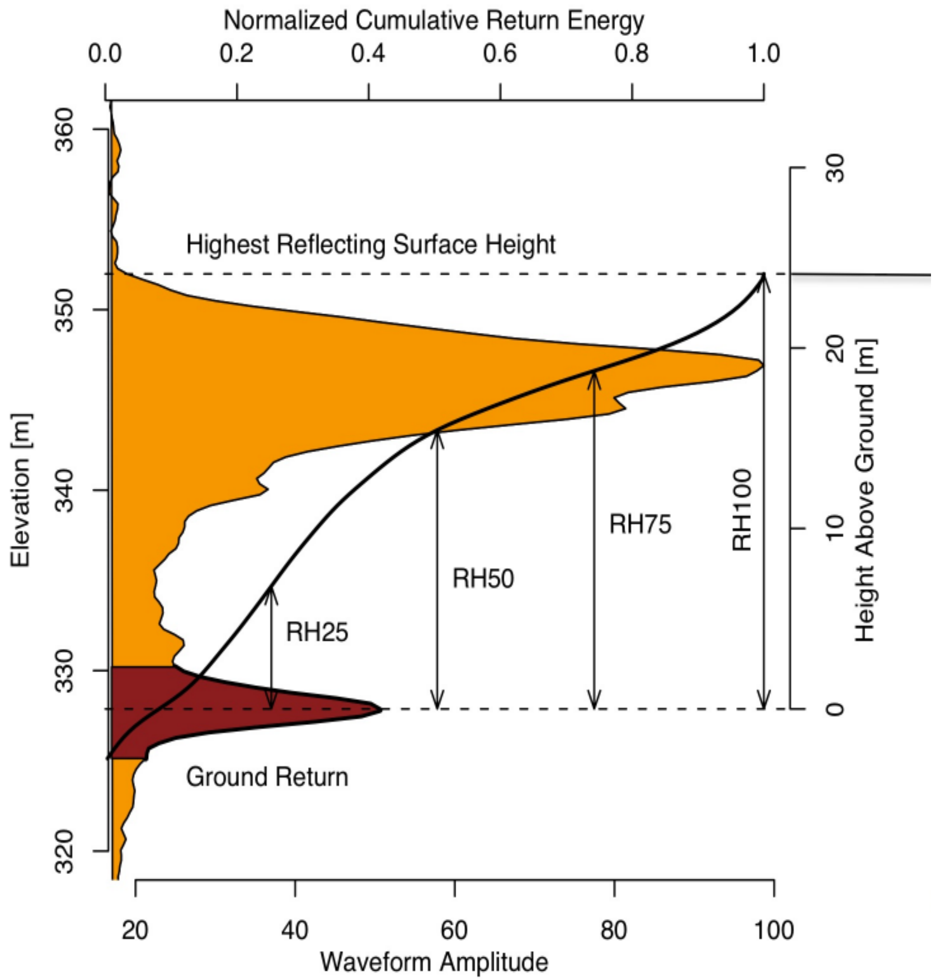
- Forest Biomass
- Disturbance and Recovery
- Carbon Sequestration Potential
- Vertical Forest Structure and its Relationship to Biodiversity

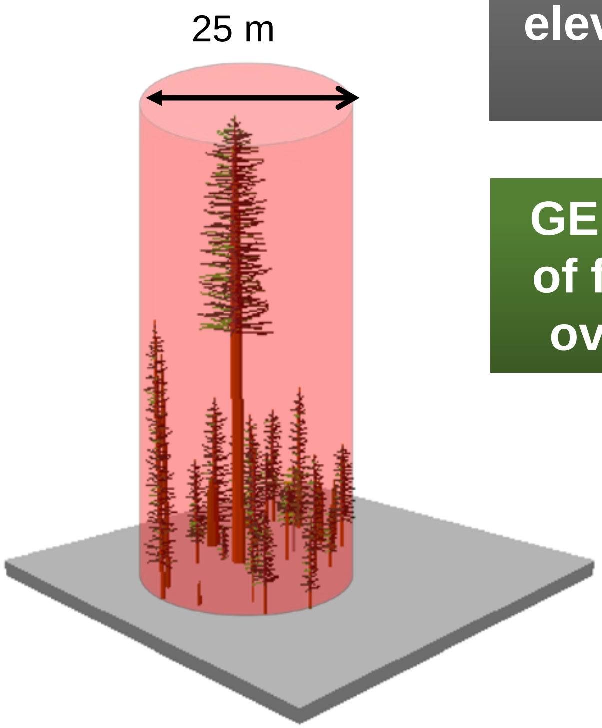
Science Applications

Geodetic-class laser ranging measurements have far reaching applications

Forest height and vertical structure; habitat quality & biodiversity; Forest carbon sinks & source areas; loss of carbon from extreme events such as fires and hurricanes; parameterization of ecosystem models	**Forest Management & Carbon Cycling**
Canopy 3D structure that influences snowmelt, evapotranspiration, canopy interception of precipitation. Glacier surface elevation change; lake & river stage; snowpack elevation; coastal tides.	**Water Resources**
Improved canopy aerodynamic profiles to parameterize weather prediction models. Canopy and biomass products that initialize and constrain climate models; impacts of land use change on climate	**Weather Prediction**
Accurate bare earth and under canopy topographic elevations for improved digital elevation models from radar. Calibration of satellite based observations of surface deformation and earthquakes	**Topography & Surface Deformation**

GEDI Lidar Measurements

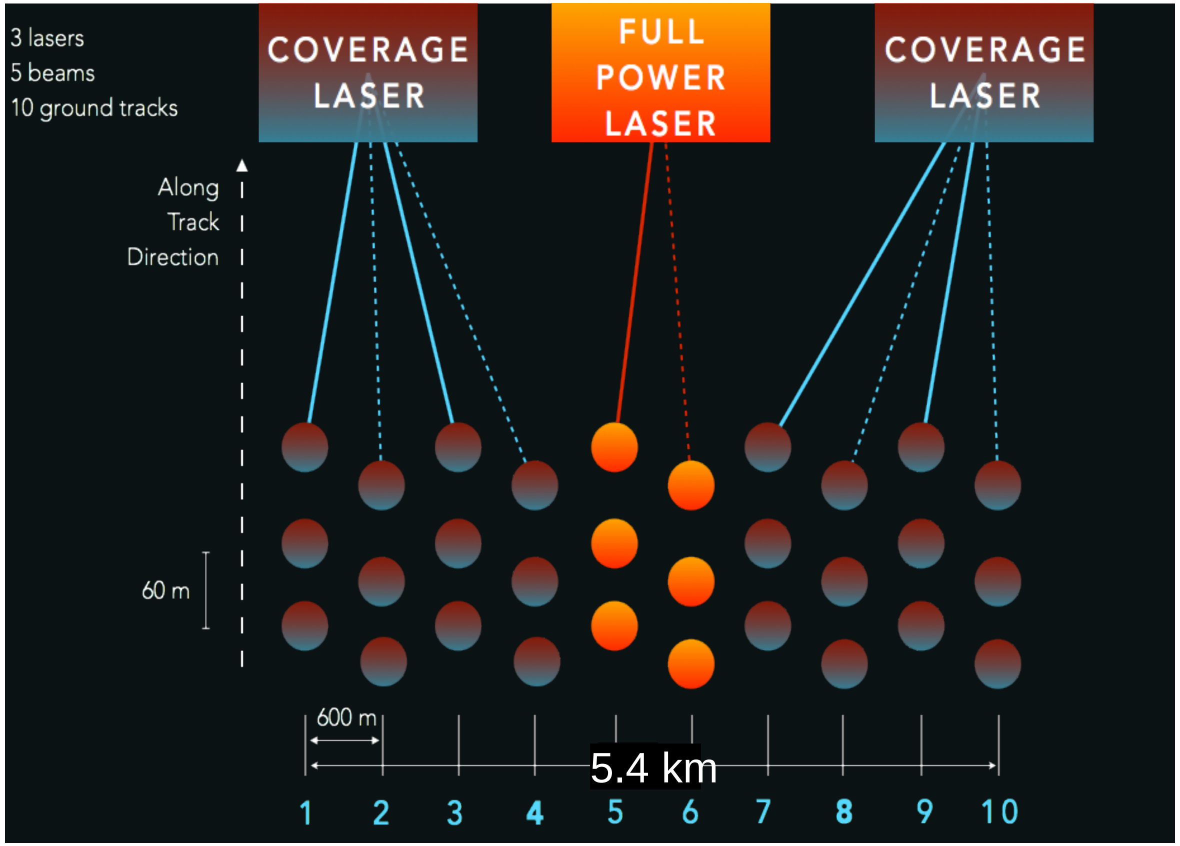




GEDI's sole observable is the lidar waveform which provides ground elevation, canopy height, cover and various profiles and metrics.

GEDI makes 12 billion observations of forest and land surface structure over its nominal two-year mission

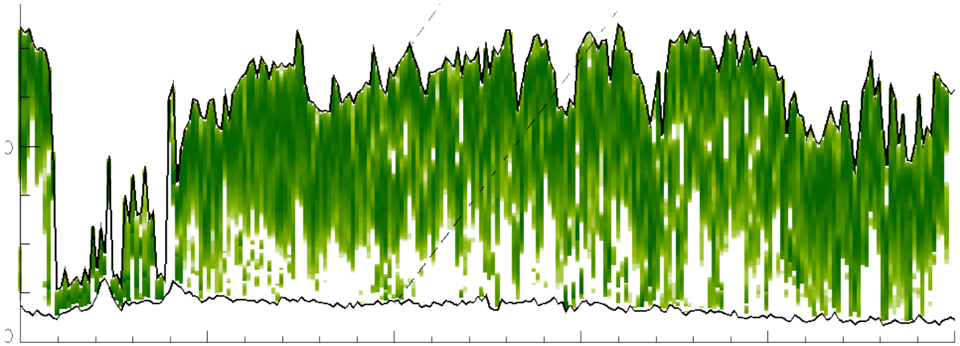
GEDI Beam Pattern



GEDI uses 3 lasers to produce 10 transects of lidar waveforms.

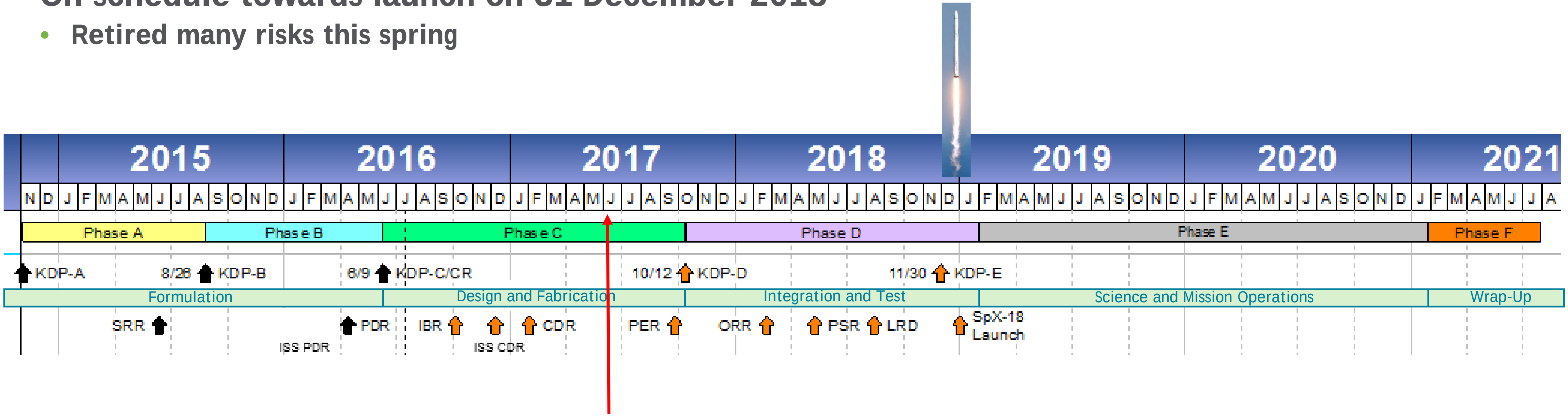
Each footprint provides the complete vertical structure of the canopy.

Dithering can be turned off for contiguous, along-track coverage.

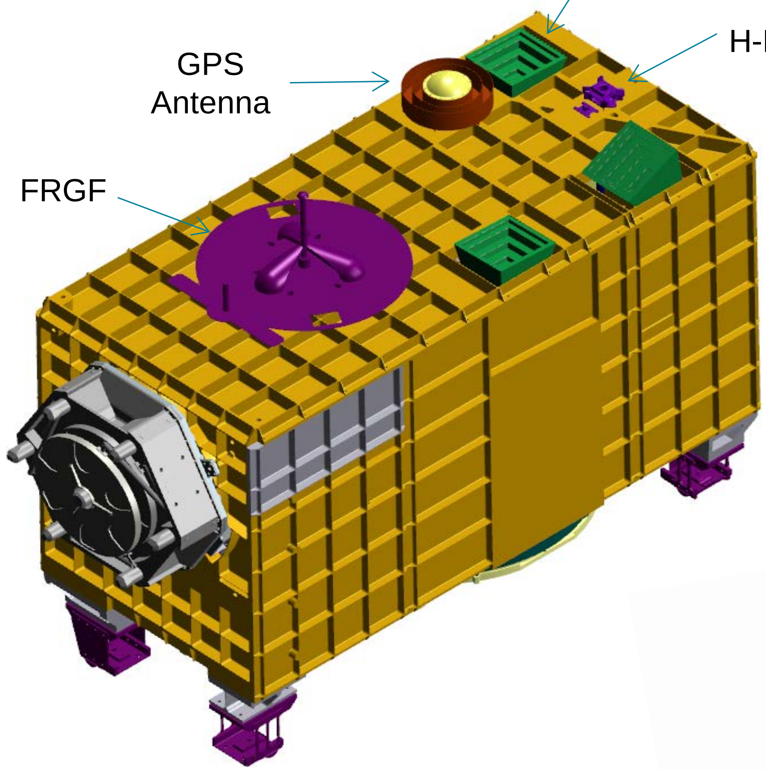


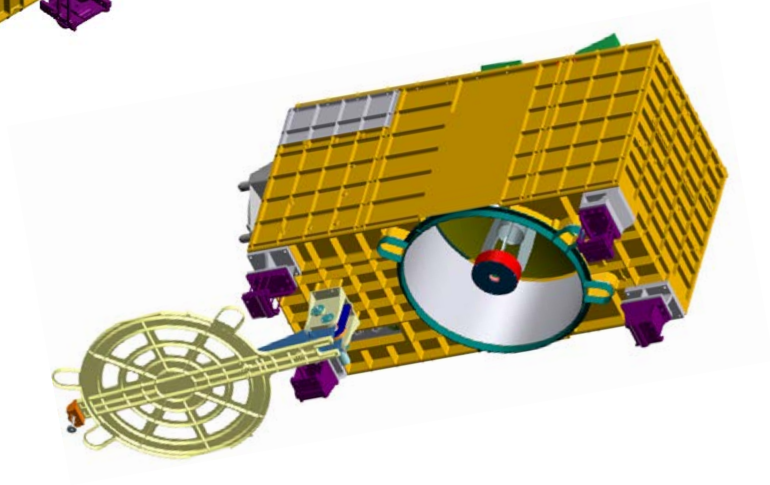
Current Mission and Engineering Status

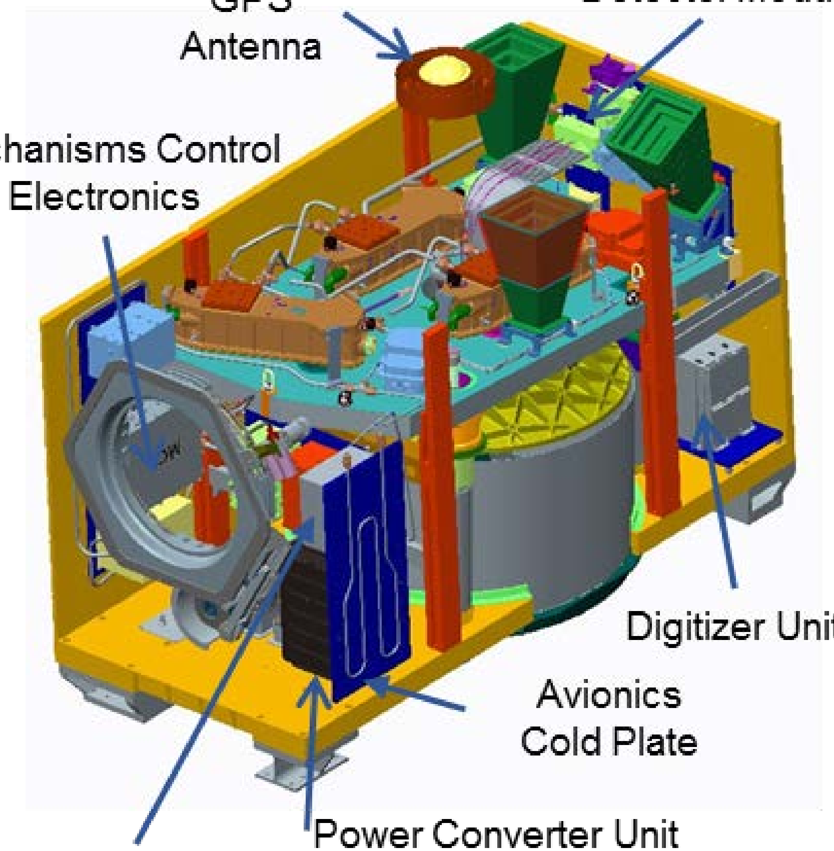
- **GEDI successfully passed key milestones:**
  - **Confirmation Review and Critical Design Review (CDR)**
- **Currently in Phase C**
- **All Algorithm Theoretical Basis Documents (ATBDs) have been created and externally reviewed**
- **Integration & Test begins in October**
- **On schedule towards launch on 31 December 2018**
  - **Retired many risks this spring**



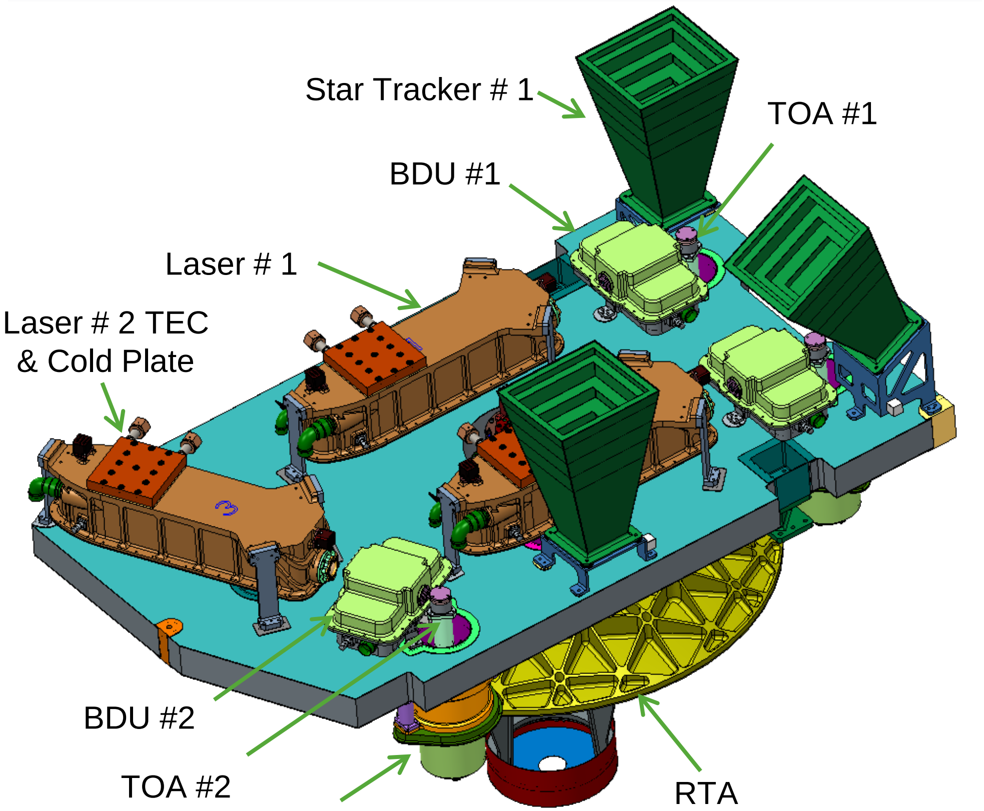
GEDI Lidar Instrument

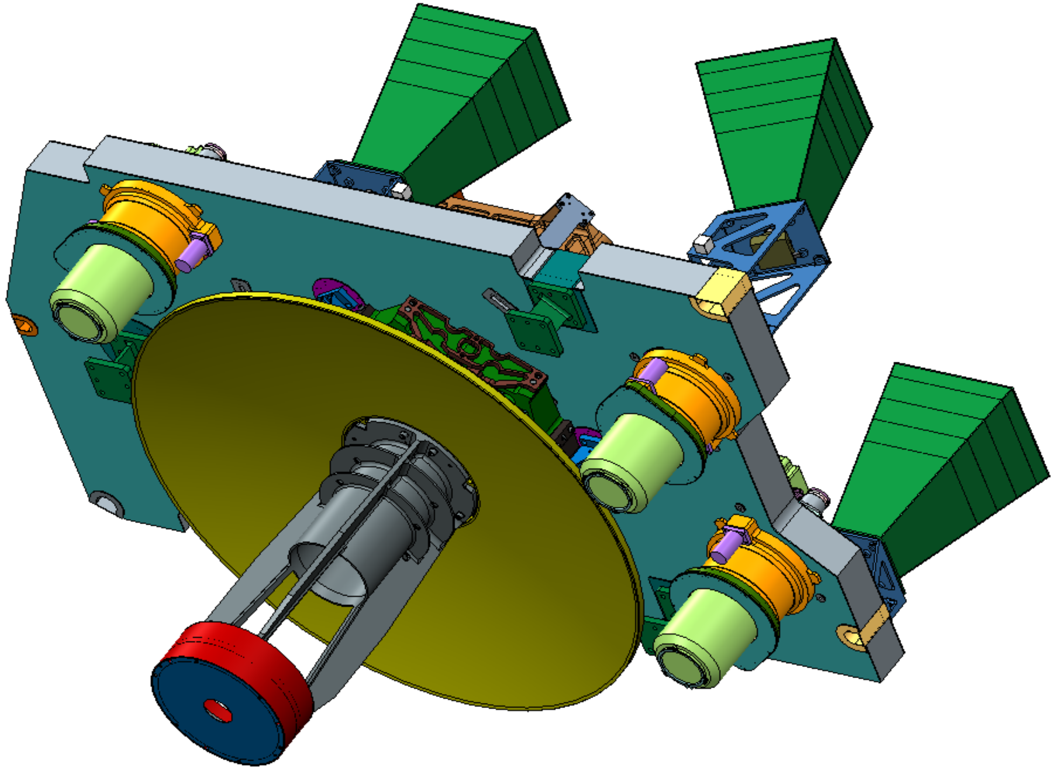






GEDI Lidar Instrument

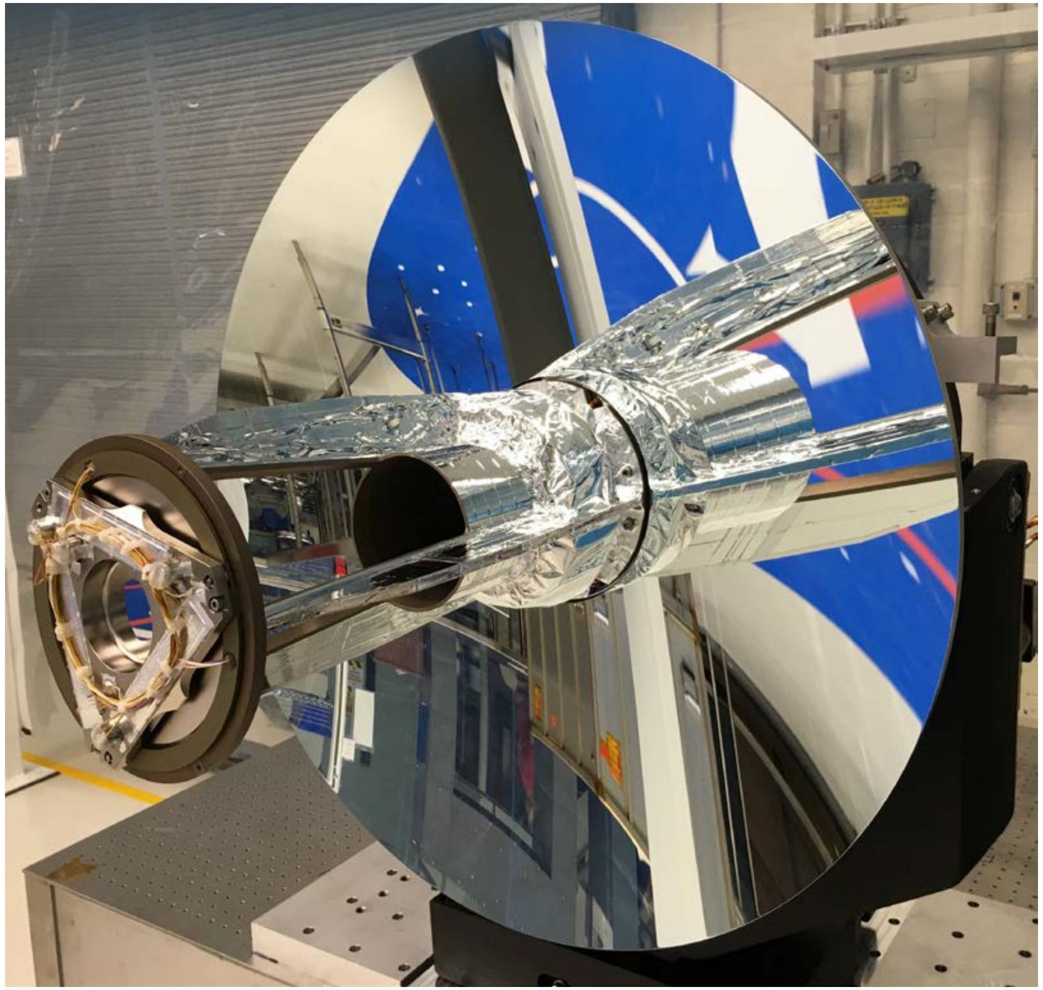




GEDI Beryllium Mirror

- GEDI mirror is exact copy of ICESat2 mirror

- Same material as James Webb Space Telescope

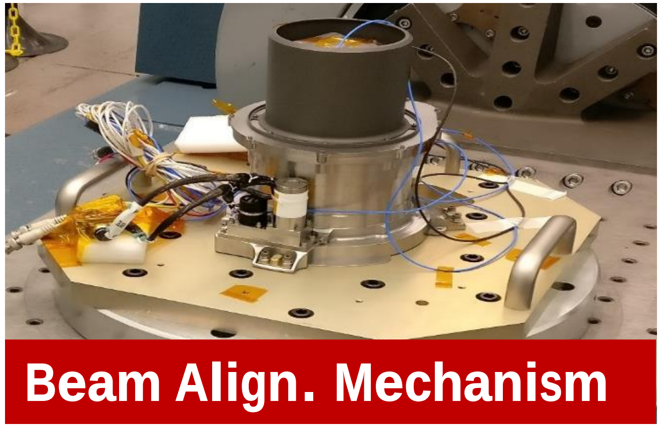


GEDI telescope assembly in the NASA GSFC Clean Room

GEDI Hardware


Housing

Laser

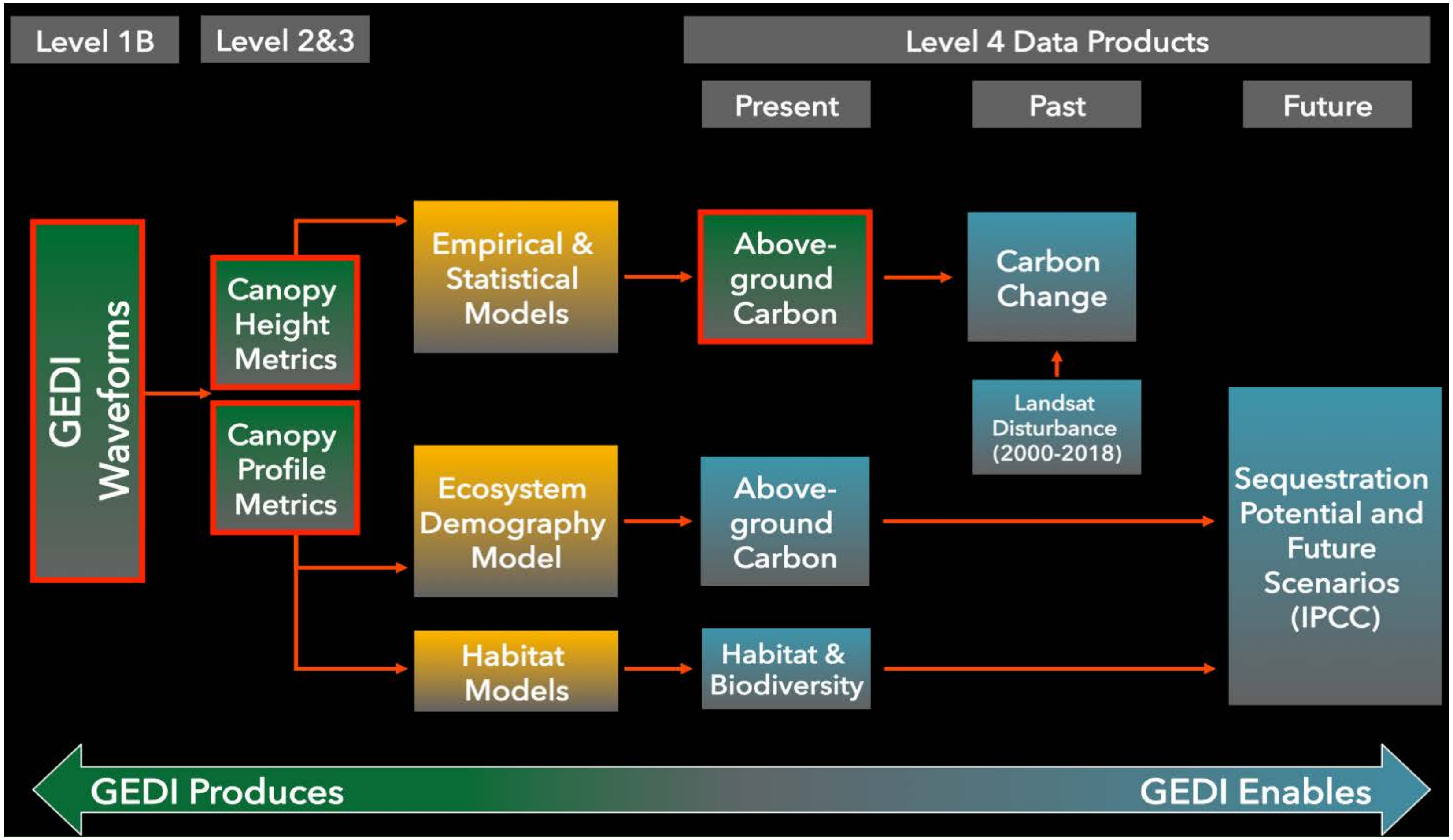

Beam Align. Mechanism


Flight Optical Bench


Beam Dithering Unit

Power Control Unit

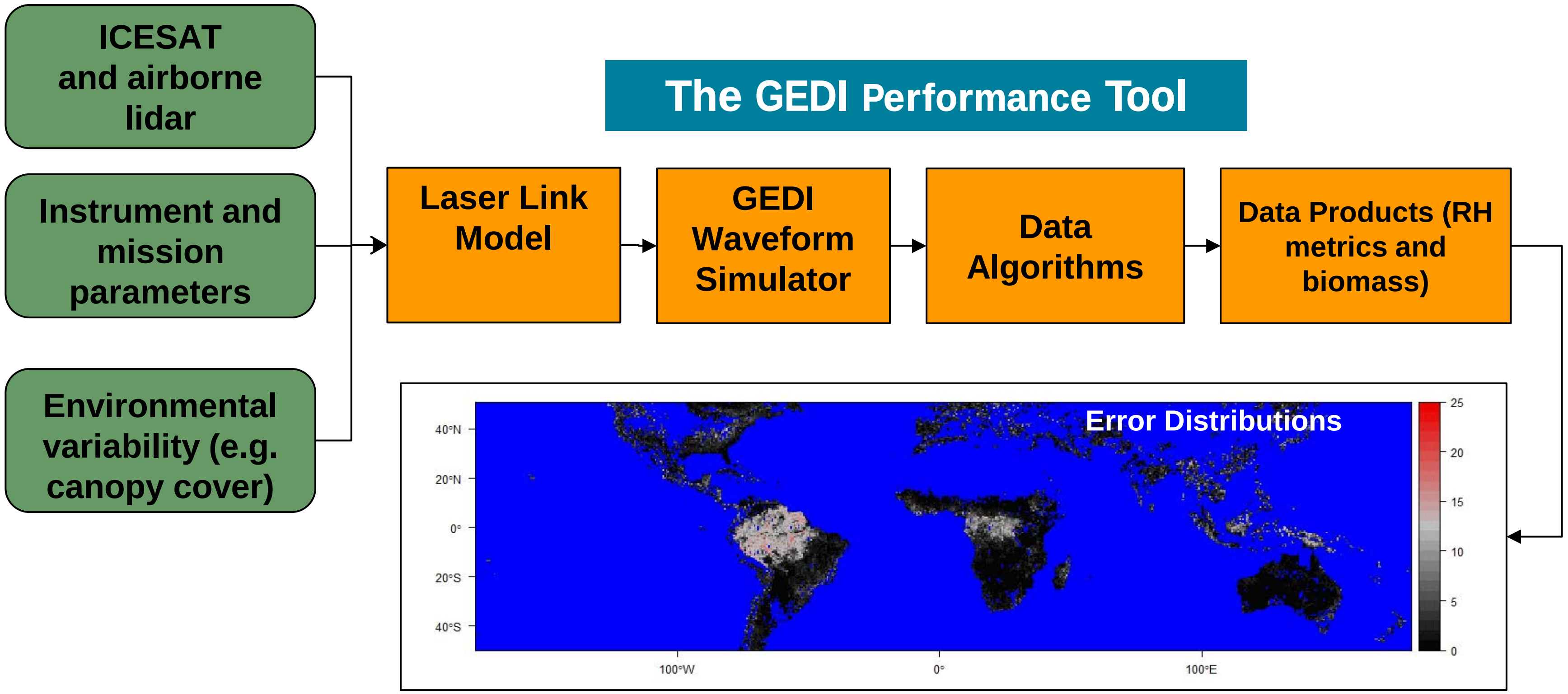
Science Approach and Data Products



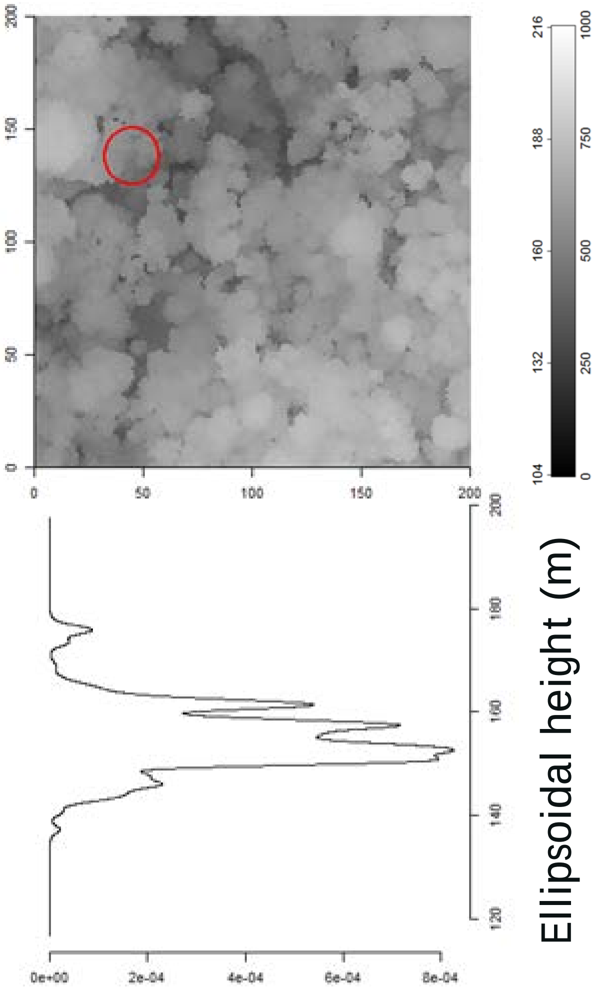
Product	Description
Level 1	**Geolocated Waveforms**
Level 2	**Canopy Height/Profile Metrics** • RH metrics • Canopy top height • Ground elevation • Canopy cover and cover profile • LAI and LAI profile
Level 3	**Gridded Footprint Metrics**
Level 4	**Biomass**
Level 4	**Demonstrative Products** • Ecosystem model outputs • Enhanced height/biomass using fusion with Tandem X & Landsat • Habitat model outputs

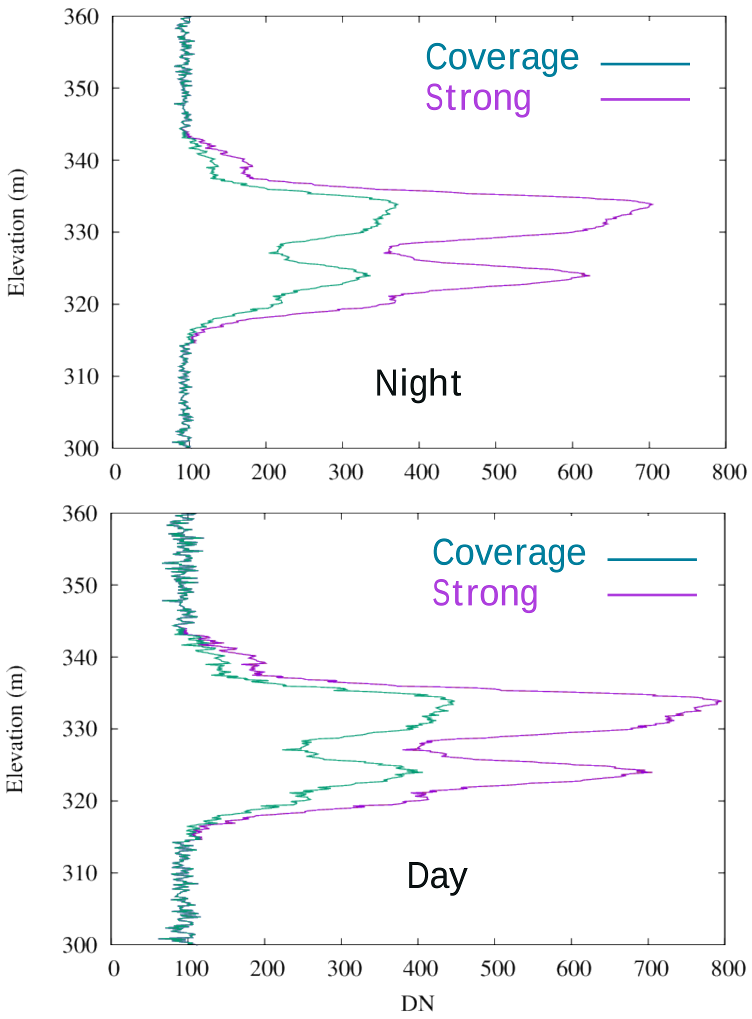
GEDI Performance Tool

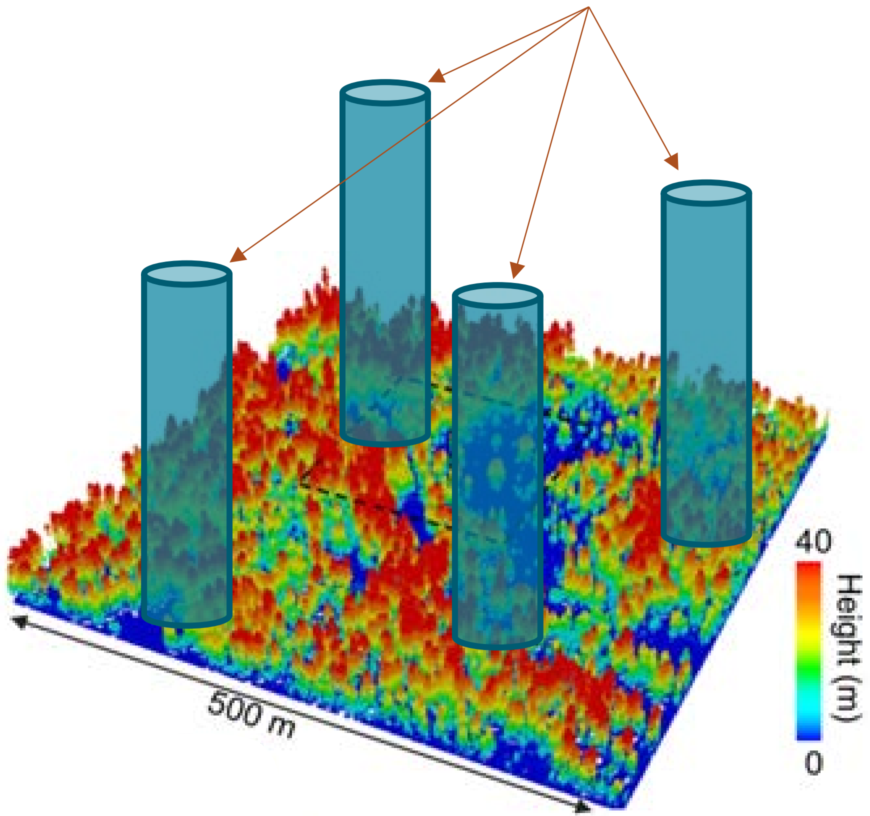
- **End-to-end waveform and mission operations/orbital simulator**
- **Used to understand science impacts and mitigations**
  - **Assess algorithm performance, environmental impacts and guide and cal/val**



Simulation of GEDI Waveforms from Airborne Lidar

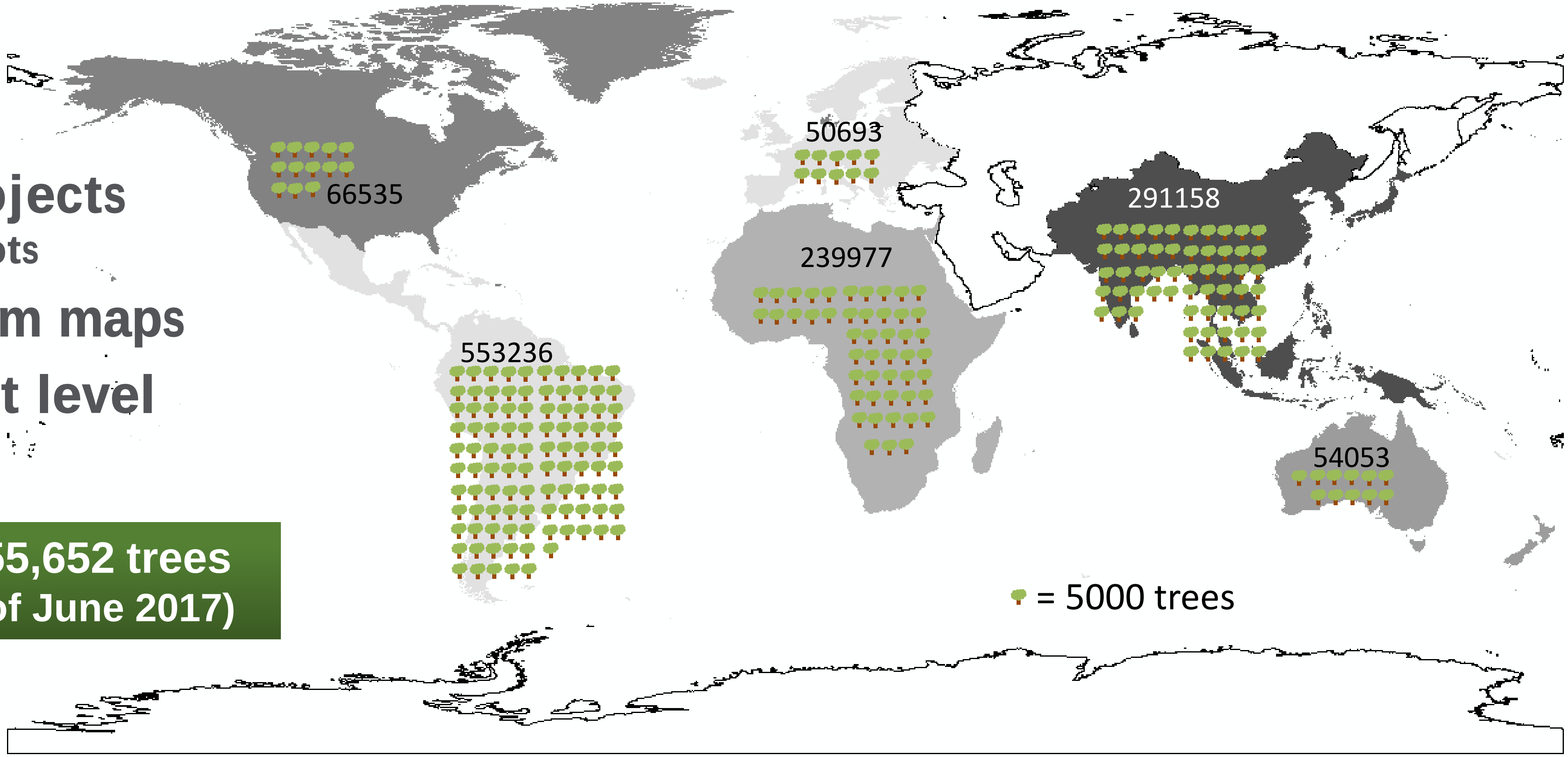






GEDI Forest Structure Data Base

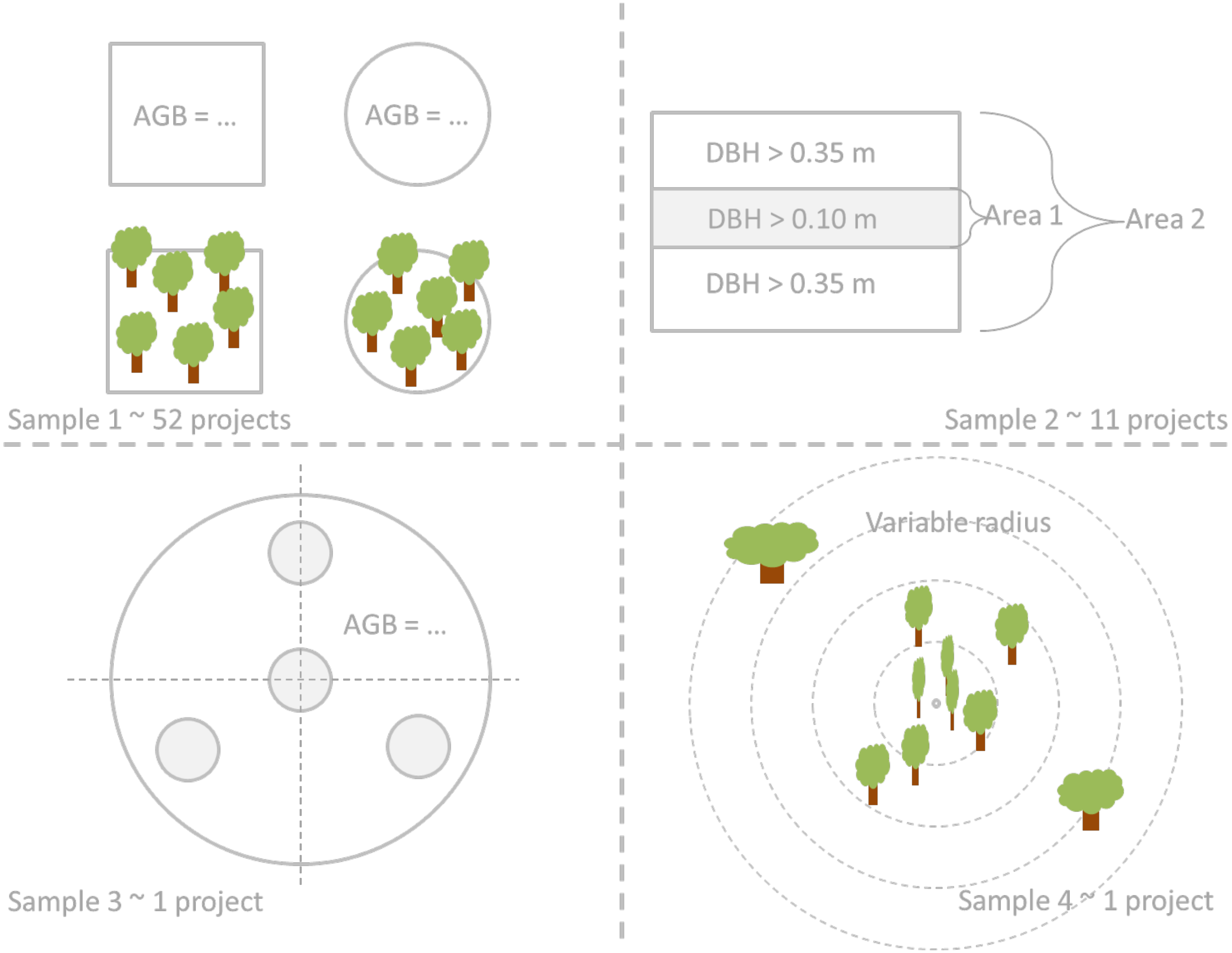
- **65 projects**
  3223 plots
- **38 stem maps**
- **27 plot level**



1,255,652 trees
(as of June 2017)

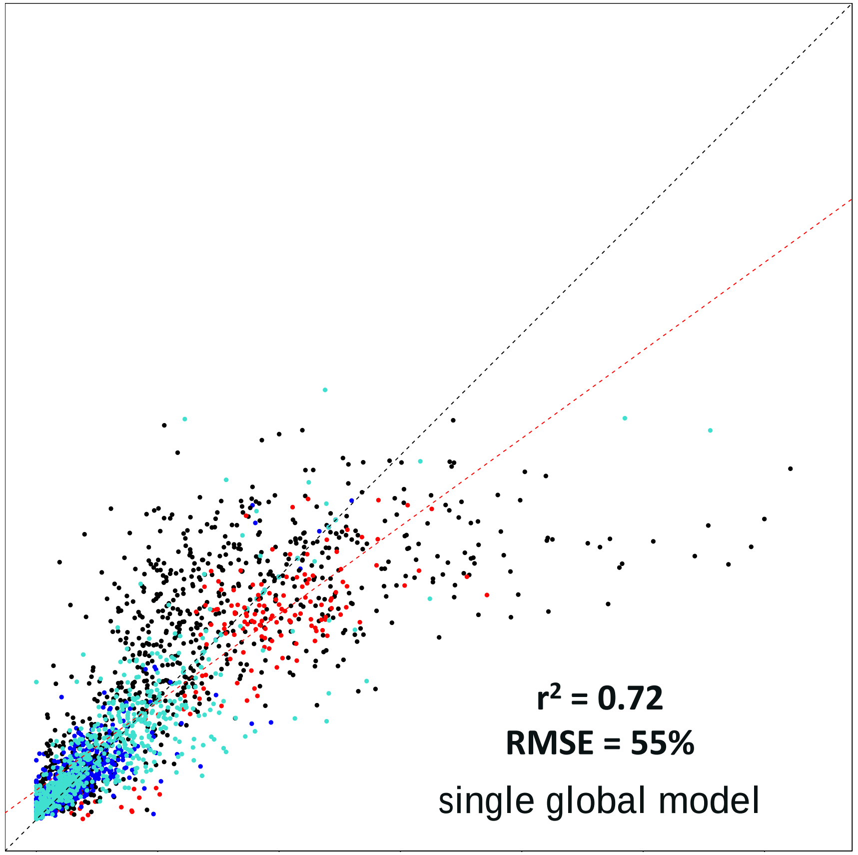
Field Plot Configurations

Plots have various sizes and configurations, which is a challenge for calibration and validation



GEDI Footprint Biomass Models

Random Forest Regression



Footprint-level biomass models are built from existing ALS/field data

Systematic comparison of model performance

Theoretical models:

AGBD ($Mg\ ha^{-1}$) = $a \times RH_i^{b1} \times SBA^{b2} \times WD^{b3}$

Empirical models:

AGBD ($Mg\ ha^{-1}$) = $b0 + b1 \times Rh_i$

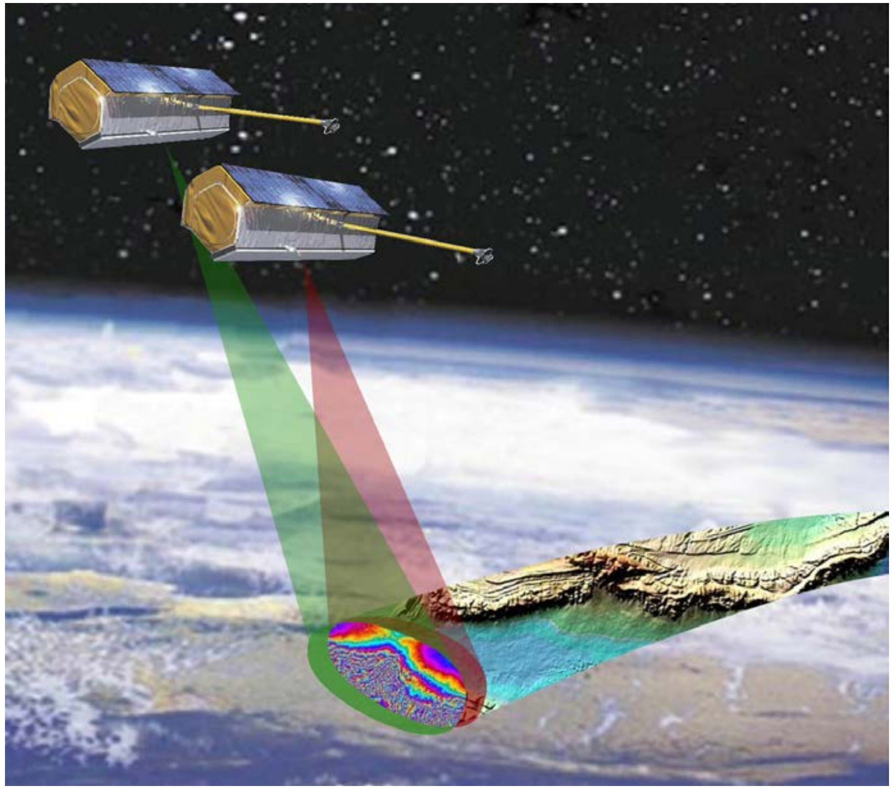
Machine learning models:

e.g. Random Forest

GEDI/Tandem-X/SAR Fusion

Immense possibilities for fusion of GEDI with Tandem-X, NISAR, BIOMASS and Tandem-L

- **GEDI/DLR scientists collaborating on fusion of GEDI and Tandem-X (TDX) data**
- **TDX provides high-resolution interferometric observations**
  - **TDX derives topography and elements of canopy structure**
- **Joint field experiments such as AfriSAR provide opportunity to explore linkages to other SAR missions**
  - **L-band and P-band backscatter/interferometry/tomography**



Key Drivers for GEDI/SAR Fusion

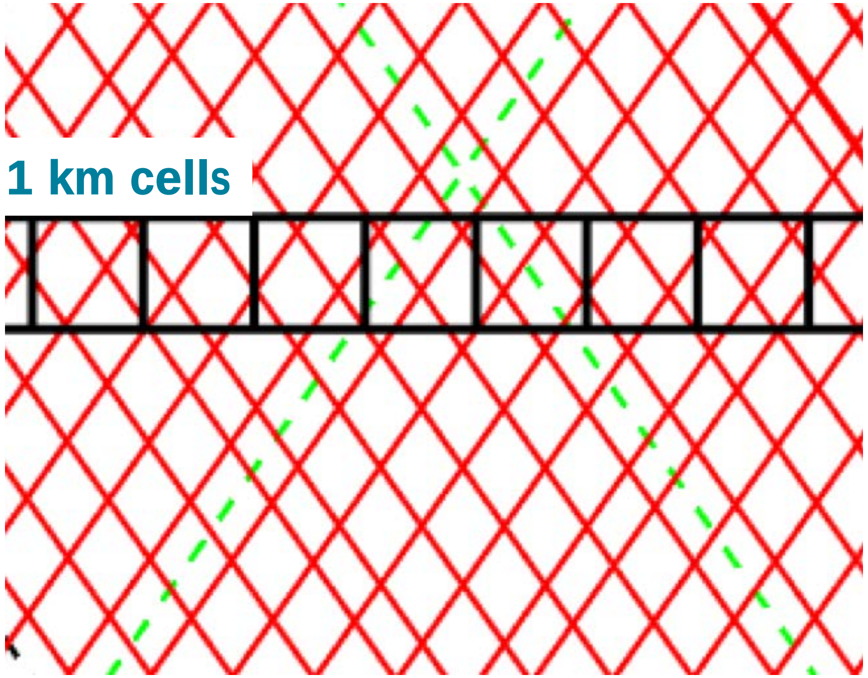
- Fill in spatial gaps in coverage for GEDI
- Produce higher spatial resolution and/or higher accuracy
- Creation of structural strata to guide biomass equation creation
- Provide alternate pathways to biomass calibration and estimation

Better understanding of the fundamental relationships between lidar measurements of canopy profiles and SAR data

One of the key research activities of the Biosphere Research

Enhancing Coverage/Resolution Using TDX

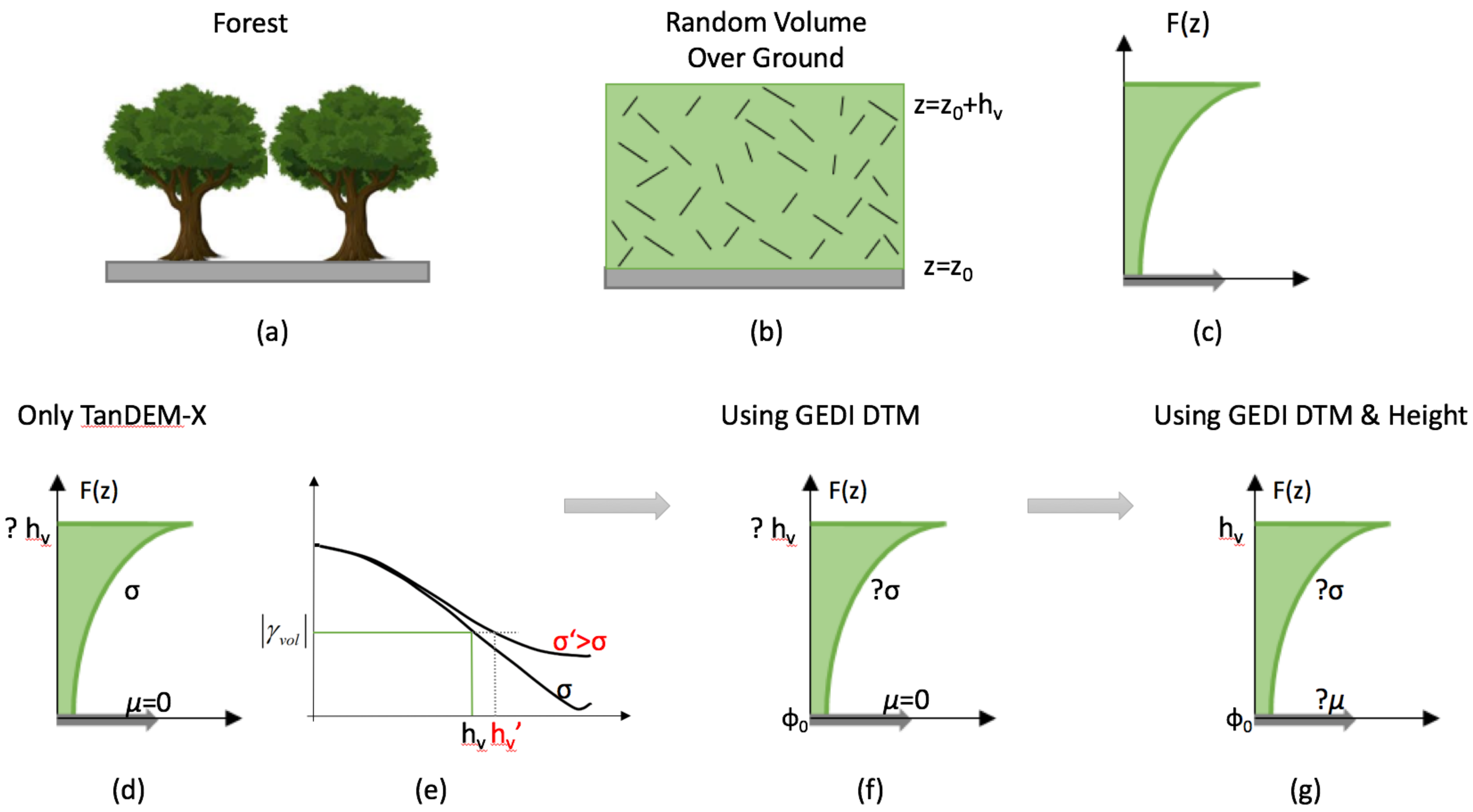
- **Use GEDI data to parameterize or constrain TDX estimates of height**
  1. Use GEDI estimates of ground topography and canopy in RVoG model
  2. Combine GEDI height metrics with TDX metrics in statistical estimation frameworks
  3. Use TDX as additional basis for Bayesian kriging and other interpolation



395 Days, 55% clouds

Mission	Tracks/Grid Cell	Leaf-ON Cells	Leaf-ON Cells, Night only Coverage Beams, Day+Night Strong Beams
10 BEAM 1000m	>=2	73.0	60.3
	>=1	92.0	84.7

GEDI/TDX Fusion in RVoG Model

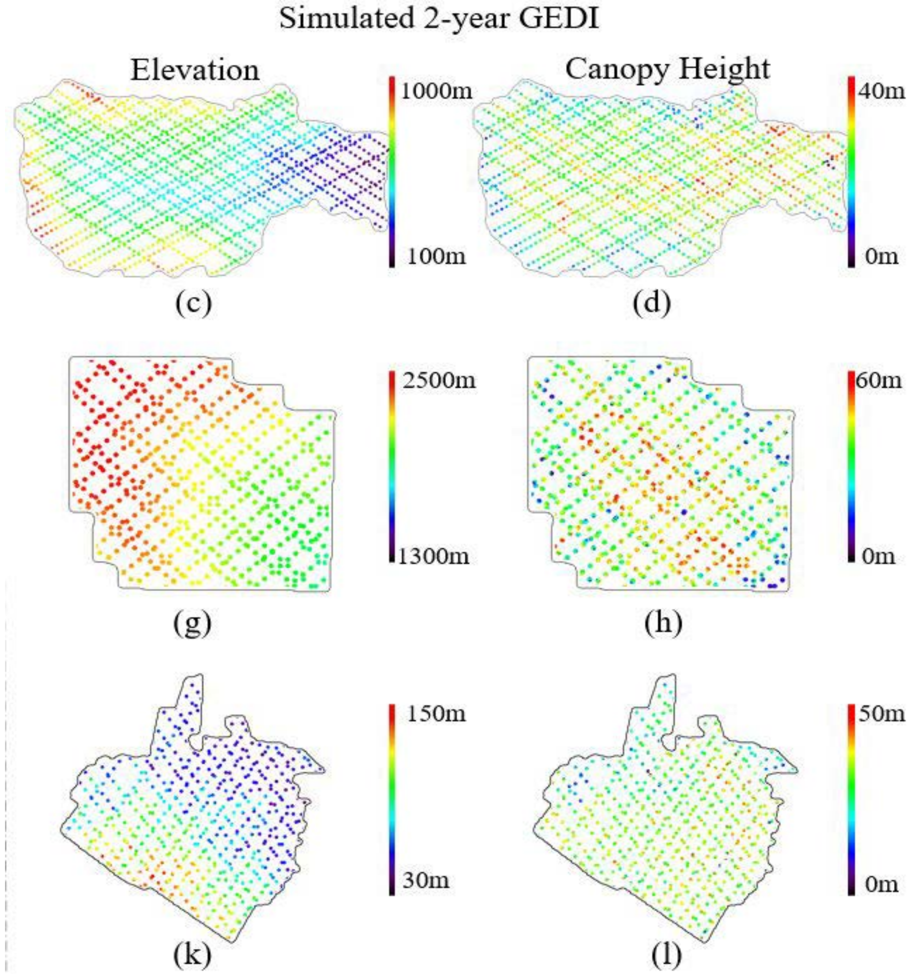


GEDI/TDX Fusion

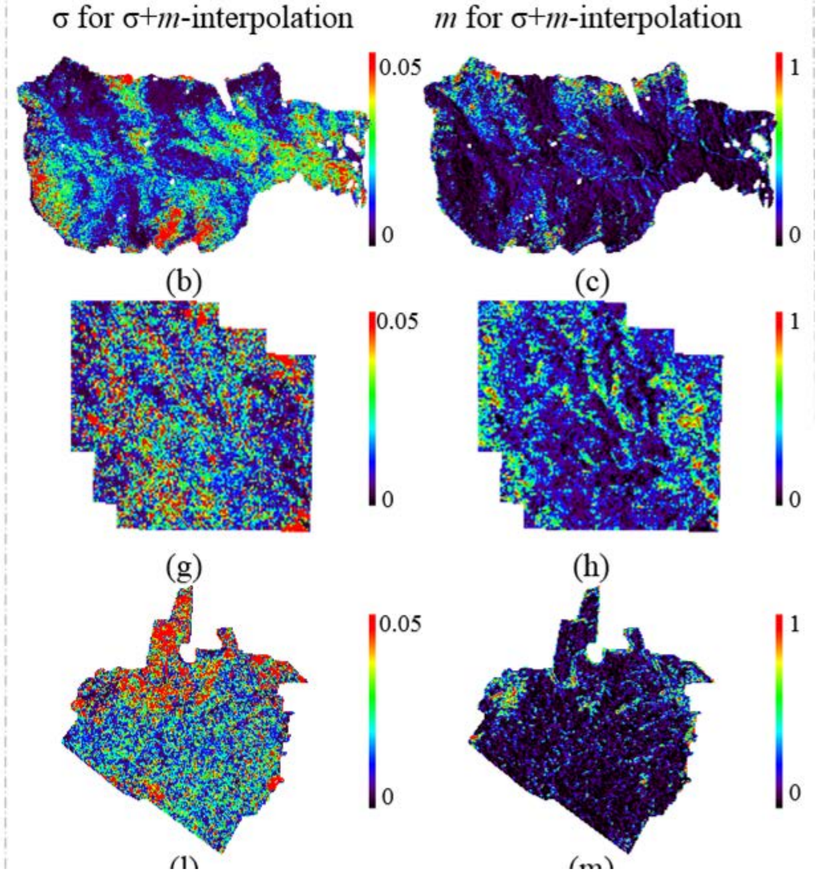
Hubbard Brook Experimental Forest

Teakettle Experimental Forest

La Selva Biological Station



Use both GEDI DTM and Height



ECOSYSTEM LIDAR

GEDI Data Products

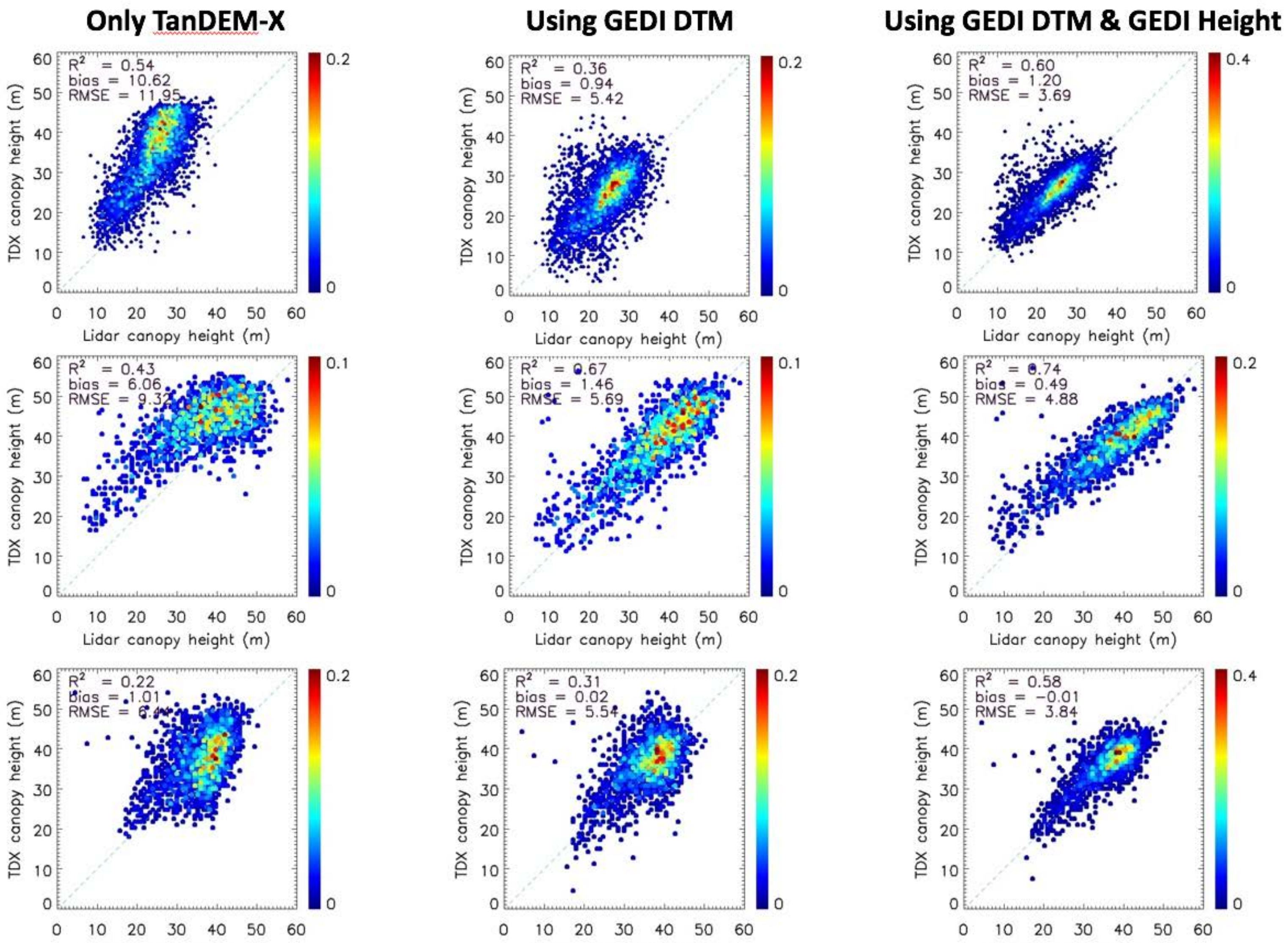
Product/ Data File	Description	Source	First Data Delivery After IOC	Data Latency	Archive Site
GEDI00_B	Level 0B Instrument Products	MOC	Within 24 hours of receipt at GSFC	Within 24 hours of receipt at GSFC	LPDAAC
GEDI01_A-TX	Level 1A-TX Transmitted Waveform Fitted Parameters	SOC	First 2 months of L1 released at 6 months	4 months in monthly intervals	LPDAAC
GEDI01_A-RX	Level 1A-RX Received Waveform Fitted Parameters	SOC	First 2 months of L1 released at 6 months	4 months in monthly intervals	LPDAAC
GEDI01_B	Level 1B Calibrated and Geolocated Waveforms	SOC	First 2 months of L1 released at 6 months	4 months in monthly intervals	LPDAAC
GEDI02_A	Level 2A Elevation and Height Metrics	SOC	First 2 months of L2 released at 6 months	4 months in monthly intervals	LPDAAC
GEDI02_B	Level 2B Canopy Cover and Vertical Profile Metrics	SOC	First 2 months of L2 released at 6 months	4 months in monthly intervals	LPDAAC
GEDI03	Level 3A Gridded Land Surface Metrics	SOC	Populated with first 2 months of L2 data at 6 months	4 months in monthly intervals	ORNLDAAC
GEDI04_A	Level 4A Footprint Above Ground Biomass	SOC	First 12 months of L3 data at 17 months	6 months after global sampling required to meet L1 requirement	ORNLDAAC
GEDI04_B	Level 4B Gridded Above Ground Biomass	SOC	First 12 months of L3 data at 17 months	6 months after global sampling required to meet L1 requirement	ORNLDAAC

GEDI/TDX RVoG Results

Hubbard Brook

Sierra Nevada

La Selva



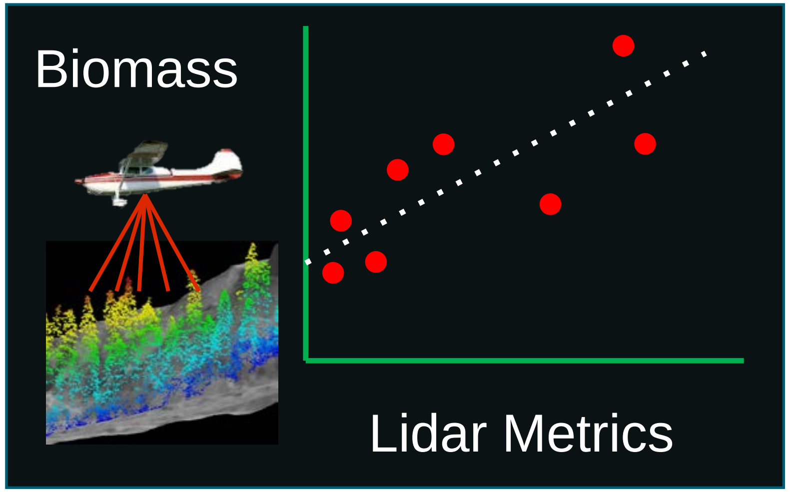
Results suggest GEDI/TDX fusion could produce height/metric grids at much finer resolution

Formal Statistical Estimation Framework

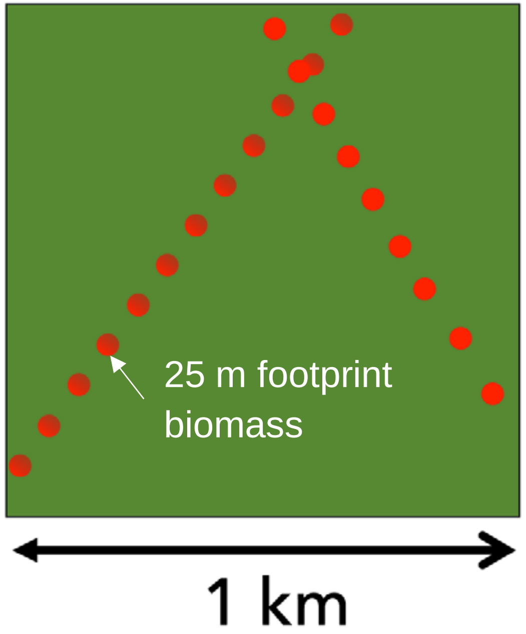
- **Define a parametric framework to provide an estimate of the mean biomass (μ) and variance of the mean (σ) for a grid cell**

$\mu \pm \sigma$ How do we correctly propagate error to find σ?

STAGE 1: Develop calibration between GEDI-like lidar and field plots



STAGE 2: Apply calibration equation to GEDI data on-orbit



Correct estimation of $\mu \pm \sigma$ for a 1 km cell is not straightforward

Two-stage estimation theory based on cluster sampling correctly propagates errors

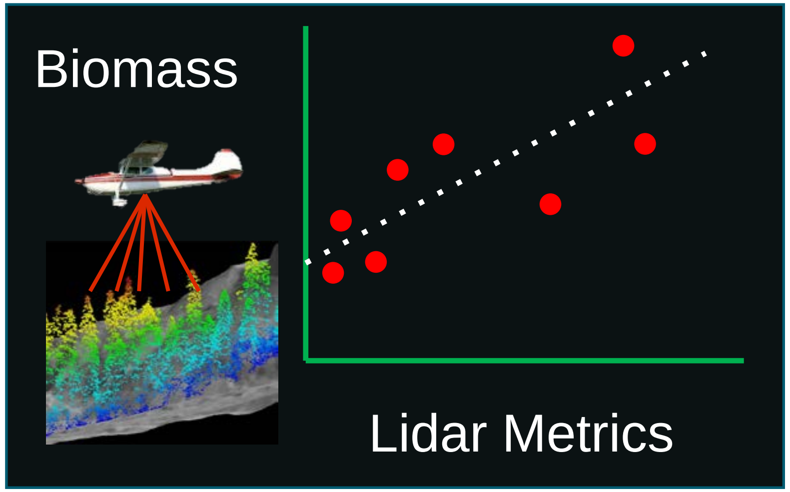
What of cells with no GEDI

Formal Statistical Estimation Framework

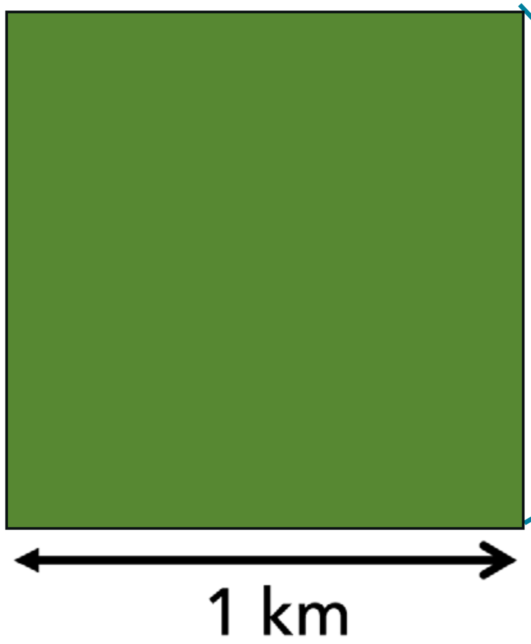
- **Define a parametric framework to provide an estimate of the mean (μ) and variance of the mean (σ) for a grid cell using a *hierarchical estimation theory***

$\mu \pm \sigma$ How do we correctly propagate error to find σ?

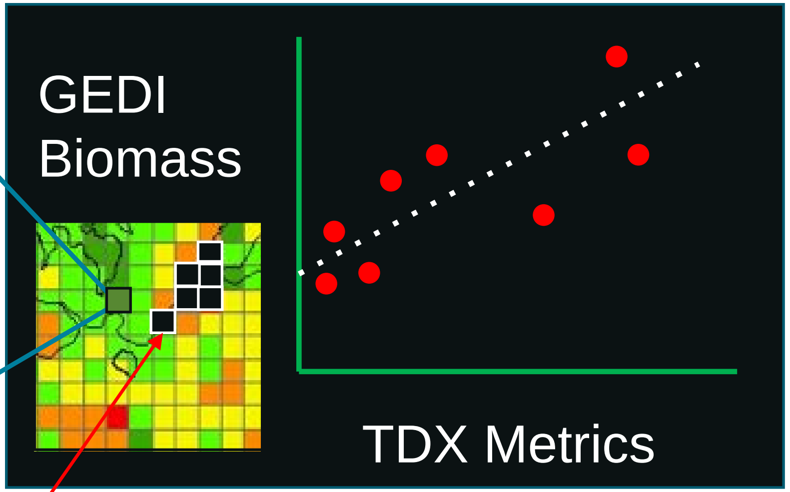
STAGE 1: Develop calibration between GEDI-like lidar and field plots



STAGE 2: Apply calibration equation to GEDI data on-orbit



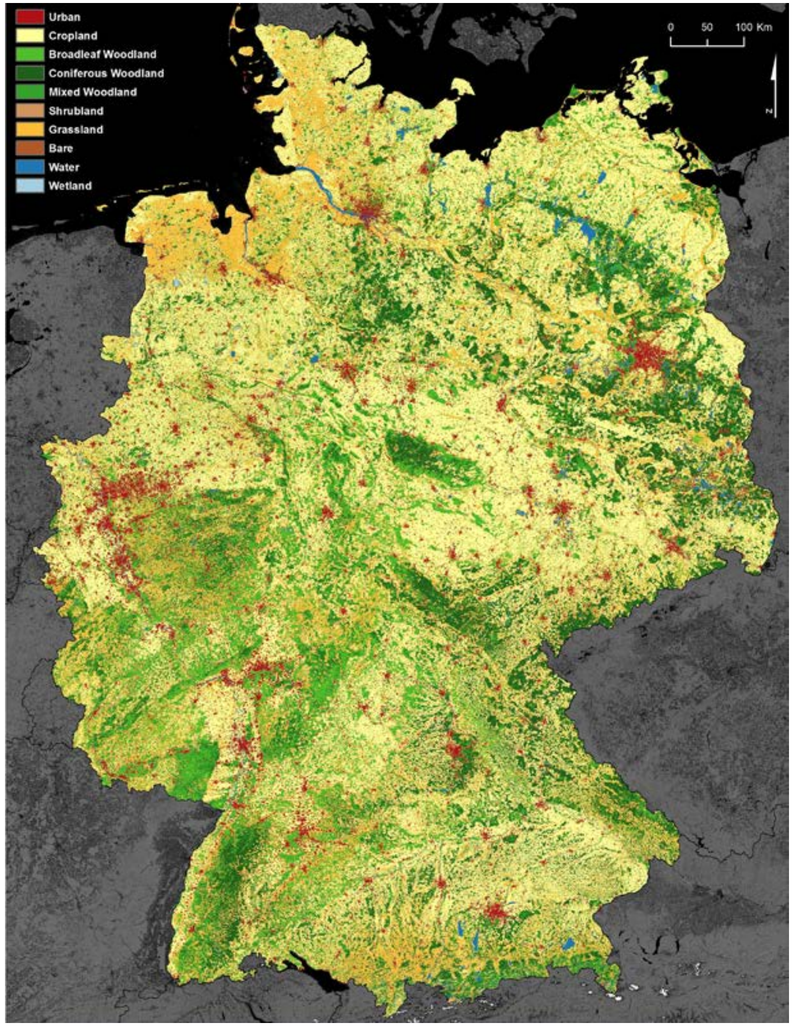
STAGE 3: Develop relationship between GEDI biomass and TDX and map across landscape [μ,σ]



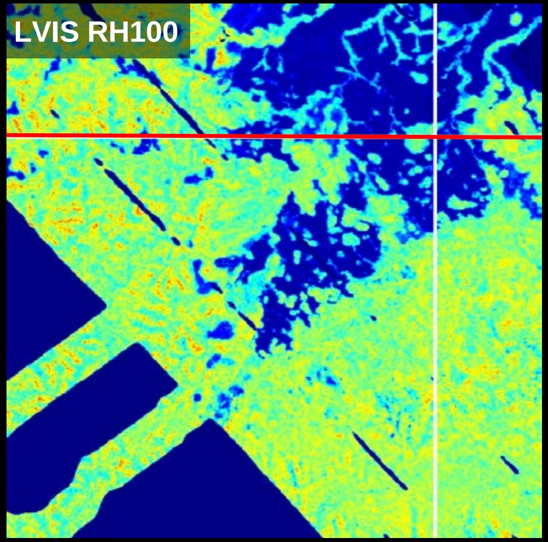
Enable predictions [μ,σ] for cells with or without GEDI data

Creating Structural Stratifications

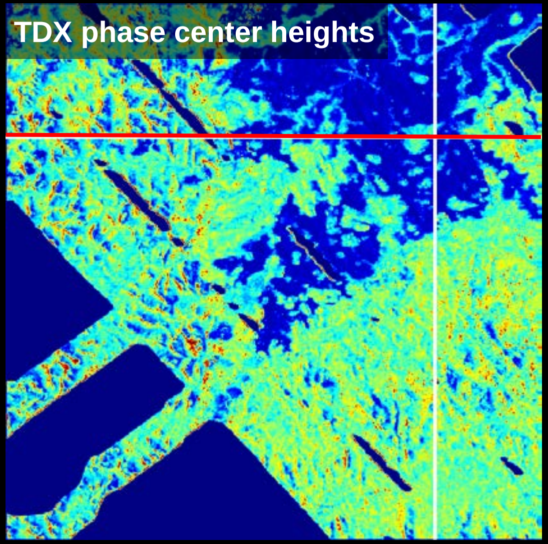
- **Structural typologies responsive to ecosystem structure have far reaching implications**
  - ***Key element of Alliance Biosphere Research Group***
- **Creating biomass equations challenging**
  - **How many equations do we need**
  - **Where does one equation begin and another end?**
  - **How can we optimally interpolate for areas of no data?**
- **Can we use spatially continuous data from SAR (TDX/NISAR/BIOMASS) to create structural strata?**
  - **Can these be used in Bayesian kriging and other interpolation approaches?**
  - **Why, how, where and when should such approaches work?**

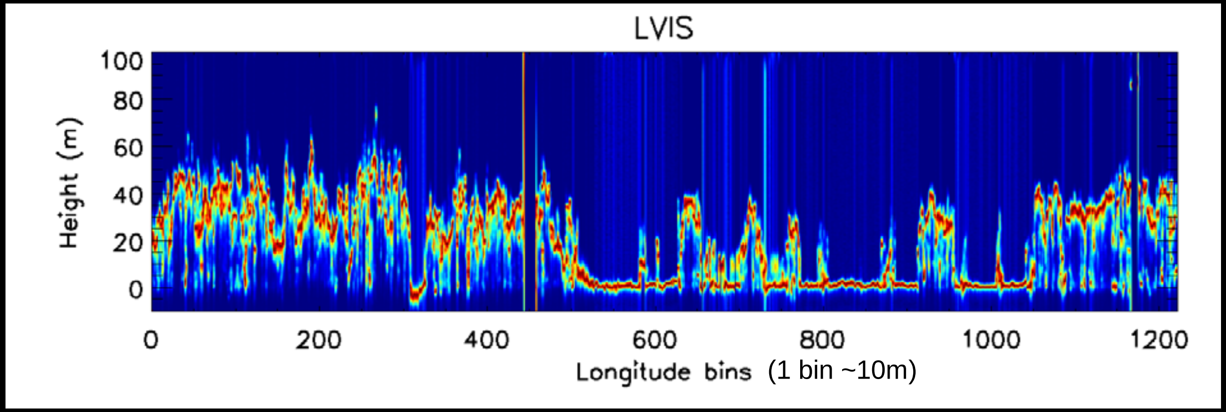


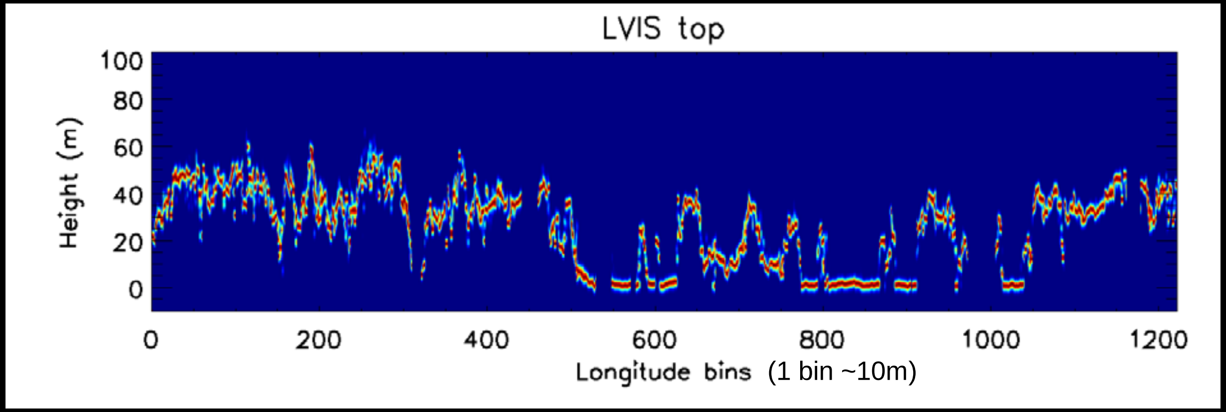
AfriSAR Gabon

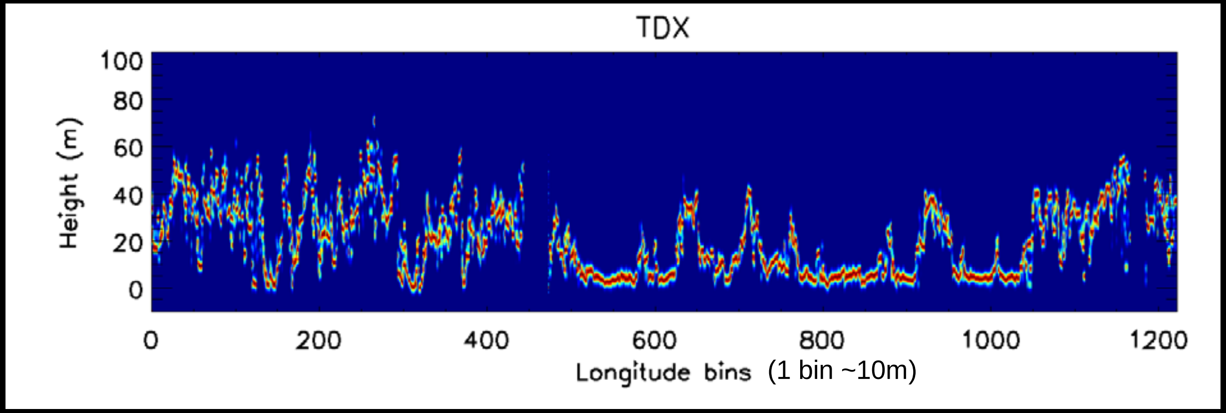


Profile scale = 25m

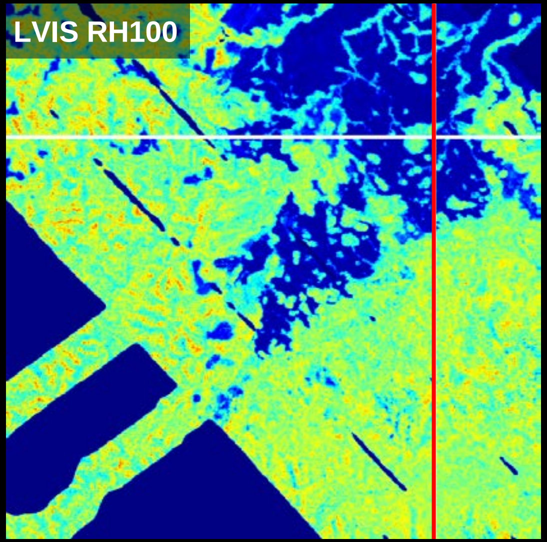


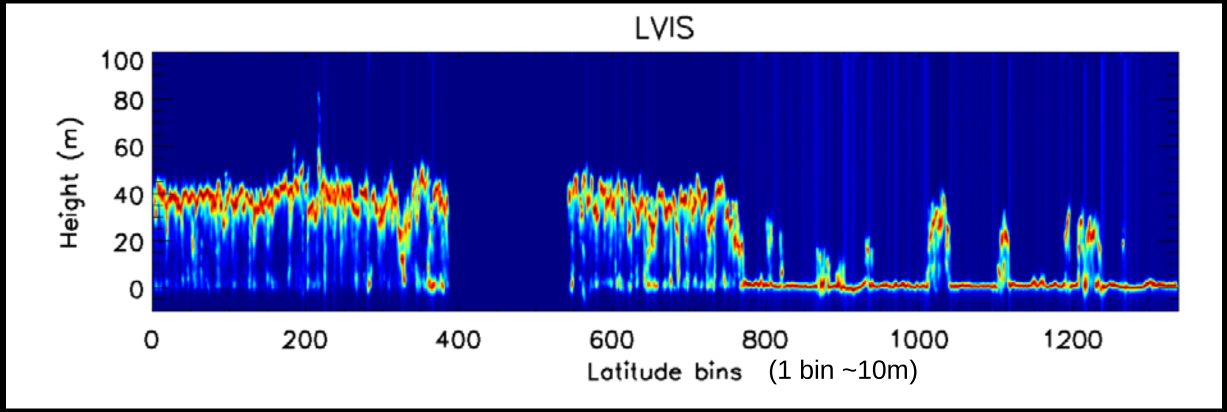






AfriSAR Gabon





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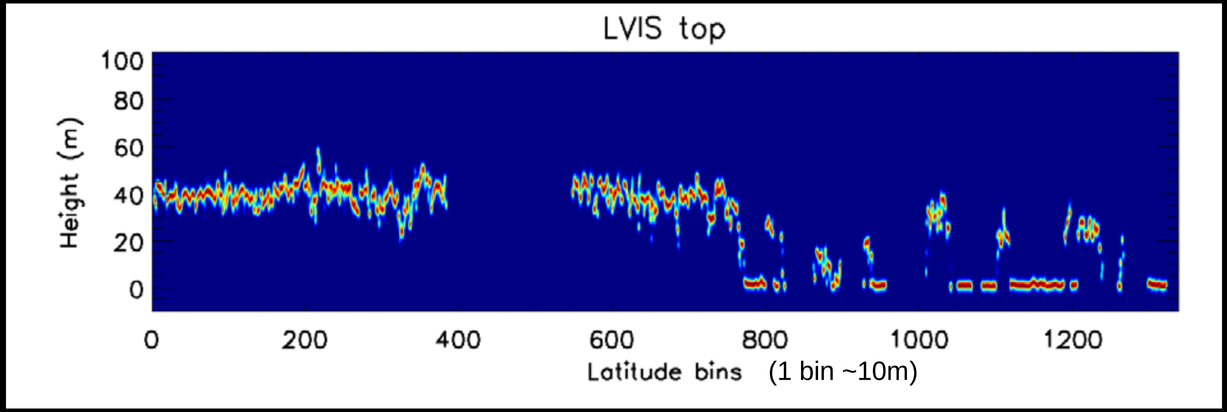
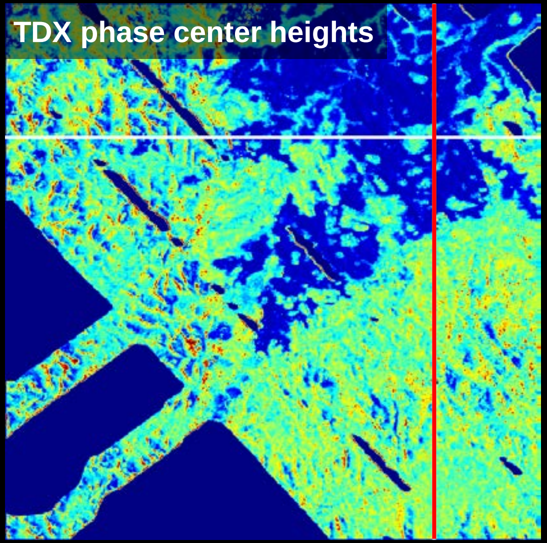
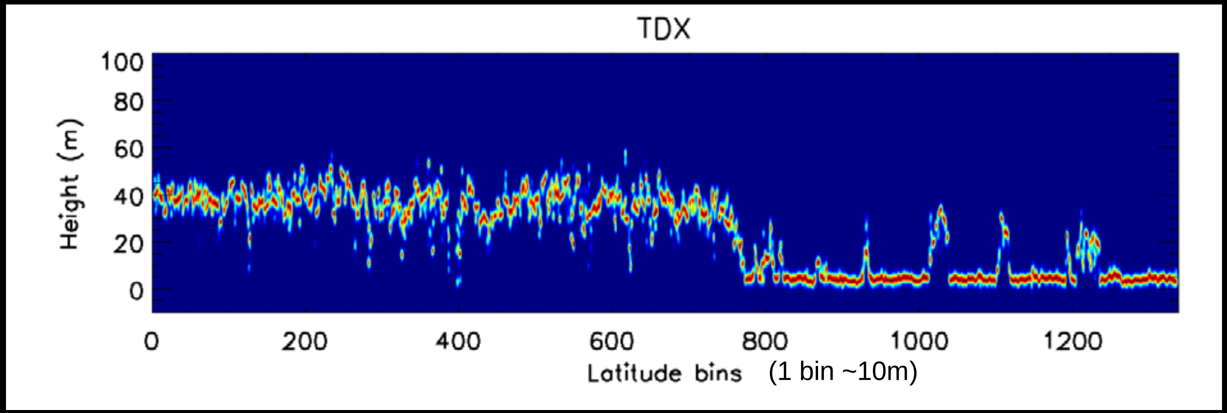




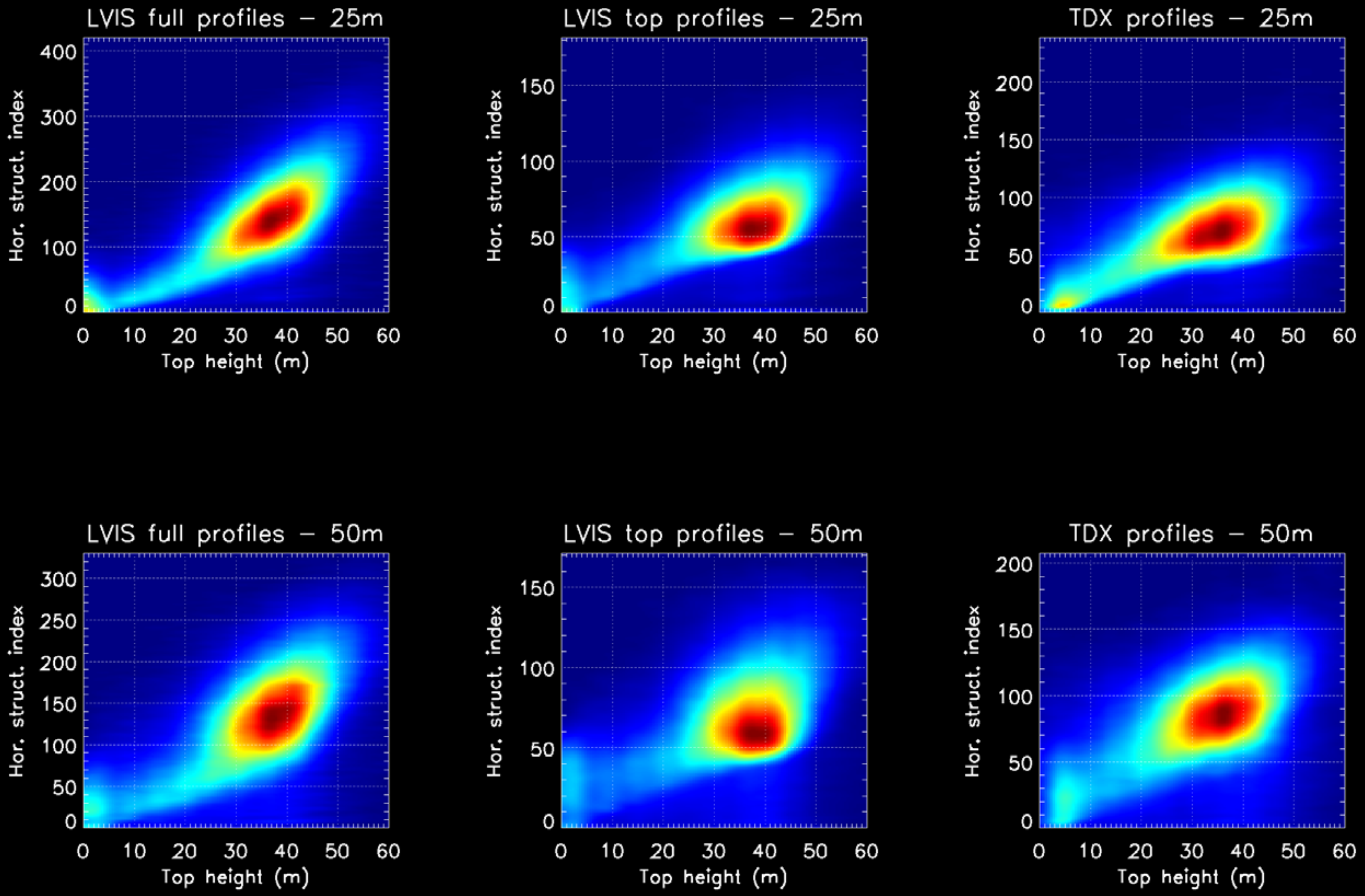


Horizontal structure index – AfriSAR Gabon

LVIS full profiles | **LVIS top profiles** | **TDX profiles**

25m (50m)

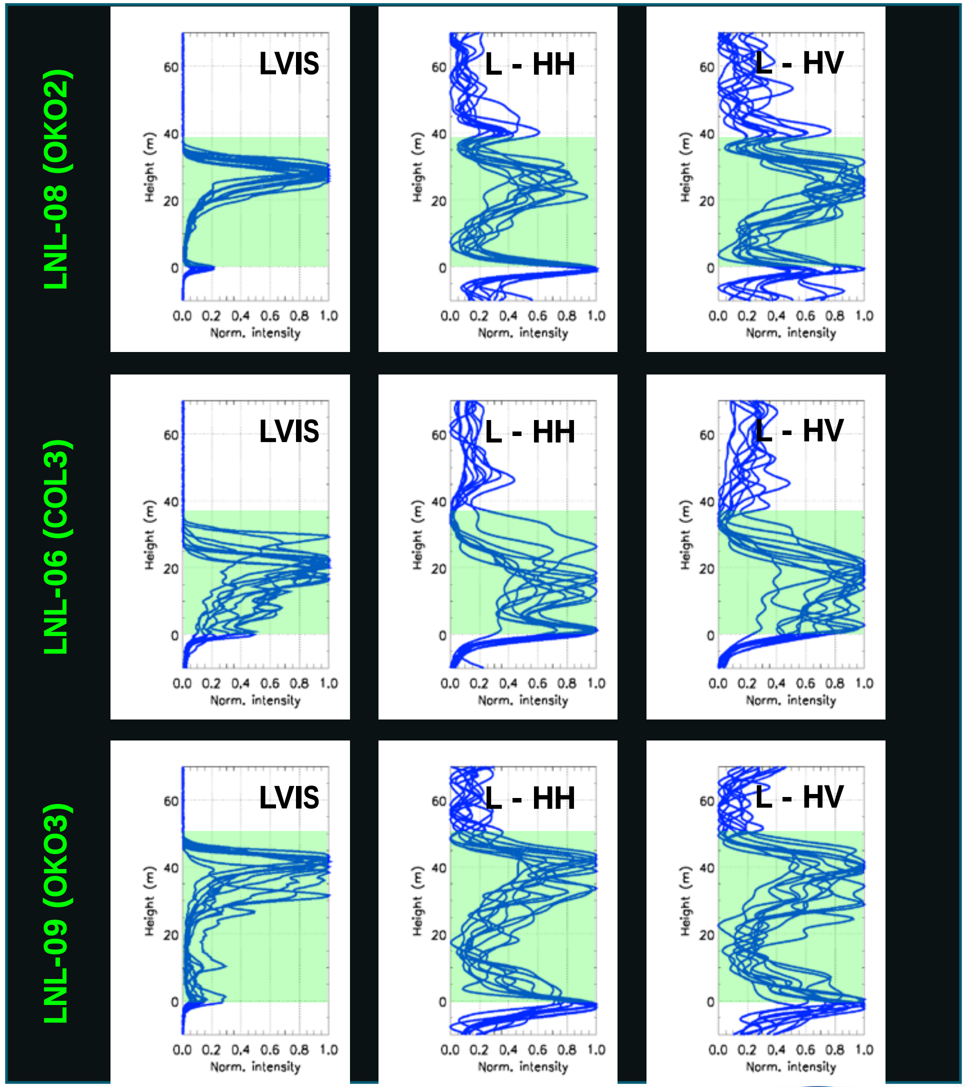
50m (100m)



Looking Forward to Tandem-L

Lidar vs L-band TomoSAR Profiles from 3 sites at AfriSAR

- Differently from X-band, L-band penetrates to the ground even in dense forest environments as in Lopè (Gabon).
- Tandem-L will allow a 3-D structure characterization globally and repeated in time
- Possibility of a synergy between Tandem-L and GEDI based on full vertical profiles and / or 3-D structural allometry



Next Steps and Conclusions

- GEDI is rapidly progressing toward launch in late 2018
- Key science issues:
  - Continued development of biomass prediction and error models
  - Expansion of field and lidar data base for model development and testing
- Fusion/collaboration with other missions of increasing importance
  - Tandem-X, NISAR, ICESat2, BIOMASS, Tandem-L
  - Joint field experiments and calibration/validation activities
- Entering unprecedented age of active remote sensing
  - Fundamental work on fusion applications linked to better understanding of ecological bases and physical remote sensing models that bridge differences in observational methodologies
- *Activities of Alliance Biosphere Research Group should have great significance for GEDI and other missions*

The GEDI Science Team

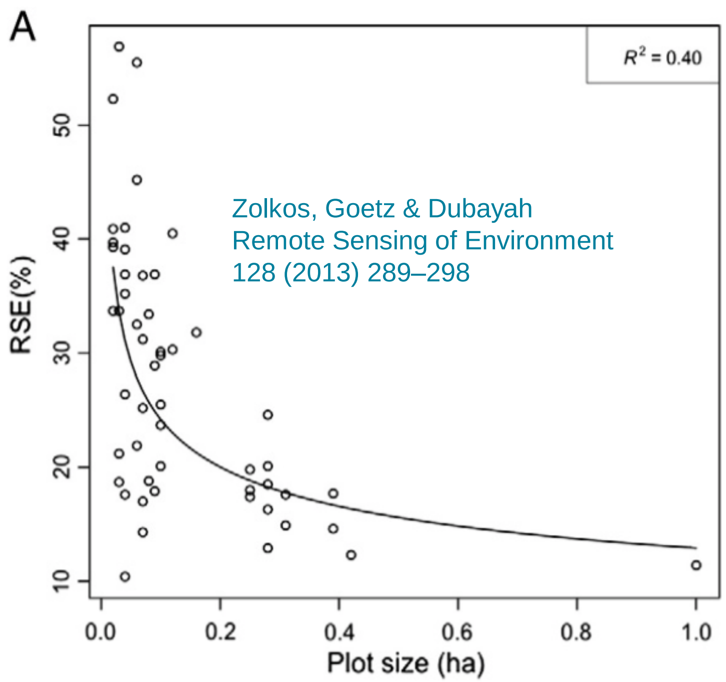
GEDI
ECOSYSTEM LIDAR

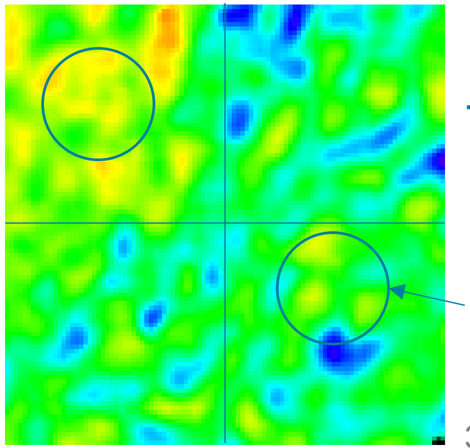
John Armston	Univ. of Maryland (DSITI)
J. Bryan Blair	NASA GSFC
Ralph Dubayah	Univ. of Maryland
Laura Duncanson	NASA GSFC
Lola Fatoyinbo	NASA GSFC
Scott Goetz	NAU
Steve Hancock	Univ. of Maryland
Matt Hansen	Univ. of Maryland
Sean Healey	U.S. Forest Service
Michelle Hofton	Univ. of Maryland
George Hurtt	Univ. of Maryland
Jim Kellner	Brown University
Scott Luthcke	NASA GSFC
Kostas Papathanasiou	German Space Agency
Hao Tang	Univ. of Maryland

Extending Calibration Approaches

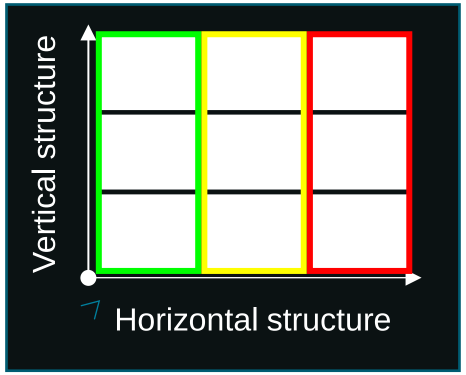
- **GEDI-size footprints (25 m) are difficult to calibrate**
  - **Edge effects, geolocation errors**
  - **"attenuation" or "dilution" bias**
  - **Calibration equations can have large RMSE**
- **Can we create calibration equations that combine metrics from GEDI with metrics from larger TDX footprint?**

$$biomass = f(GEDI_{25m} + TDX_{50m})$$

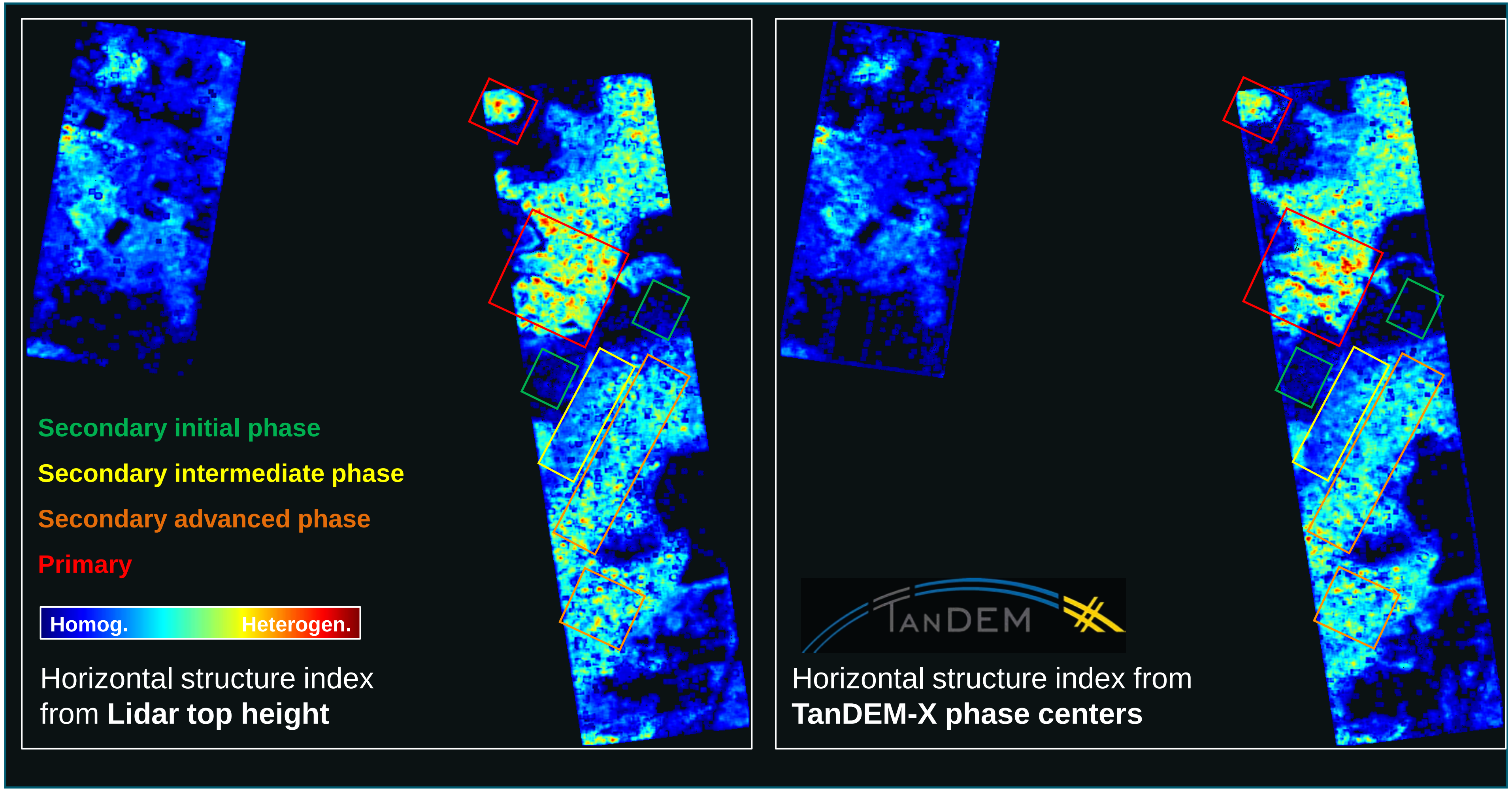




Structure Characterization from TDX



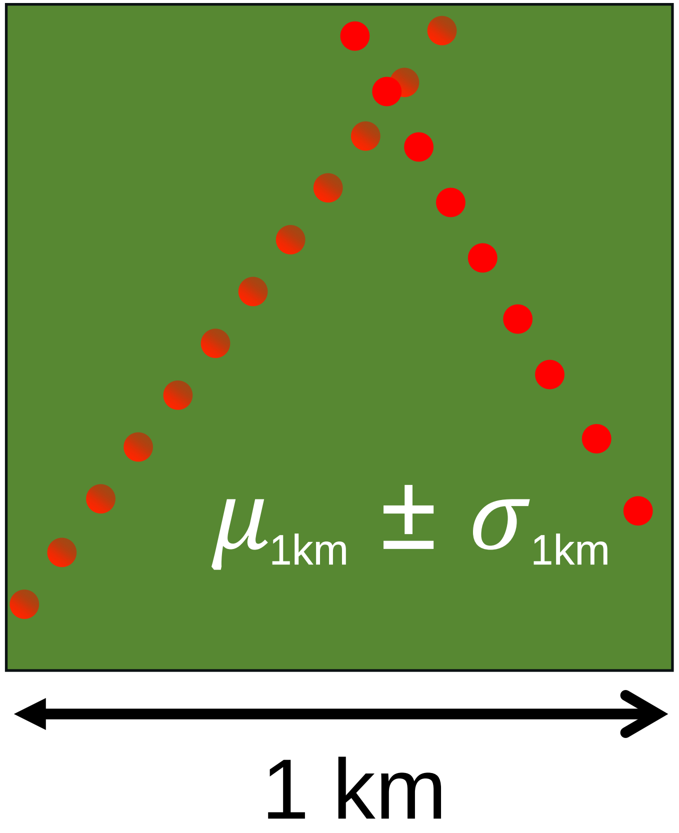
- An horizontal structure index (50m scale) calculated by aggregating height profiles at 10m scale

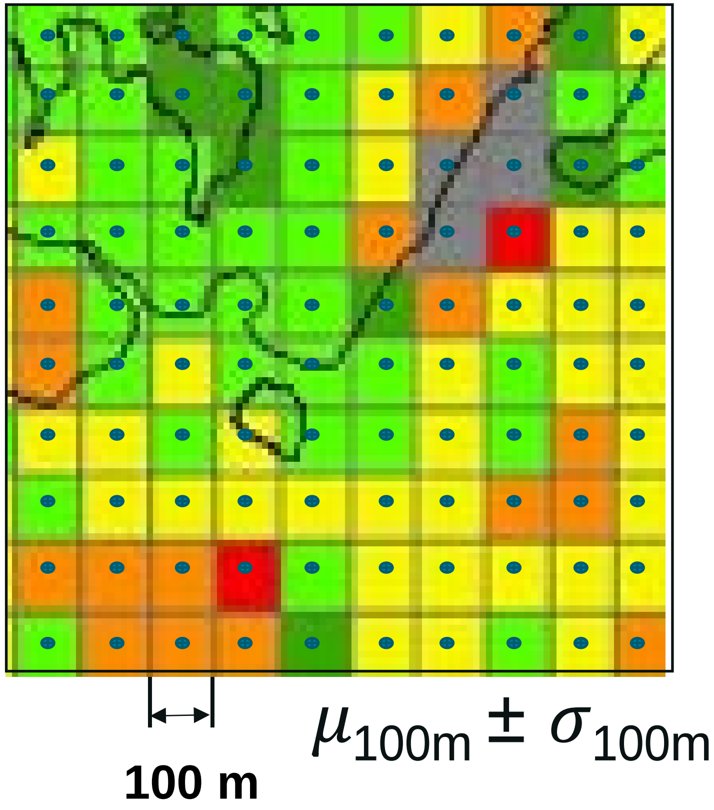


Graveyard

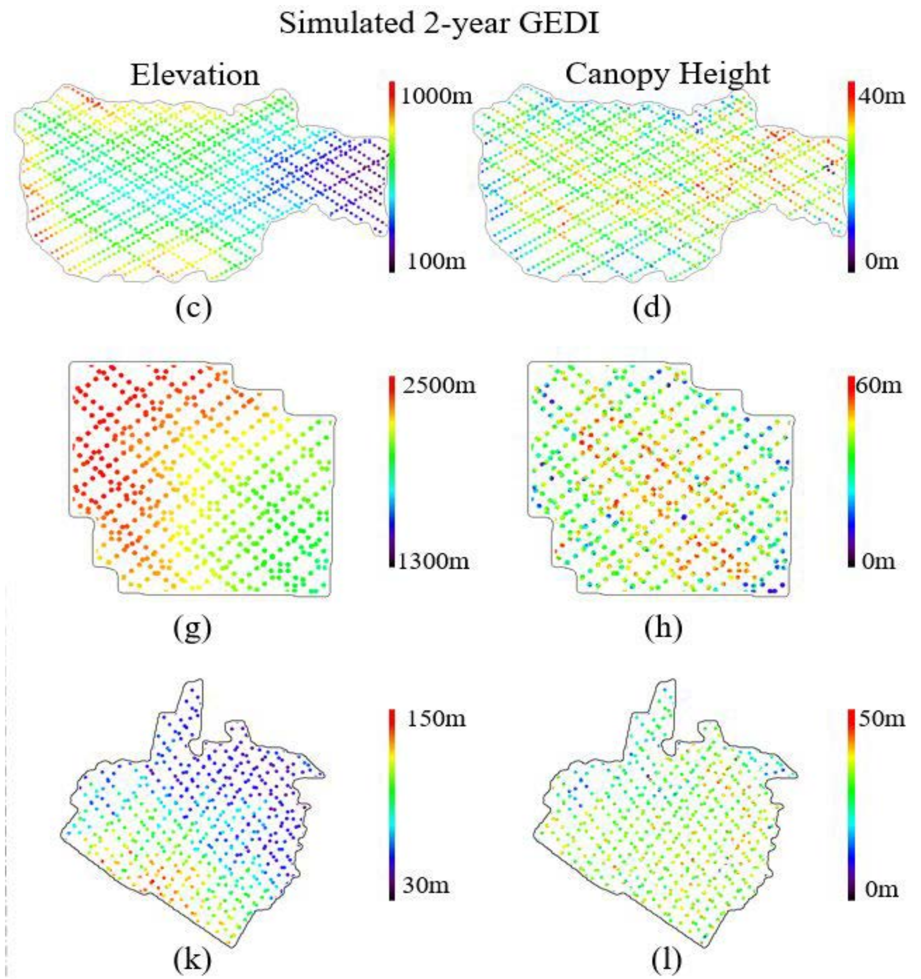
Improving Spatial Resolution Using TDX/SAR

- Provide higher spatial resolution for GEDI products
  - Large gap between native resolution of 25 m and 1 km
- Many applications need higher spatial resolution
  - Biomass holy grail is about 100 m resolution
  - Tracking biomass gain/loss from disturbance
- Hierarchical estimation theory (3 stage) can be used here

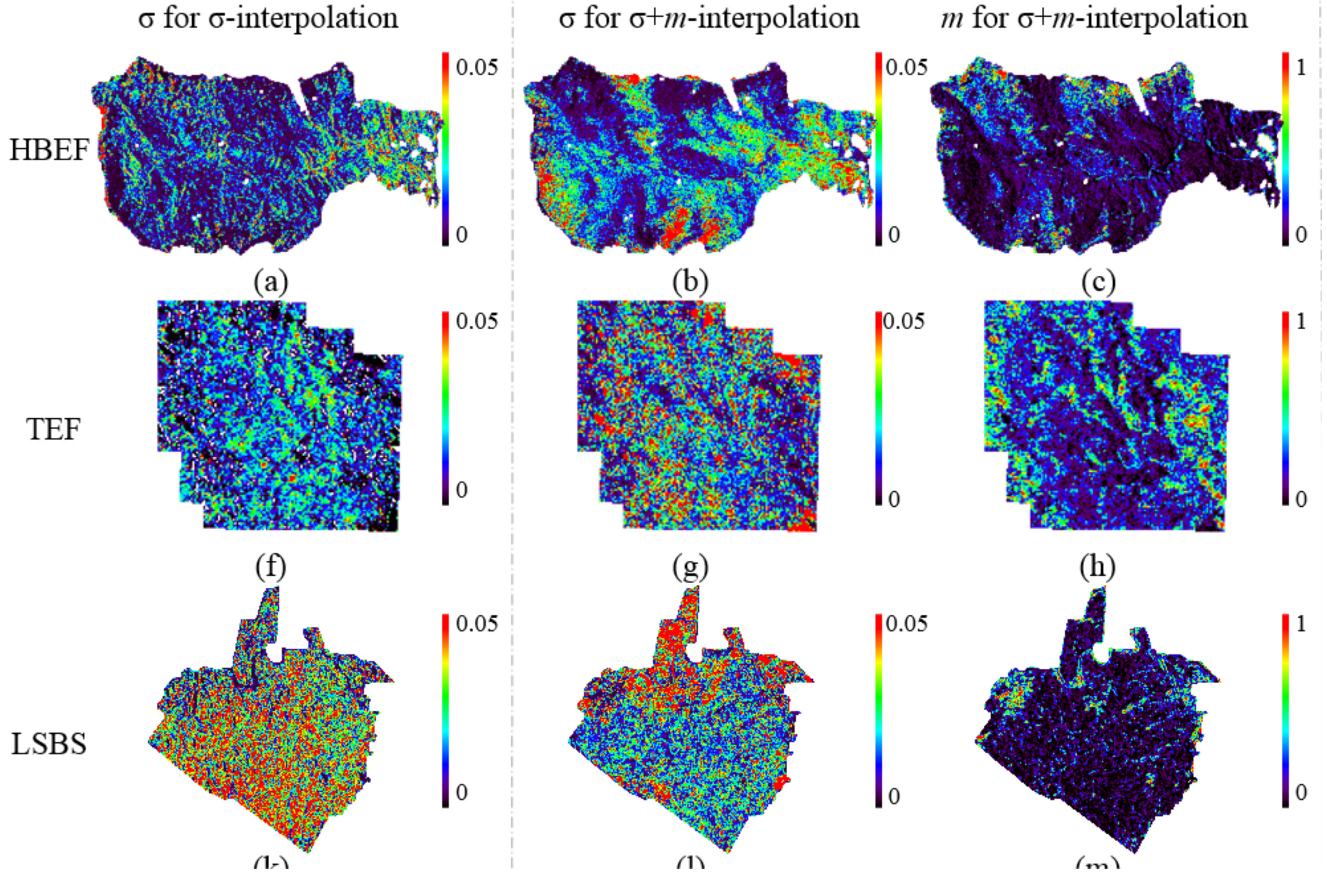




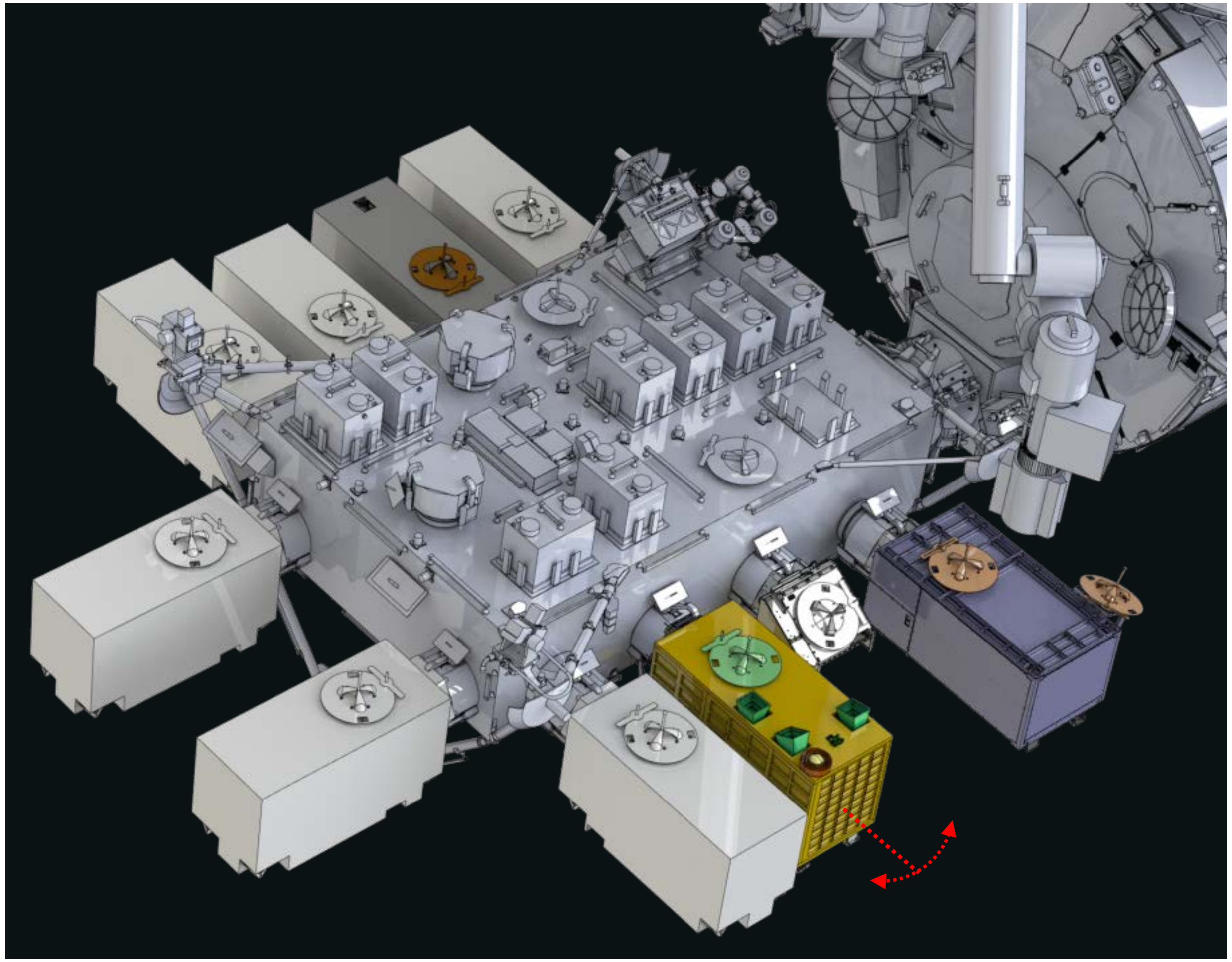
GEDI/TDX Fusion



GEDI DTM only | **Use both GEDI DTM and height**



Deployment on ISS/JEM-EF



GEDI/TDX Fusion

Hubbard Brook Experimental Forest

Teakettle Experimental Forest

La Selva Biological Station