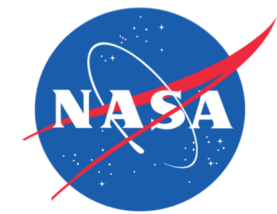
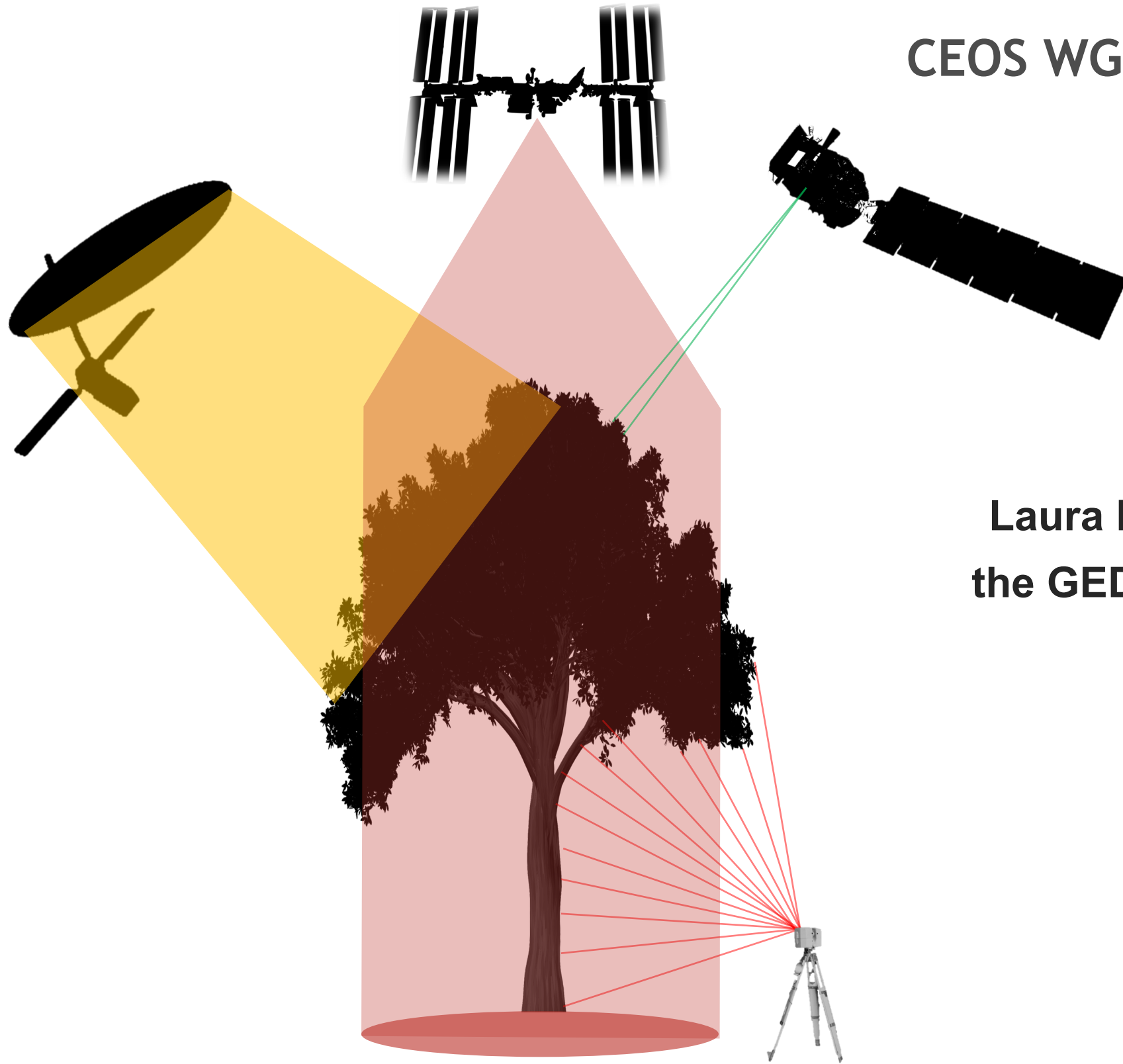


CEOS WGCV LPV Biomass Validation Protocol and Activities

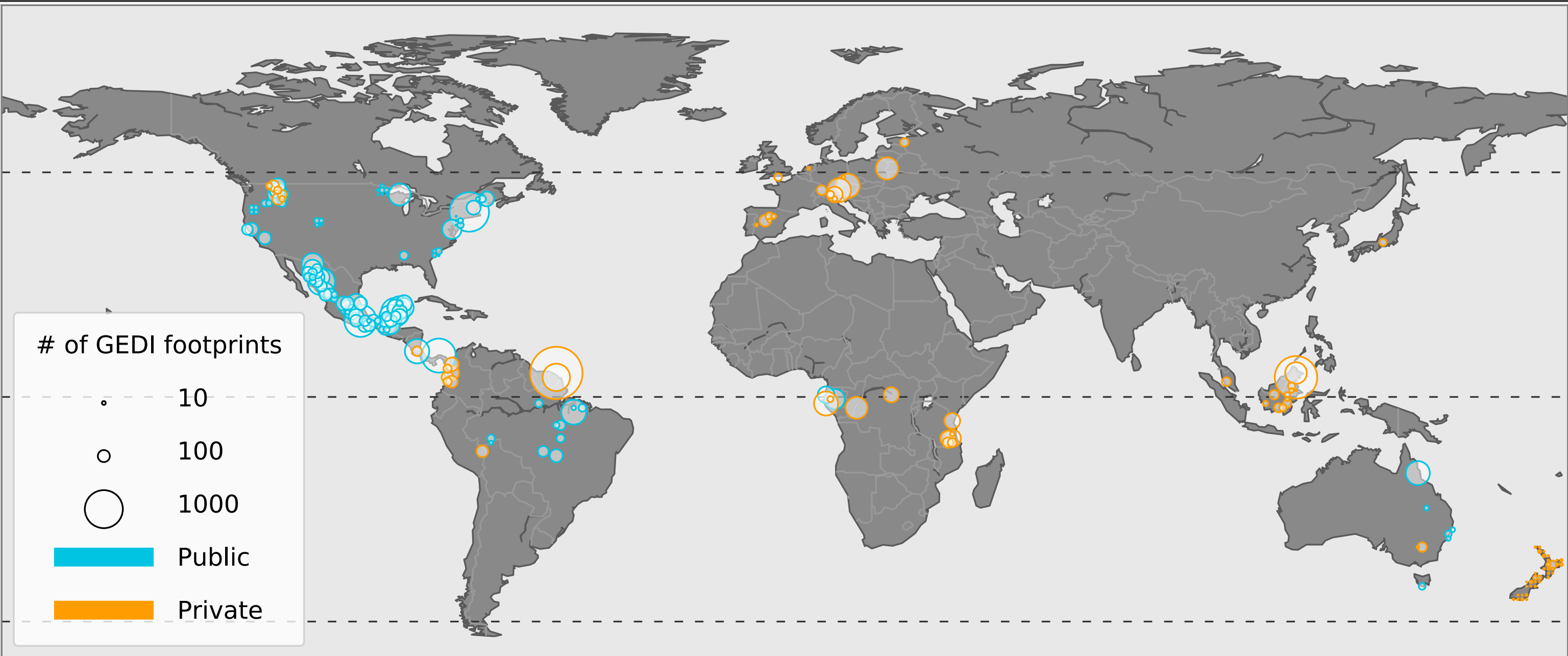
**Laura Duncanson, John Armston, Mat Disney,
the GEDI Science Team & the CEOS WGCV LPV
Protocol Development Team**



Many Upcoming Missions Will Provide Data That Will Be Used to Map Biomass

Mission	Funding Agency	Expected Launch Date	Data Type	Biomass Product Resolution	Geographic Domain	Accuracy Requirement
NISAR	NASA/ISRO	2022	L-band SAR	1 ha (<100 Mg/ha)	Global	<20% RMS accuracy for <100 Mg/ha
GEDI	NASA	Dec 5, 2018	1064 nm waveform lidar	1 km	ISS (+/- ~51.6°)	<20% SE for 80% of forested 1 km cells
BIOMASS	ESA	2022	P-band SAR	4 ha	Global (minus defense issues)	Accuracy of 20%; 10 Mg/ha for <50 Mg/ha
MOLI	JAXA	2023?	1064 nm waveform lidar	500 m	ISS (+/- ~51.6°)	NA
SAOCOM 1A	CONAE	October 8, 2019	L-band SAR	NA	Global	NA
ICESat-2	NASA	Sept 15, 2018	532 nm photon counting lidar	NA	Global	Global
TanDEM-L	DLR	2022-2023?	L-band SAR	1 ha	Global	20% accuracy or 20 Mg/ha
ALOS-4	JAXA	2020	L-band SAR	NA	Global	NA

GEDI's Biomass Algorithms are Trained with Existing Field Data

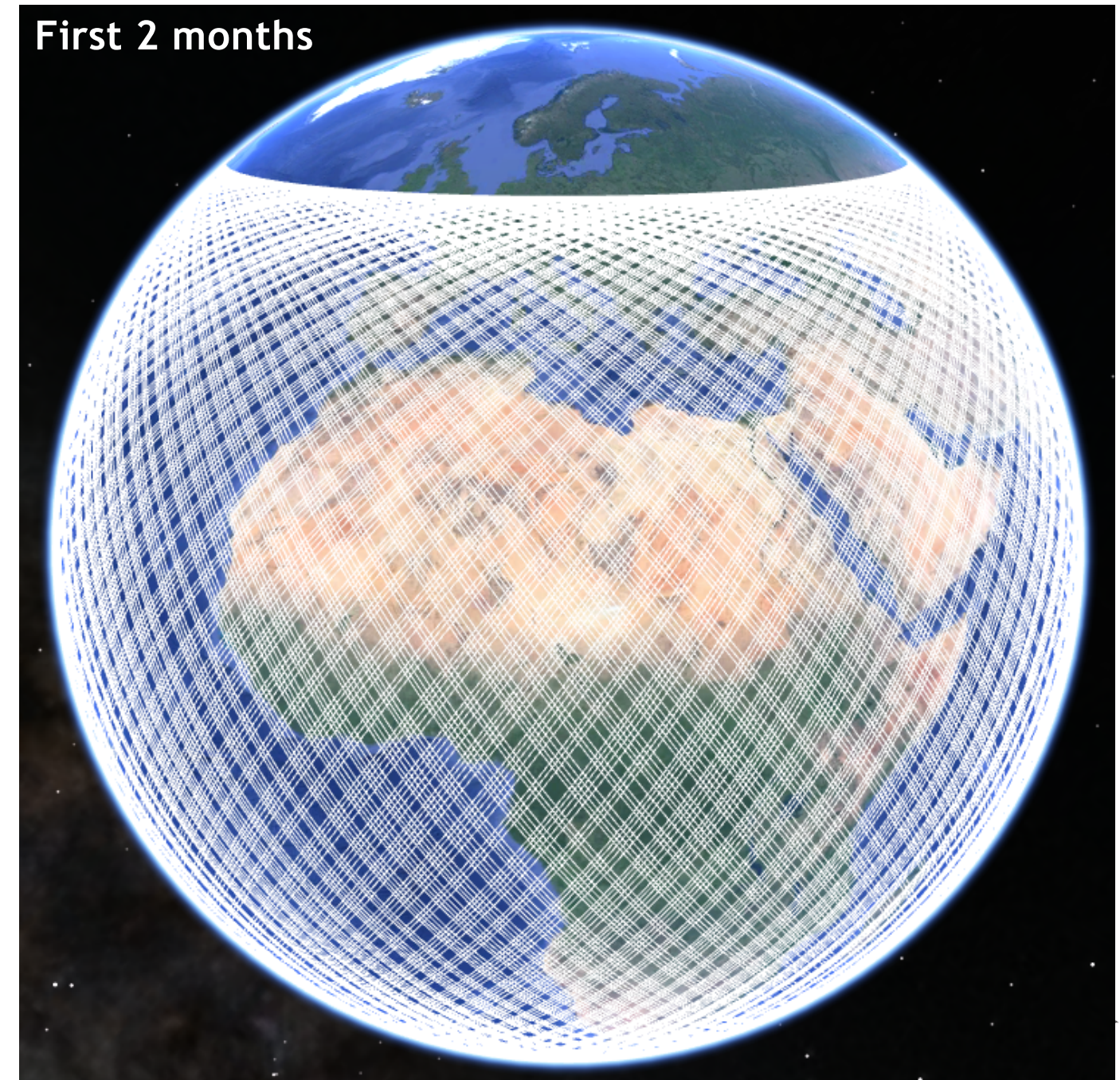
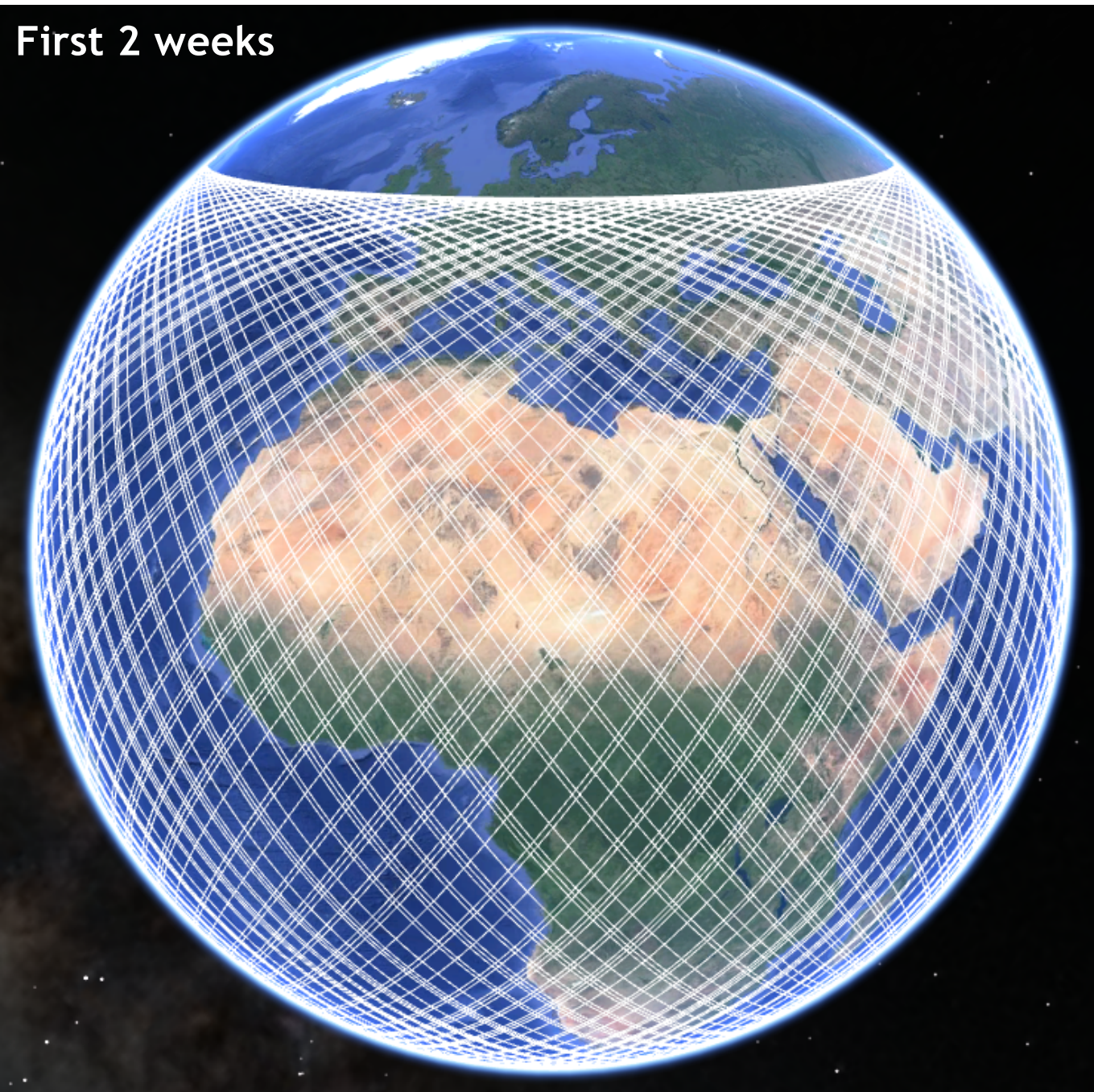


Field and Airborne lidar data crowd-sourced from lidar and forest plot communities

CEOS WGCV Supersite and Biomass Meeting, Canberra, March 2020



GEDI Orbital Coverage



SMAP
2014

DSCOVR
(NOAA)
2015

GRACE-FO
2018

ICESat-2
2018

CYGNSS
(EVM-1)
2016

OCO-2
2014

Landsat 8
(USGS)
2013

Suomi NPP
(NOAA)
2011

SORCE
2003

Aqua
2002

International Space Station
LIS on ISS 2017
SAGE III on ISS 2017
TSIS-1 on ISS 2017
ECOSTRESS on ISS (EVI-2) 2018
GEDI on ISS (EVI-2) 2018
OCO-3 on ISS 2019

Terra
1999

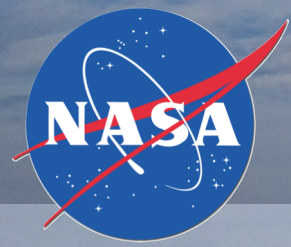
Aura
2004

CALIPSO
2006

CloudSat
2006

GPM
Core Observatory
2014

Landsat 7
(USGS)
1999



ICESat-2 Mission Overview



Payload

ATLAS – Advanced Topographic Laser Altimeter System developed at GSFC

Measures time of flight of laser pulses

Measures pointing direction

Single-photon sensitive detection

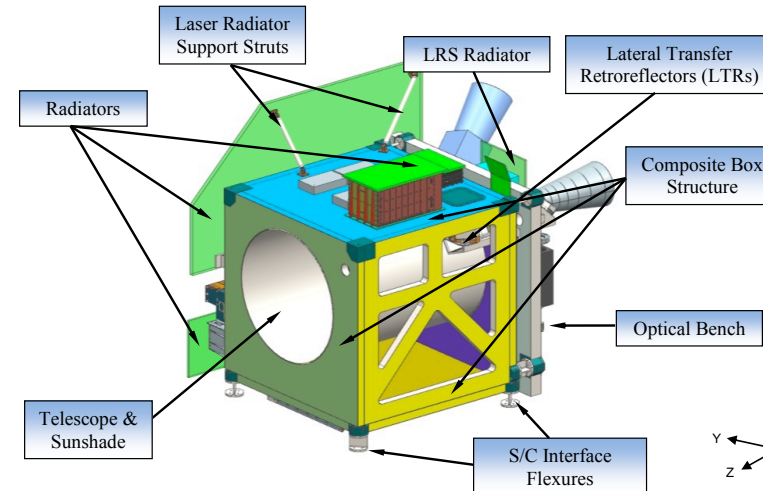
6 beams, arranged in 3 pairs

10 kHz pulse-rep. rate

14 m footprint

spaced 0.7m along-track

532nm wavelength



Implementation

Launch Date: September 15, 2018

Lifetime: 3 years, with consumables for 5+

Orbit: 454 km, non-sun-synch, 92° inclination

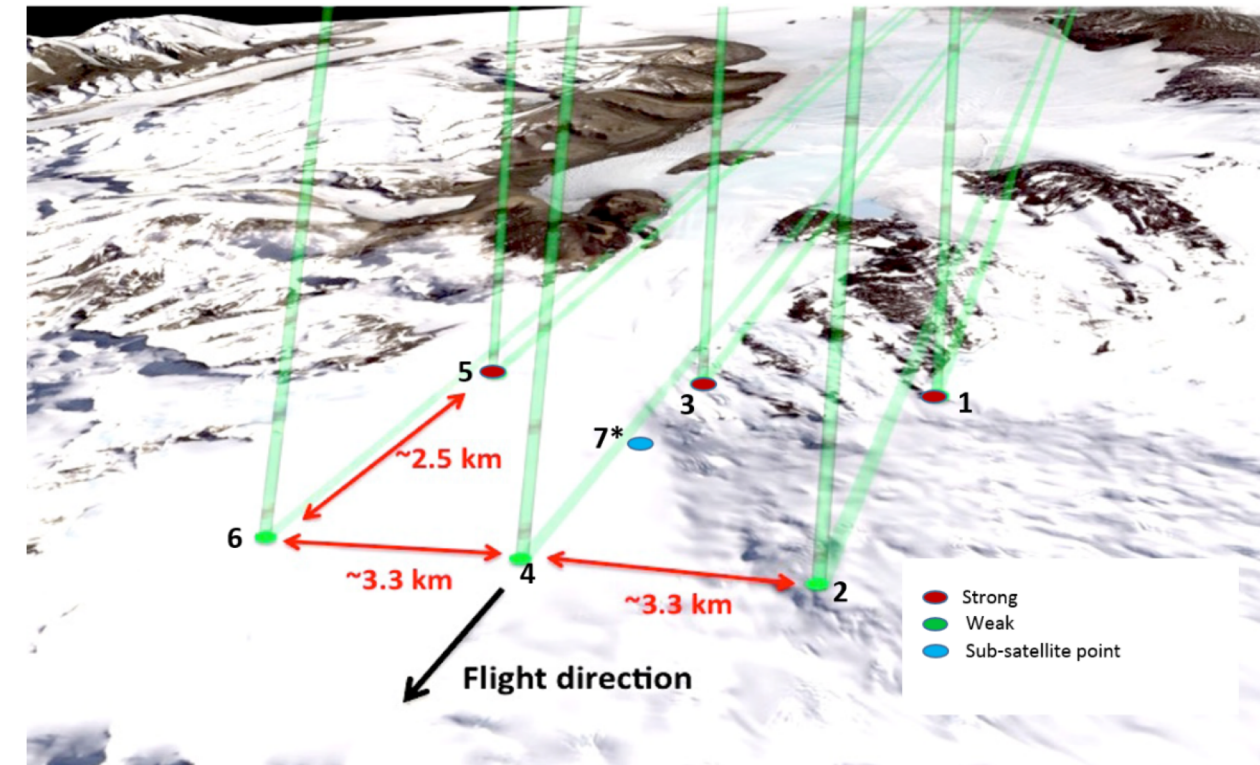
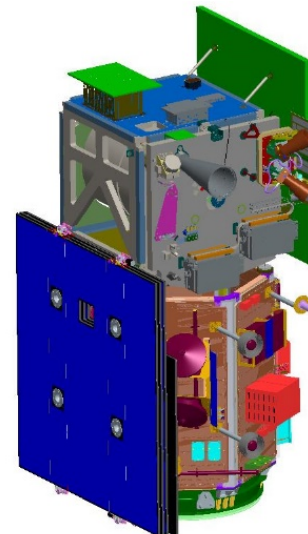
Repeat: 91 day exact repeat, ~30 day sub-cycle

Veg Mode: off-nadir pointed in mid-latitudes to increase spatial distribution of measurements over land

Science Data: 1 TB/day

System Pointing: Control = 45 m (14.3 m, CBE)

Knowledge = 6.5 m (4.0 m, CBE)



Single laser pulse at 532nm split into 6 beams.
Single-photon sensitive detection.

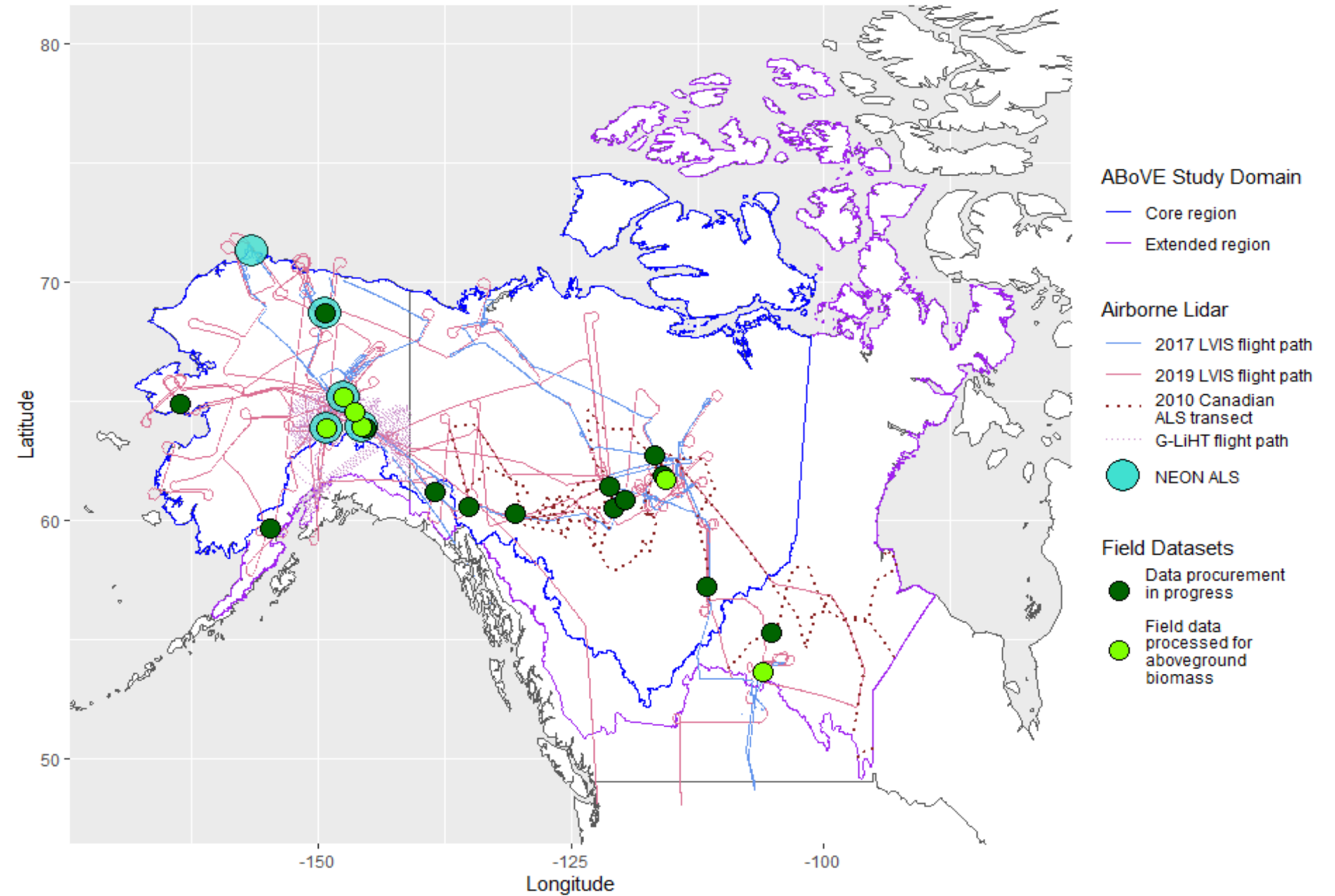
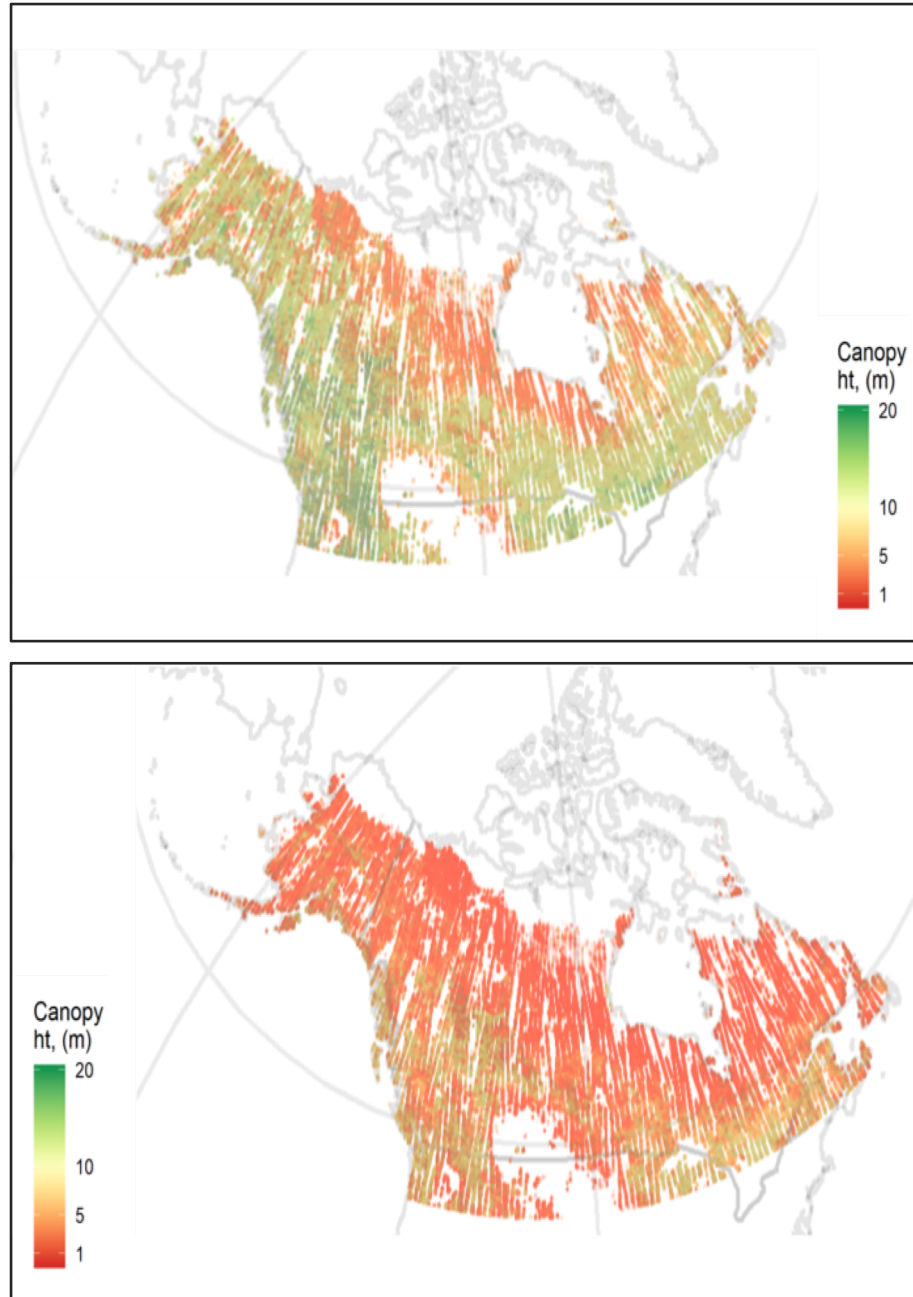
~3 km spacing between pairs provides spatial coverage

~90 m pair spacing for **slope determination** (2° yaw)

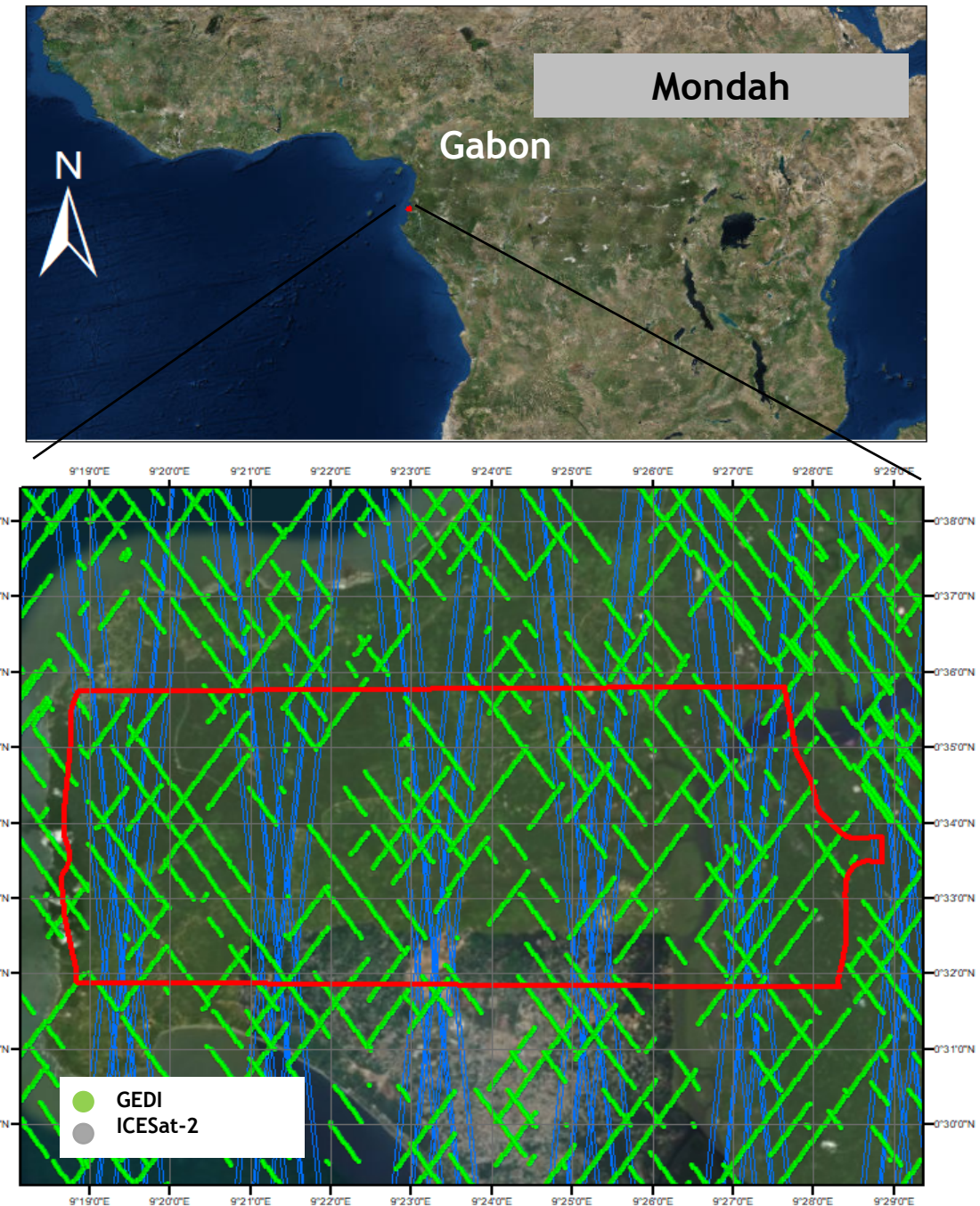
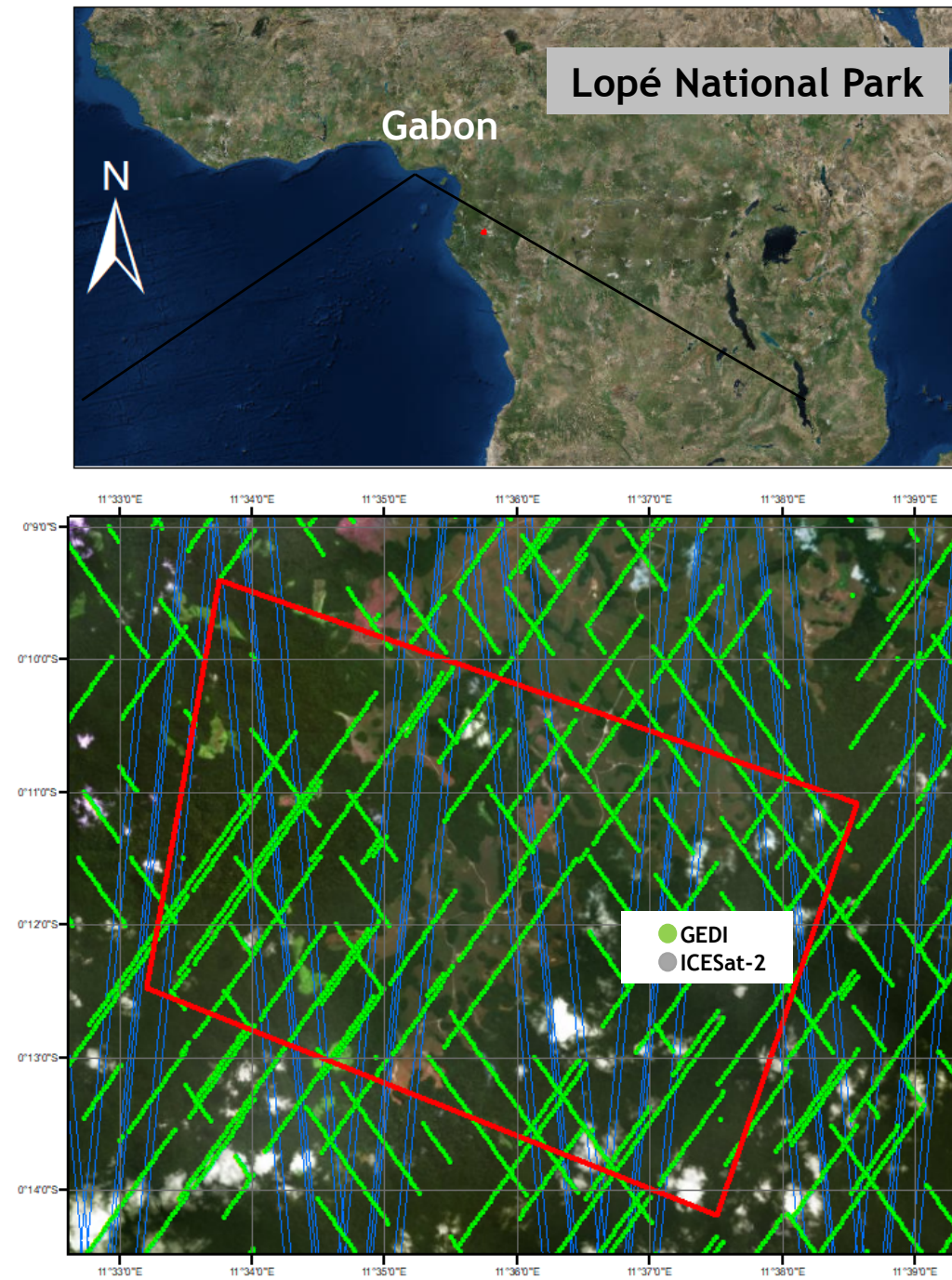
high-energy beams (4x) for better performance over low-reflectivity targets.



ICESat-2 Biomass Mapping in the Boreal



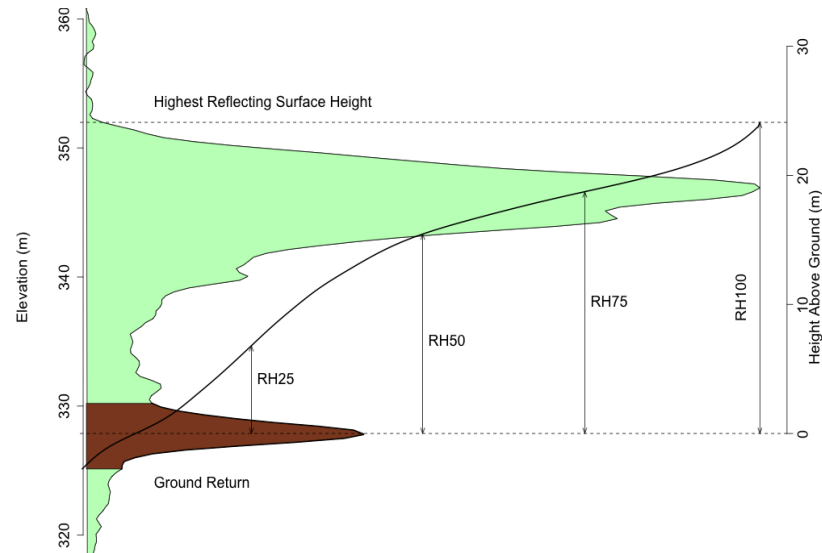
GEDI and ICESat-2 Increase Lidar Samples



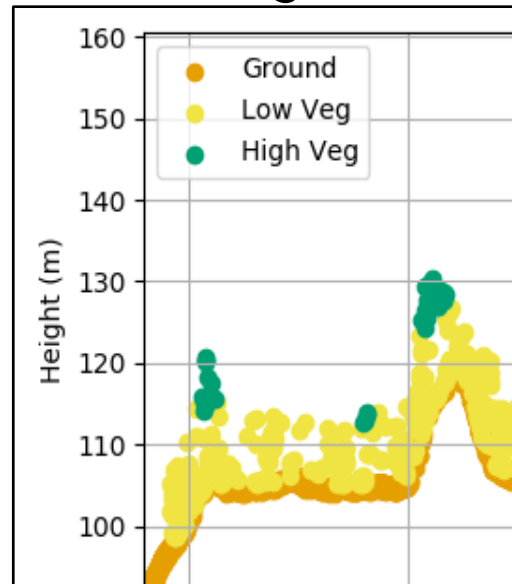
Comparing ICESat-2 Heights to GEDI Heights: NOT APPLES TO APPLES!

1) Different Canopy Metrics

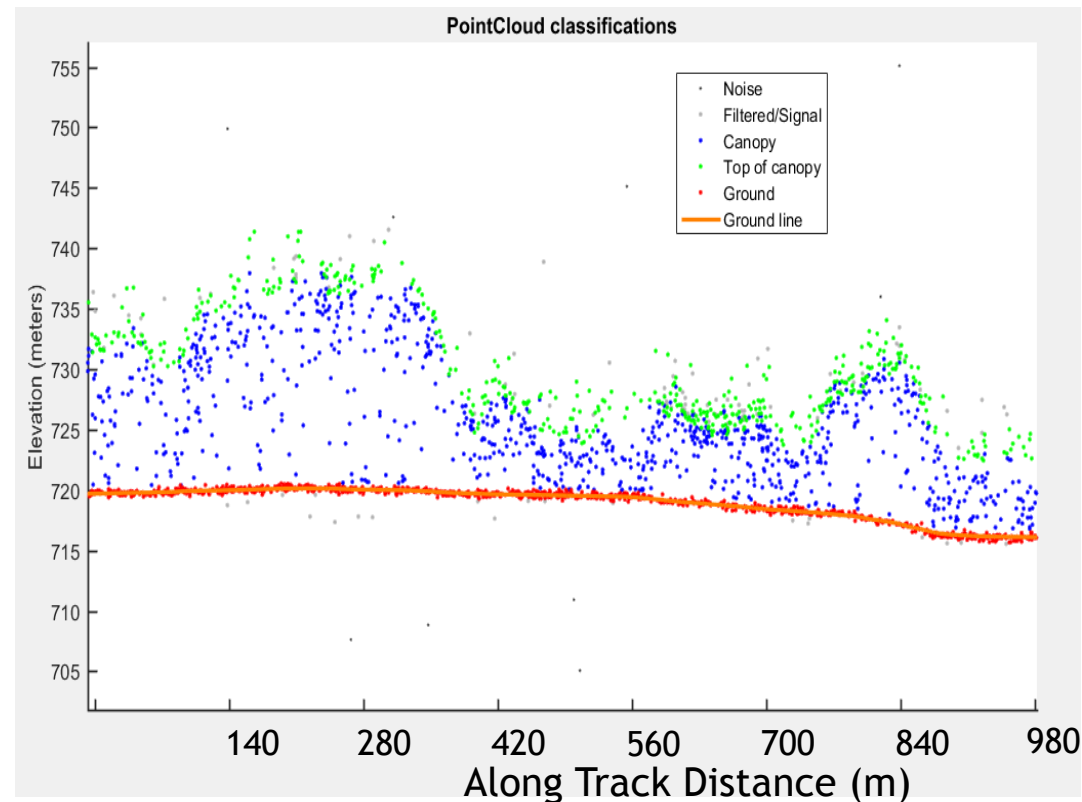
Percentile Heights *including* ground



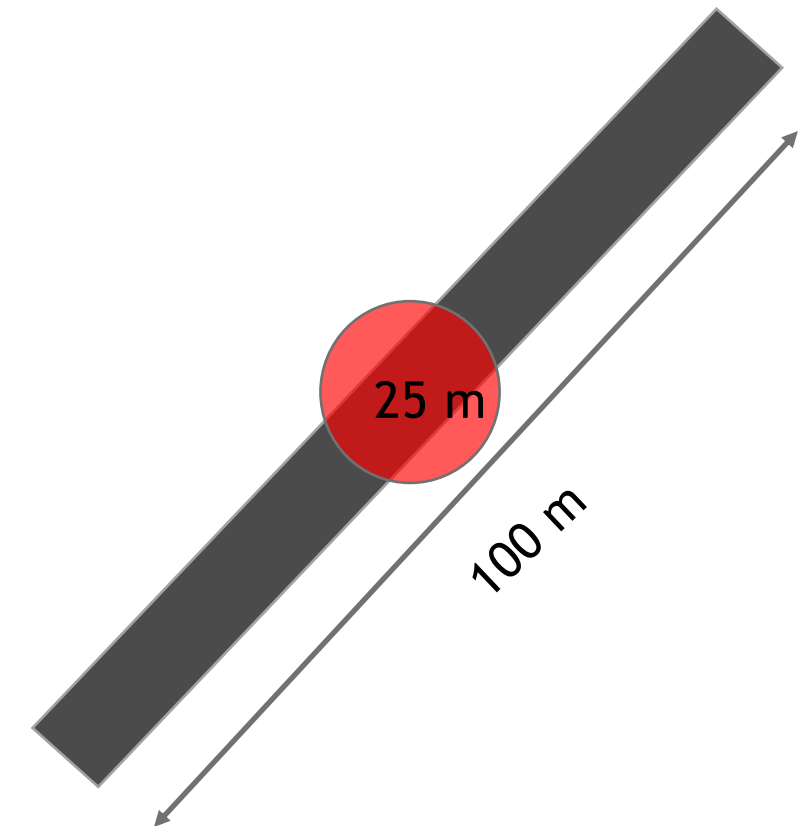
Percentile Heights *above* ground



2) Different Canopy Penetration



3) Different Resolutions



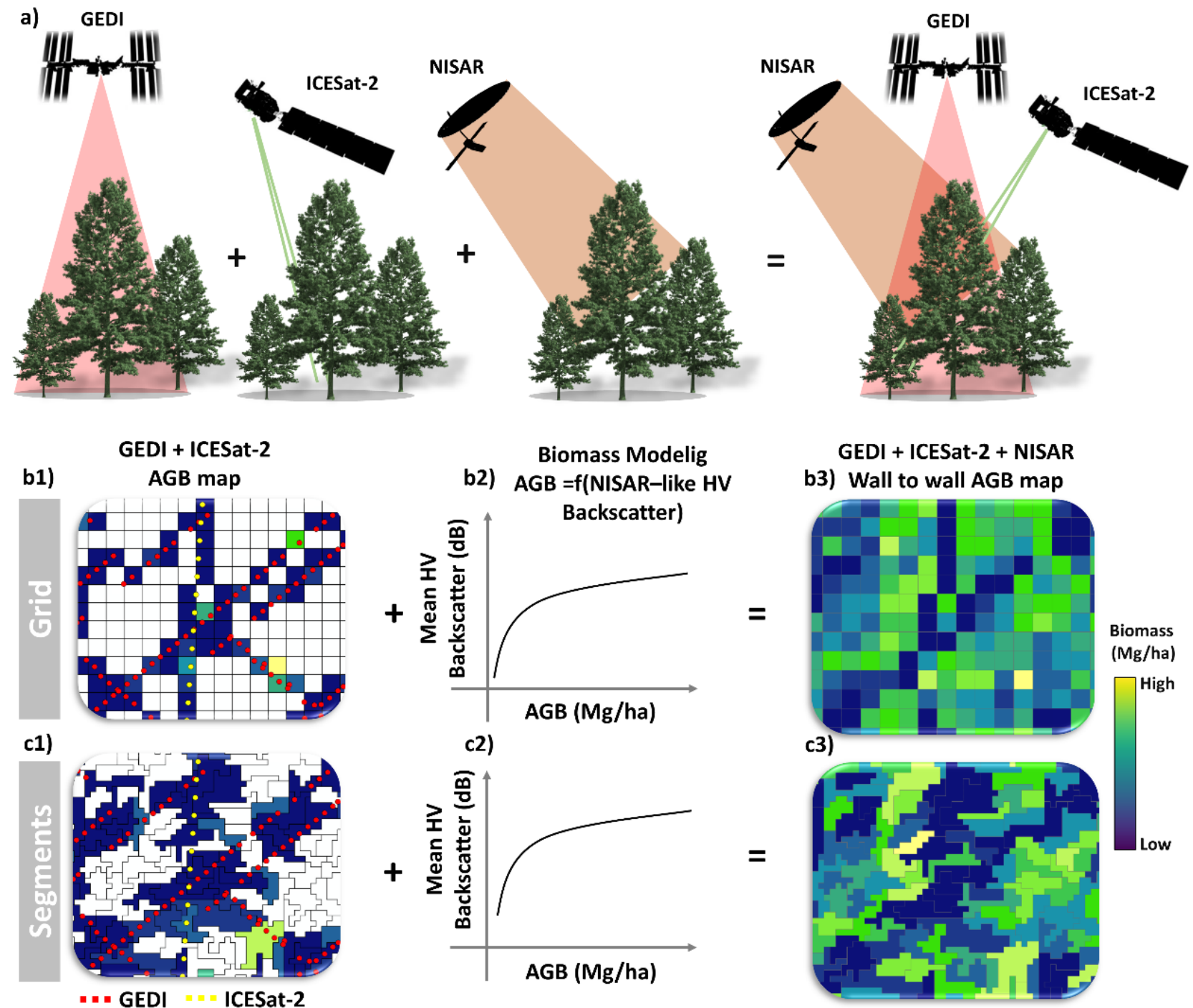
Biomass Mapping Through Fusion

Combining GEDI, ICESat-2 and NISAR (or landsat, TandemX, etc.) allows:

- Reduced errors
- Higher resolution maps

NASA CMS, Carlos Silva et al., in prep

CEOS WGCV Supersit



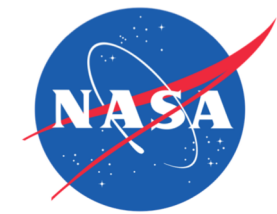
How will users make sense of all the new biomass products?

Mission	Funding Agency	Expected Launch Date	Data Type	Biomass Product Resolution	Geographic Domain	Accuracy Requirement
NISAR	NASA/ISRO	2022	L-band SAR	1 ha (<100 Mg/ha)	Global	<20% RMS accuracy for <100 Mg/ha
	‘If data are not turned into useful, actionable information in a timely fashion, then our field is simply recording history rather than changing it.’					
MOLI	JAXA	2022?	1064 nm waveform lidar	500 m	ISS (+/- ~51.6°)	NA
SAOCOM 1A	CONAE	October 8, 2019	L-band SAR	NA	Global	NA
ICESat-2	NASA	Sept 15, 2018	532 nm photon counting lidar	NA	Global	Global
TanDEM-L	DLR	2022-2023?	L-band SAR	1 ha	Global	20% accuracy or 20 Mg/ha
ALOS-4	JAXA	2020	L-band SAR	NA	Global	NA

Components of CEOS LPV Biomass Protocol

The protocol will be a good practices guide to biomass model calibration and product validation at a global (or near global) scale

- **Good practices for biomass estimation in the field (Keryn Paul, Jerome Chave, Kim Calders)**
 - Allometric Error
 - Field Measurement Error
 - Terrestrial Laser Scanning
- **Linking remote sensing observations to field estimates (Maxime Réjou-Méchain, Barbier, Armston, Duncanson)**
 - Geolocation & Spatial Scale
 - Using airborne data to scale from field to spaceborne data
- **Error Propagation (Stephen Roxburgh, Ron McRoberts)**
 - Sources of Uncertainty
 - Extrapolating models to global maps
- **Recommendations for User-led validation (Valerio Avitabile)**
 - Harmonization of definitions
 - Screening of Data
 - Considerations of Scale
- **Utility of Protocol for Other Communities**
 - Modeling community (Mat Williams)
 - Policy communities (Martin Herold, Sarah Carter)
 - Non-forest communities (Natasha MacBean)
- **Knowledge Gaps**
 - Experiments that will advance the field
 - Airborne / Field data gaps
 - Cross mission cal/val plans
 - Improvement of allometric models
 - Development of tools for validation and intercomparison



Field Biomass Estimation: Field Measurements, Allometry, TLS

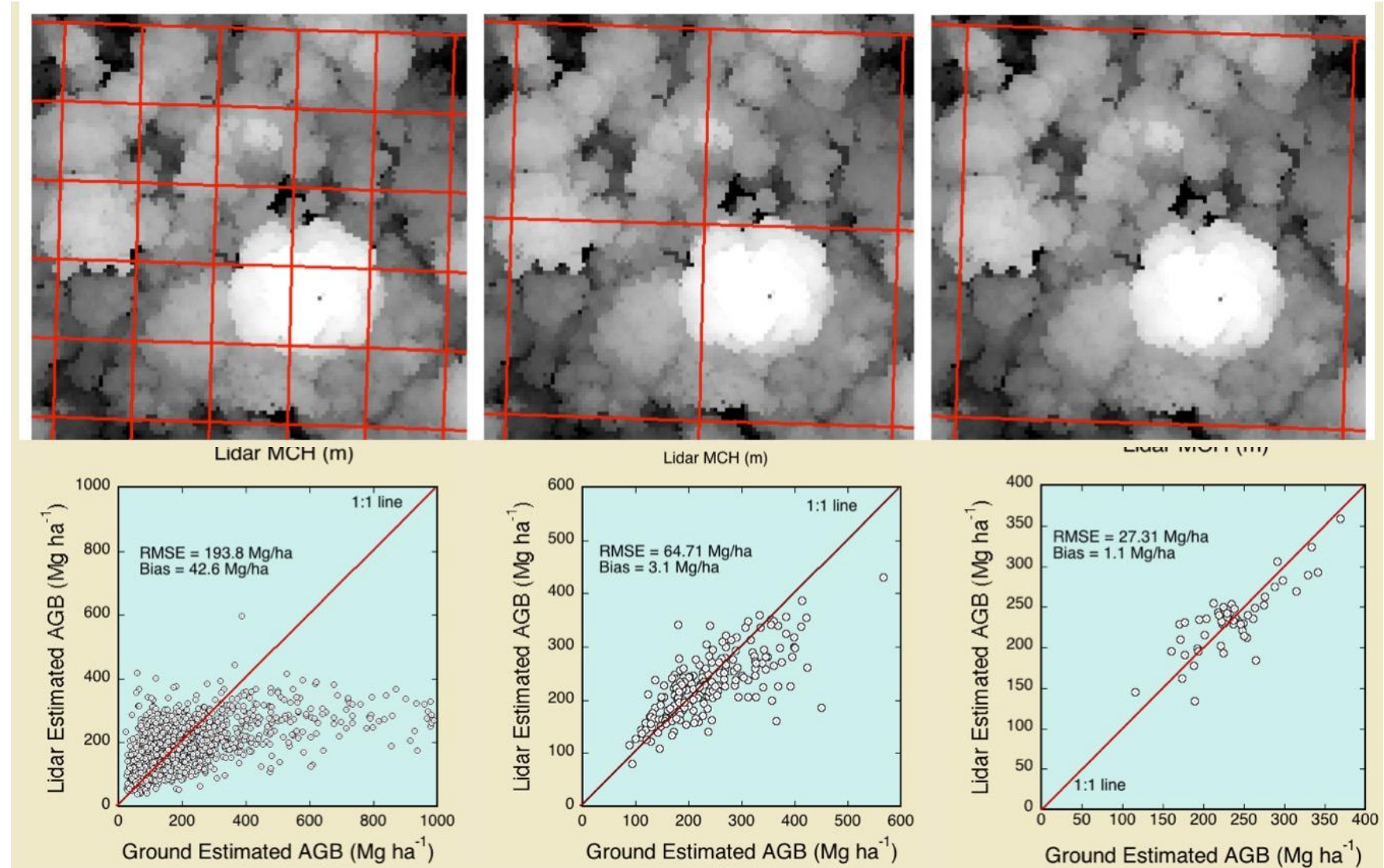
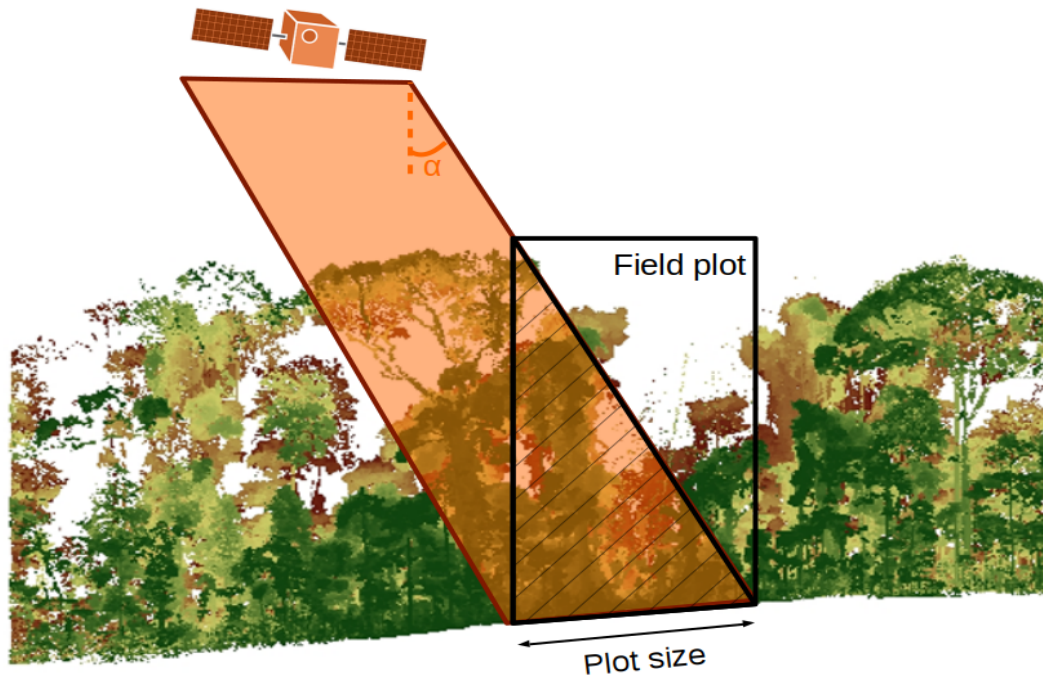
Field Estimates are Estimates - we generally use allometry. There are large errors.

- Need transparent handling and reporting of errors, consistent definitions
- Provision of individual tree measurements to facilitate error checking
- TLS where possible
- New TLS-driven allometric models



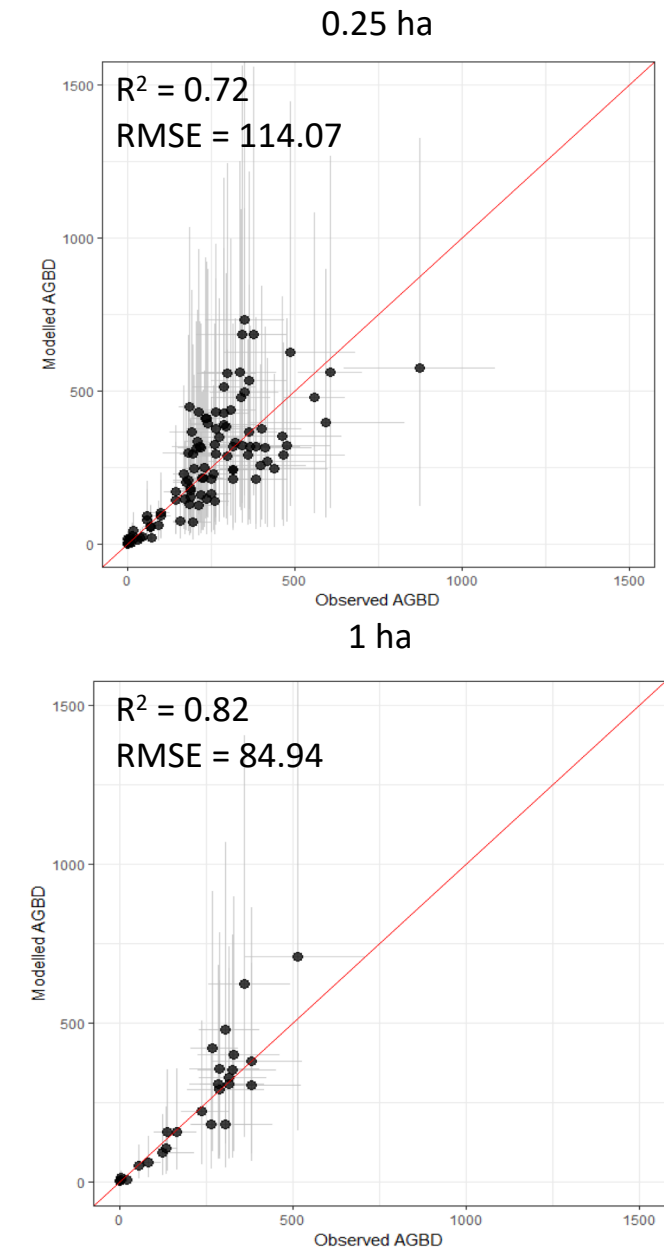
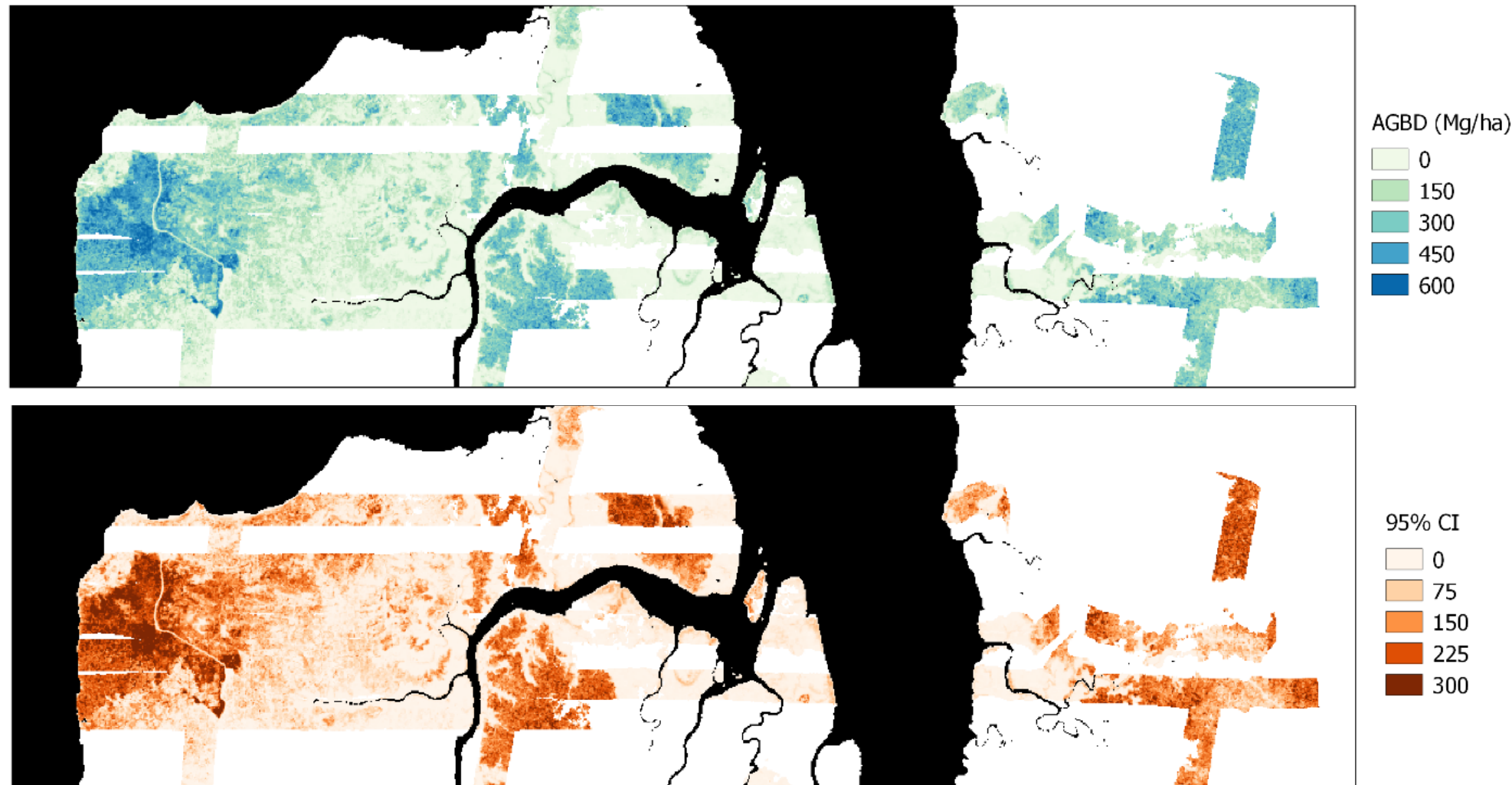
Linking Field Plots to Satellite Observations

- Small plots with poor geolocation are not useful for validation at the pixel-level
- Large plots reduce errors, particularly from large crowns/edge effects and geolocation
- 0.25 ha - 1 ha in tropics; smaller (~20 m) sufficient in temperate/boreal assuming good geolocation



Using Airborne Lidar Biomass Maps for Scaling Armston & Duncanson

Airborne lidar biomass maps can do multi-resolution validation (provided they are calibrated with local high-quality field plots over the range of environmental conditions covered by the lidar)

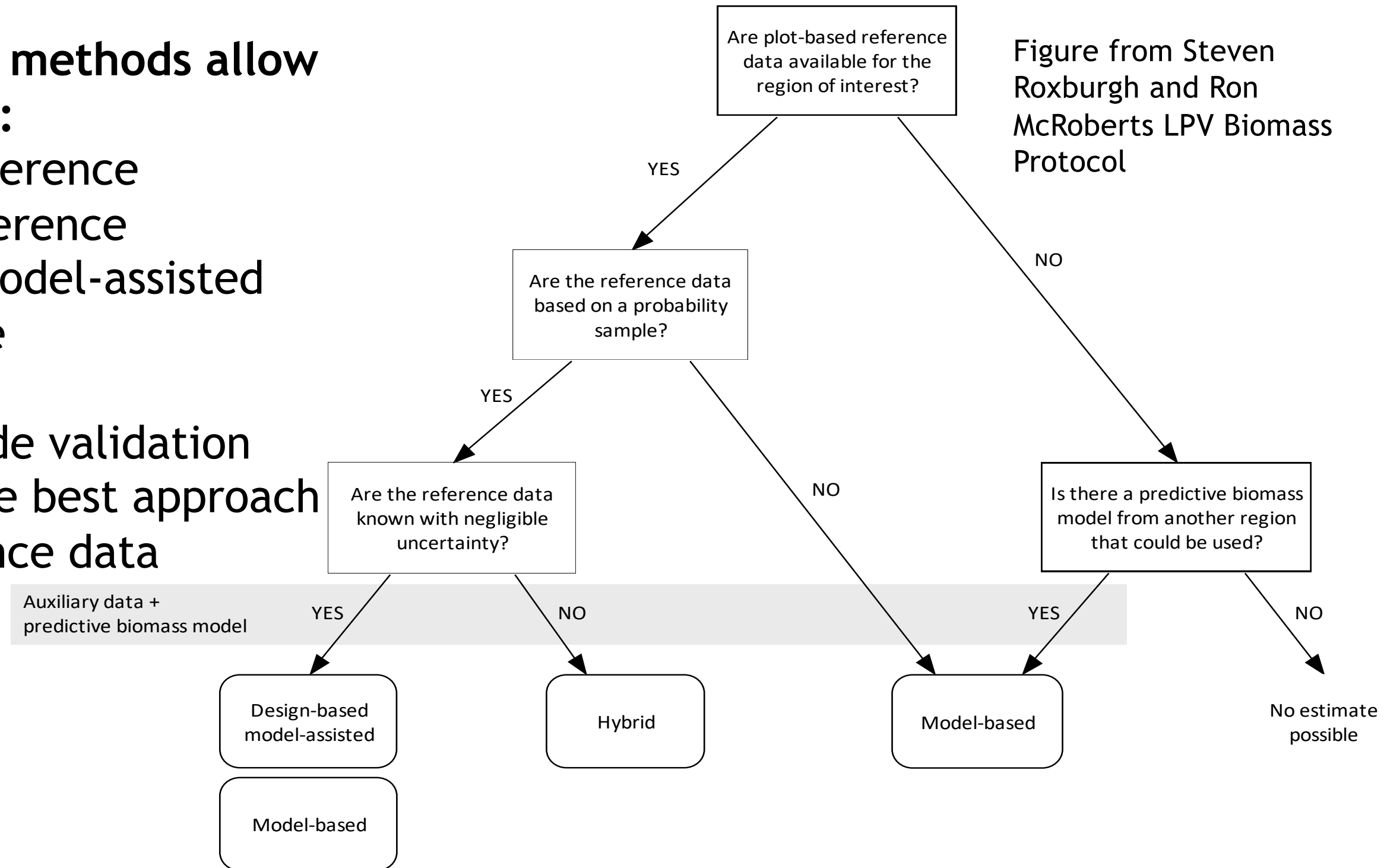


Error Estimation in Biomass Maps (McRoberts & Roxburgh)

Several statistical methods allow error propagation:

- Design-based inference
- Model-based inference
- Design-based, model-assisted
- Hybrid inference

Protocol helps guide validation activities to choose best approach given their reference data



User-led Product Validation

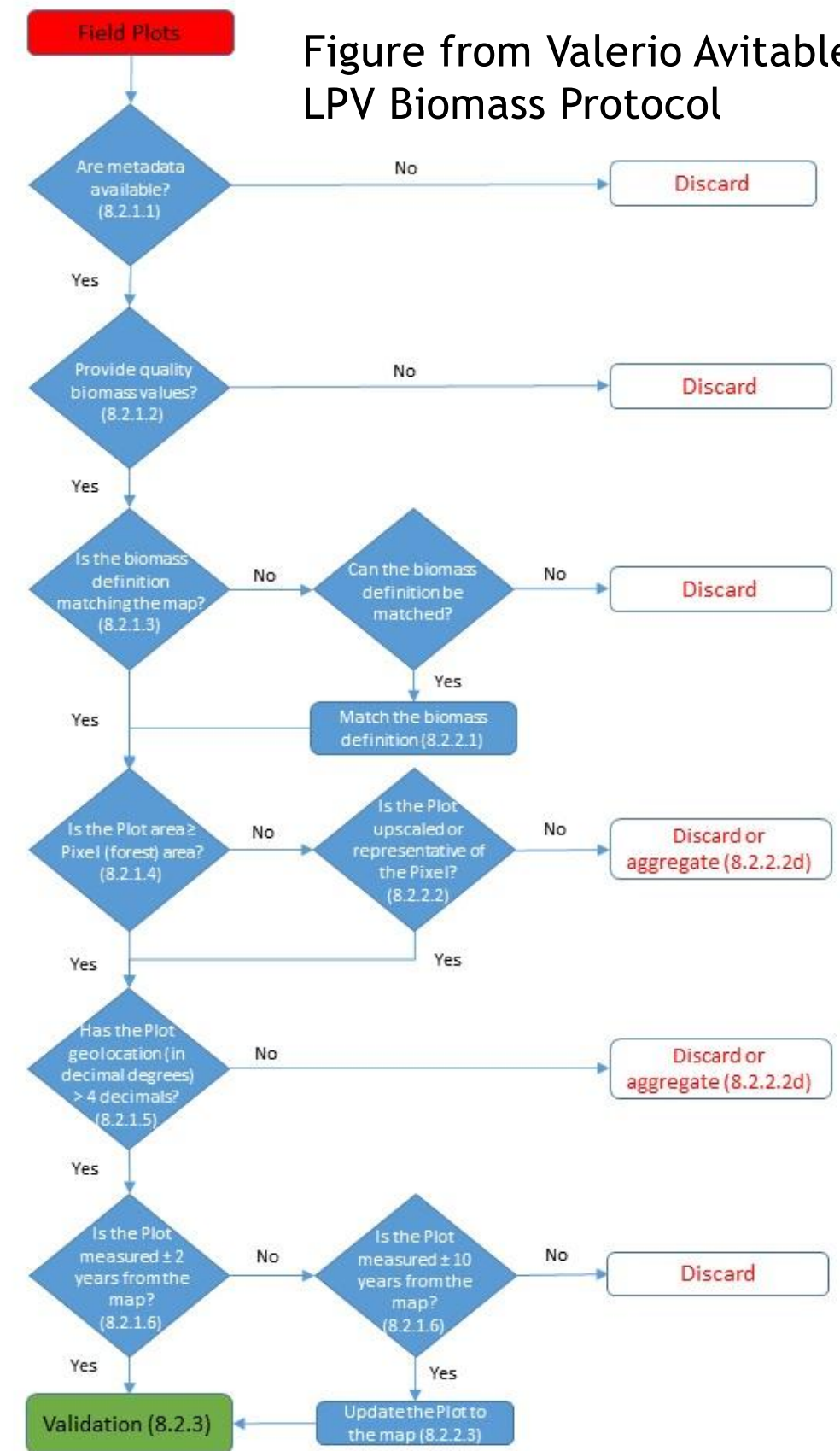
Chapter led by Valerio Avitabile

Recommendations for user-led validation using
a) Field Plots, b) Regional Statistics, c) Local
biomass maps (e.g. from airborne lidar)

We have a series of workflows and suggestions
for harmonization, but do not have a tool for
user-led validation

- Potential collaboration with FAO?
SERVIR?
- Collect Earth, SEPAL, etc.
- (World Bank, SilvaCarbon ...)

Figure from Valerio Avitabile
LPV Biomass Protocol



Knowledge and Data Gaps

Knowledge Gaps:

- Community vetted validation tools
- Improved allometric models
- Scalable TLS processing algorithms
- Coordination of height and wood density protocols
- User-friendly Error Propagation and Scaling of Errors

Data Gaps:

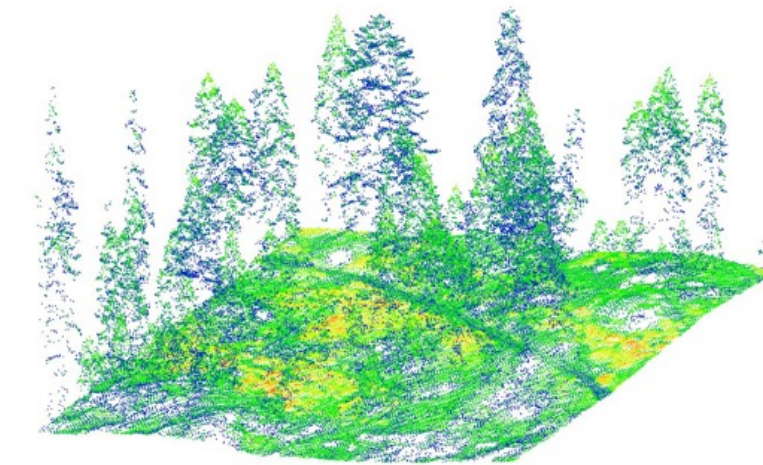
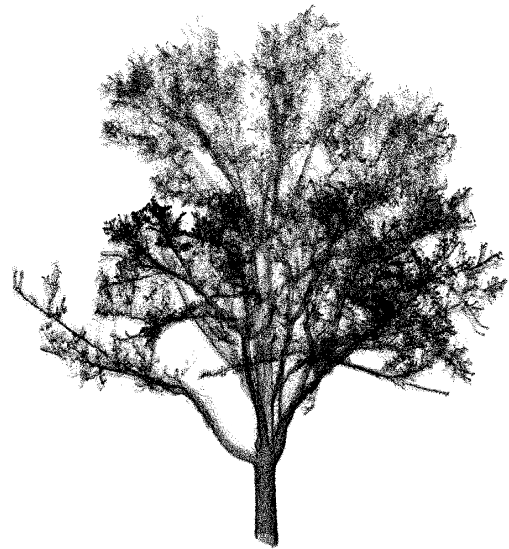
- Field plot and lidar over biomass supersites
- More systematically acquired TLS data
 - Should be publicly available
 - Collected following protocol
 - Re-surveyed every ~5 years or when disturbance is detected
- **Field and plot gaps:**
 - Continental Asia
 - Dryland/woodland ecosystems
 - Time series in tropics



CEOS: General Biomass Validation Concept

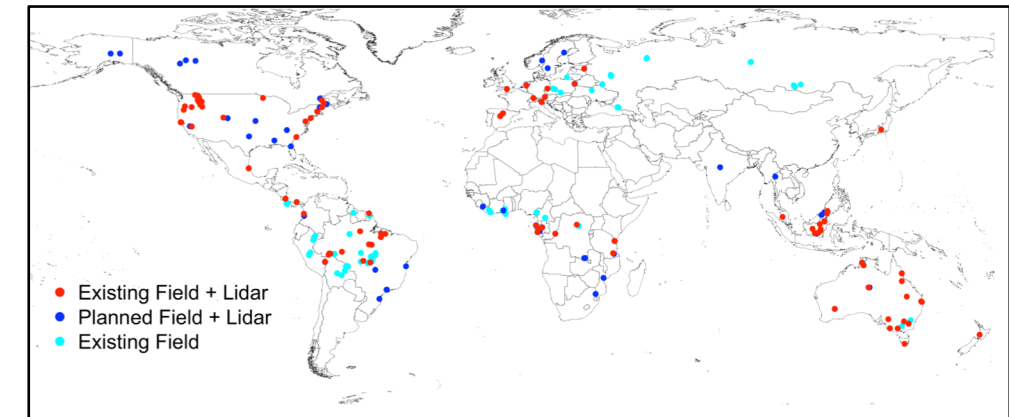
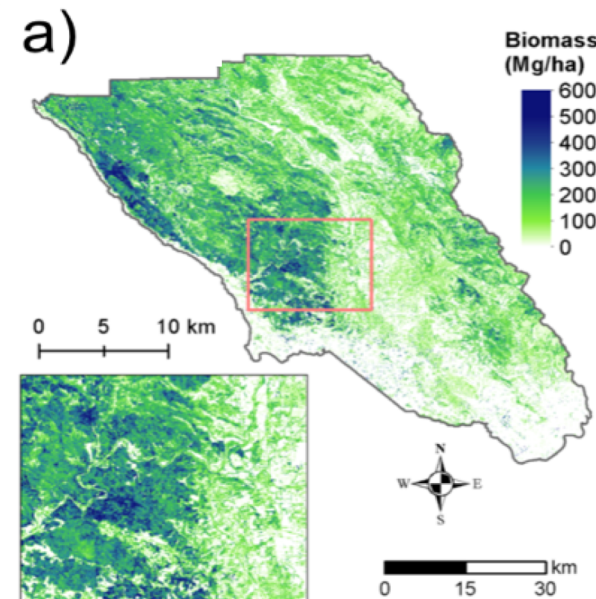
Error Propagation

1. Collect field data for plot biomass estimates (TLS where possible)



2. Collect airborne lidar to scale between plots and satellite data

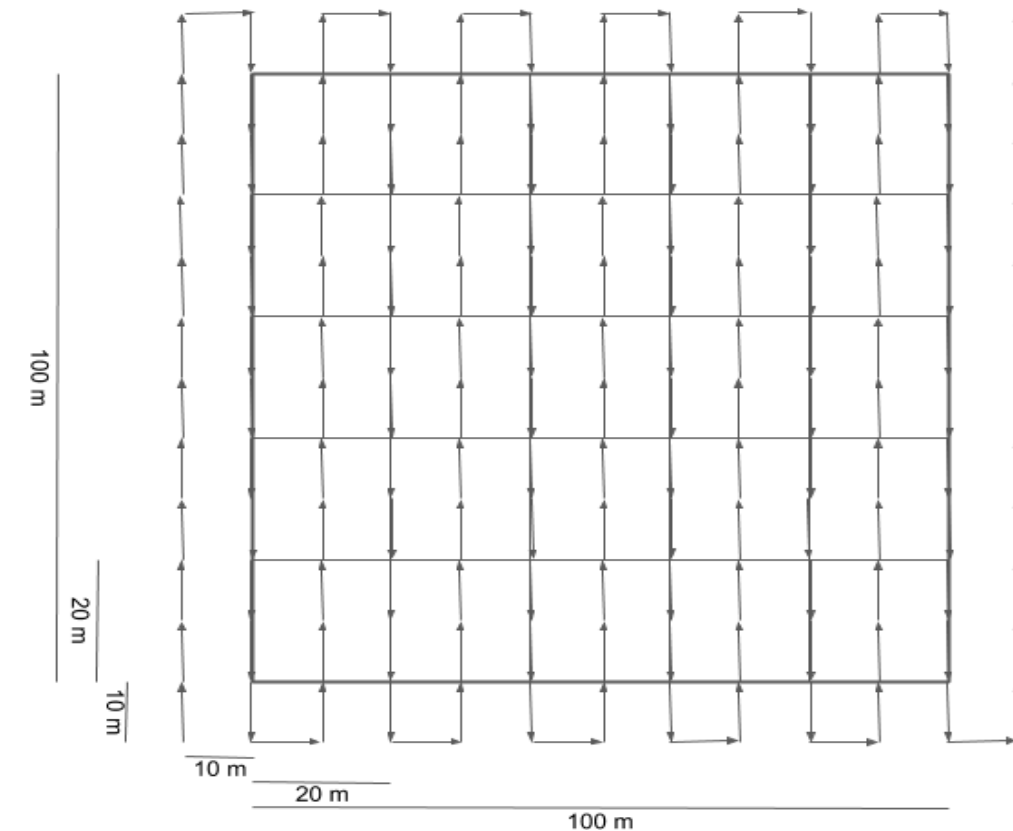
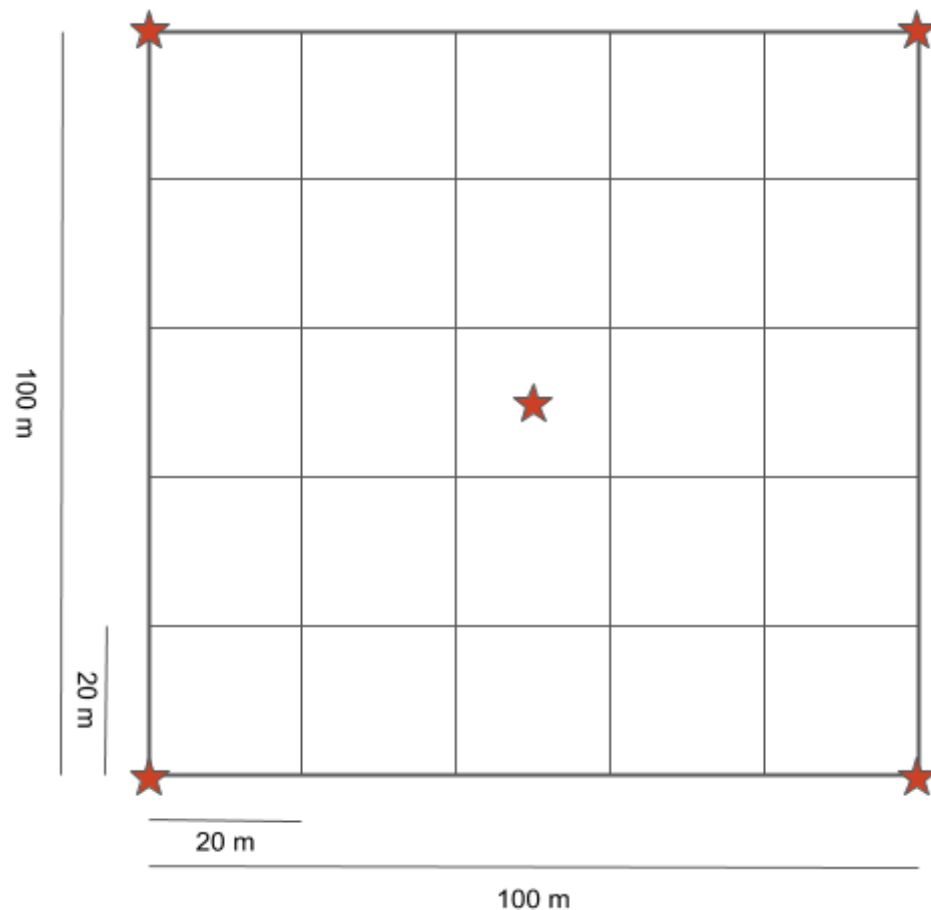
3. Generate airborne lidar biomass maps + errors



4. Use suite of reference maps from global biomass 'supersite' network for product validation

Appendices will be more hands-on guides for Data Collection

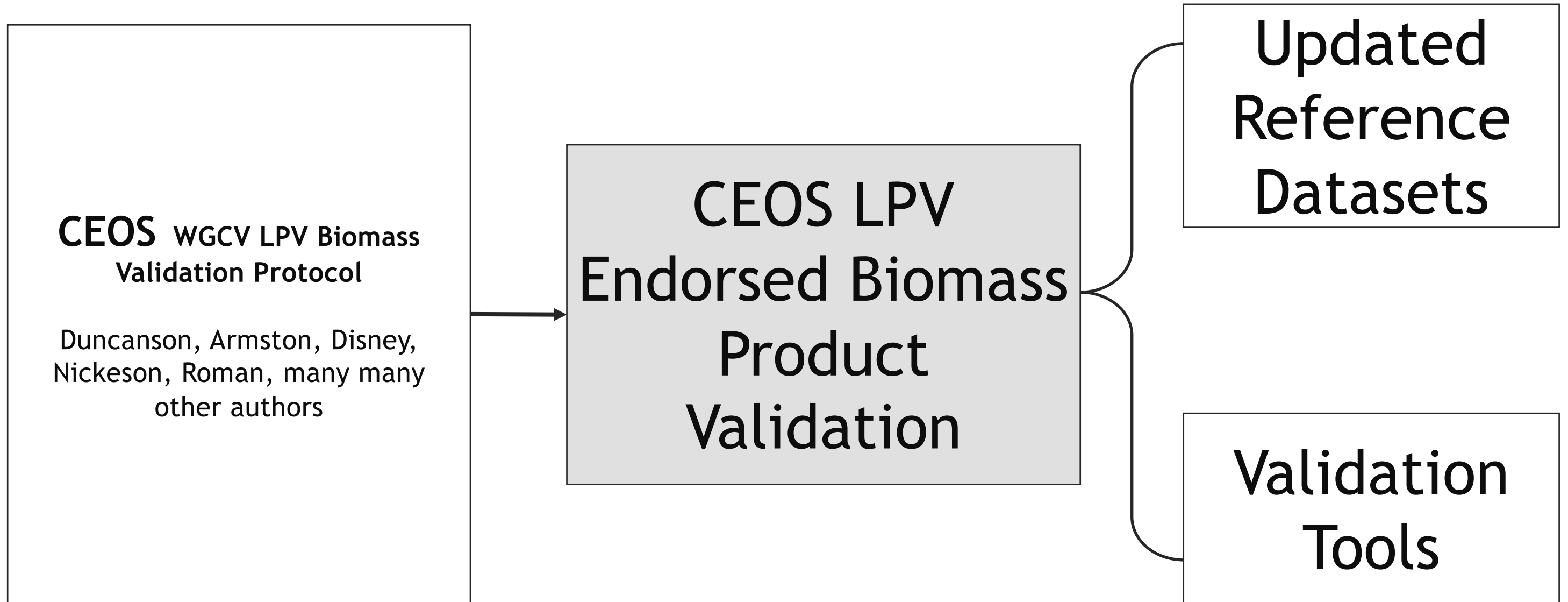
- Guide for field sampling of new plots
- Guide for TLS sampling of new plots
- Guide for ALS acquisitions / minimum specs



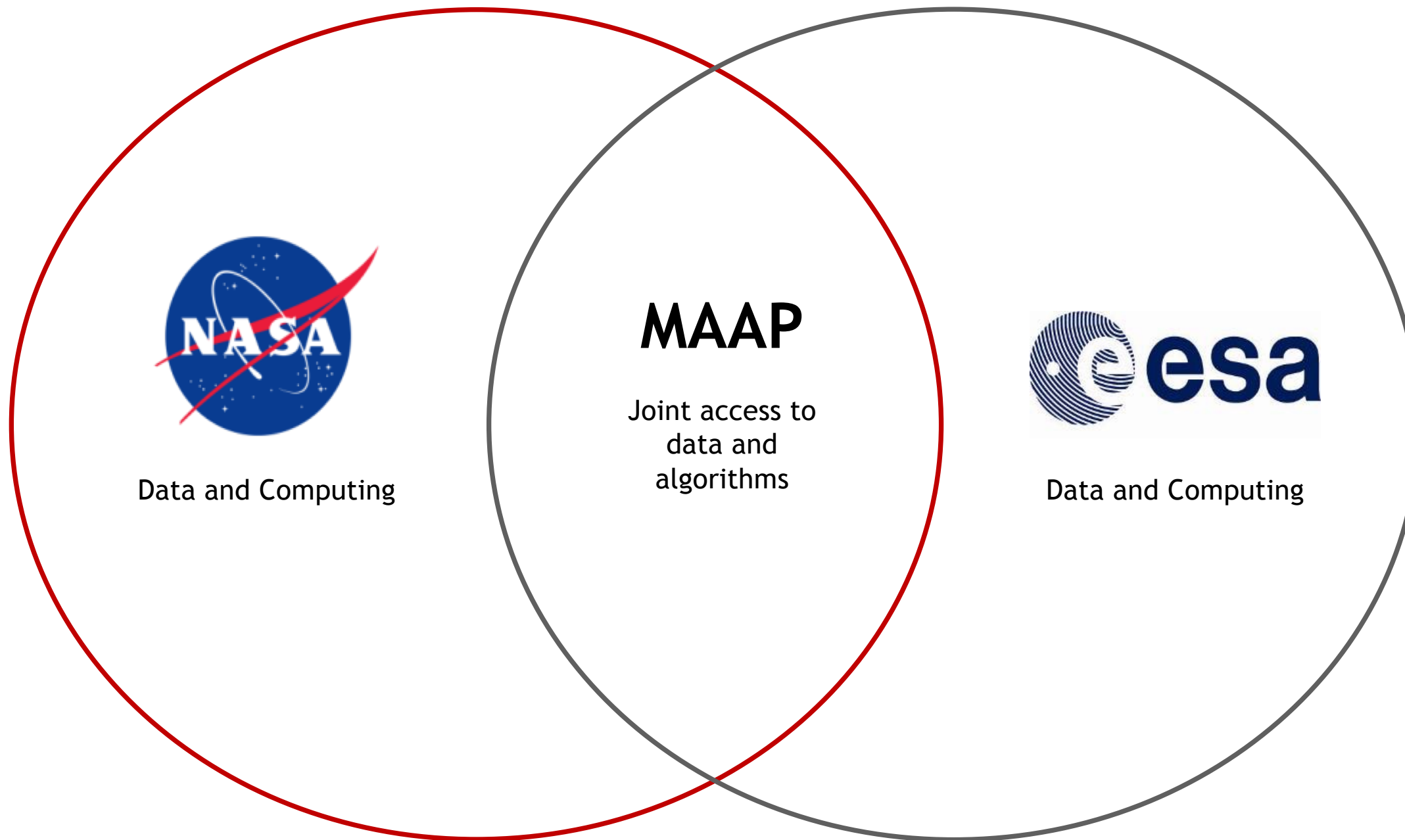
- Field data can be collected using several existing field sheets, we will provide protocol compliant examples (e.g. here from forestplots.net)

Plot code:											
Plot name:											
State, Country, Continent											
Census date:											
Funding project:											
Project PI(s):											
Inventory leader:											
Botanist(s):											
Assistants:											
Plot form, area and layout		Add to Plot Notes:									
Plot area (ha):		Ground / Projected Planar		Corner stakes present (PVC/metal)?							
Minimum plot dimension (m):		Maximum plot dimension (m):		Internal subplot stakes present (PVC or metal)?							
Note: standard plot set up is as below. Modify 'actual field system' map based on actual plot layout.											
Standard example											

CEOS Protocol Implementation Considerations



ESA-NASA Multi-Mission Algorithm and Analysis Platform (MAAP)



MAAP will host *public* satellite data (focused on Lidar and SAR), airborne campaign data and field data

Community will (hopefully!) develop open-source validation packages for biomass products

Multi-Mission Biomass Cal/Val Group

- **NISAR:**

- Bruce Chapman
- Paul Siquiera
- Sassan Saatchi
- Paul Rosen

- **GEDI:**

- Ralph Dubayah
- Laura Duncanson
- Michelle Hofton
- Lola Fatoyinbo
- John Armston
- David Minor
- Jim Kellner

- **BIOMASS:**

- Klaus Scipal
- Shaun Quegan
- Jerome Chave
- Nicolas Labriere
- Clement Albinet

- **Plot Networks:**

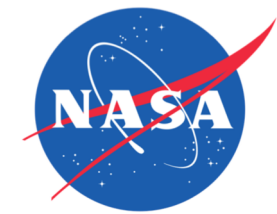
- Stuart Davies (ForestGEO)
- Oliver Phillips (ForestPlots)
- Jerome Chave (FOS)
- Tim Baker (ForestPlots)
- Dmitry Schepaschenko (FOS)

- **MAAP:**

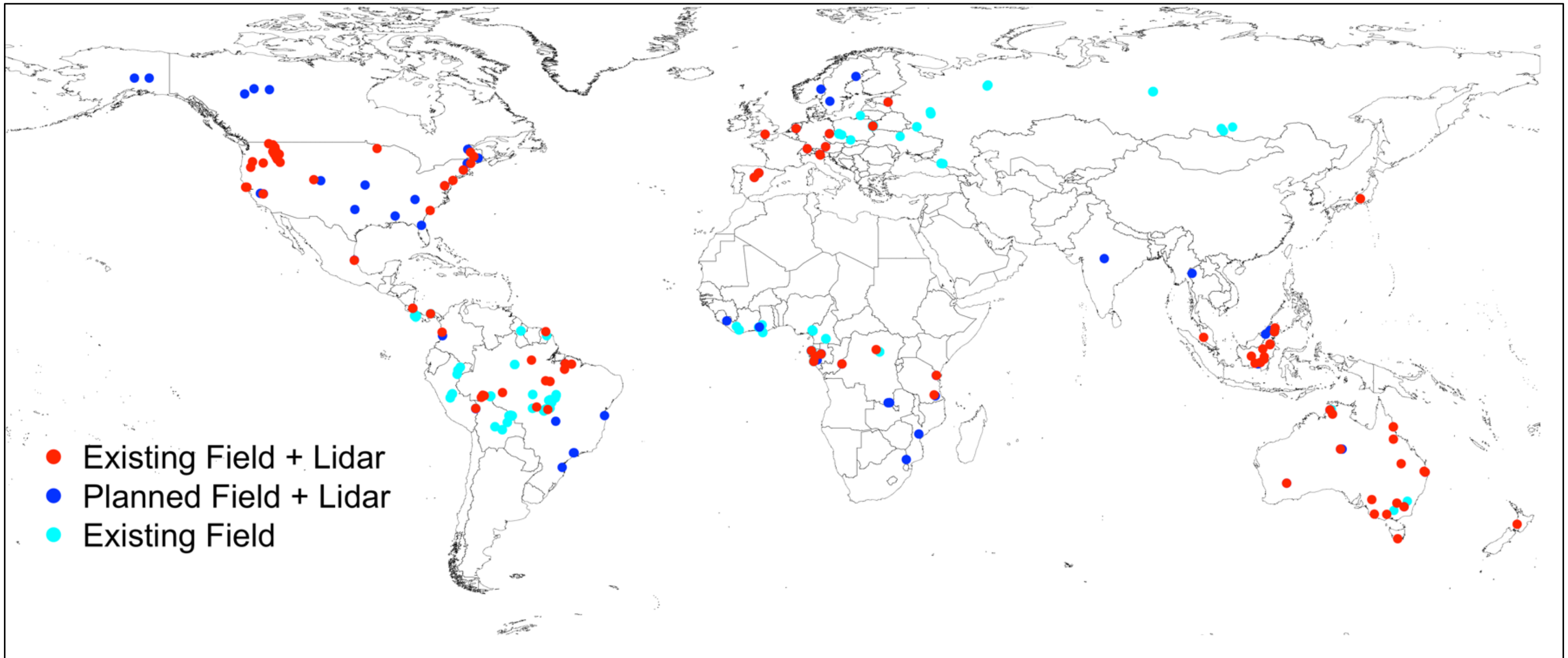
- Marco Lavallo
- Clement Albinet
- Amanda Whitehurst
- Laura Duncanson

- **Other:**

- Mike Falkowski (NASA HQ)
- Richard Lucas (CCI Biomass)
- Amy Neuenschwander (ICESat-2)
- Mat Disney (UCL, CEOS LPV)
- Ake Rosenqvist (JAXA missions)

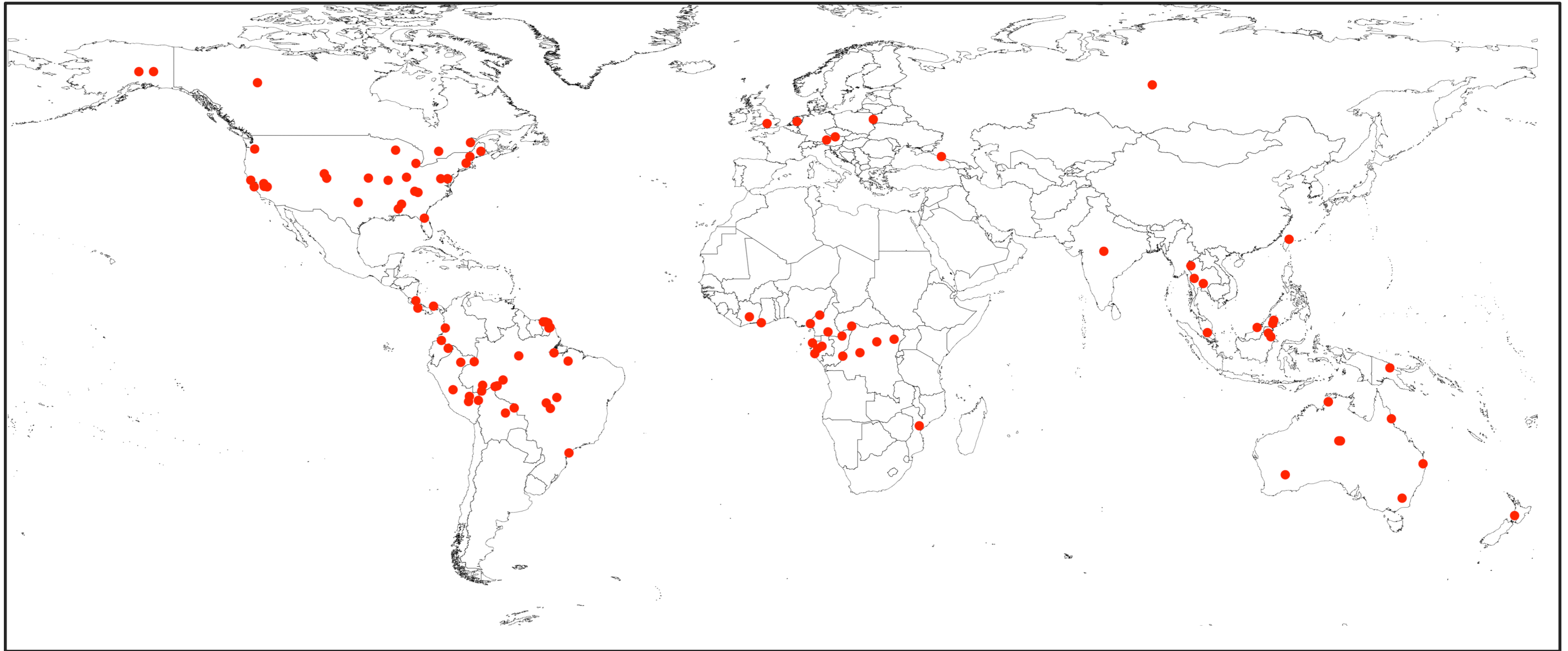


Data Sharing and Coordinated Data Collection



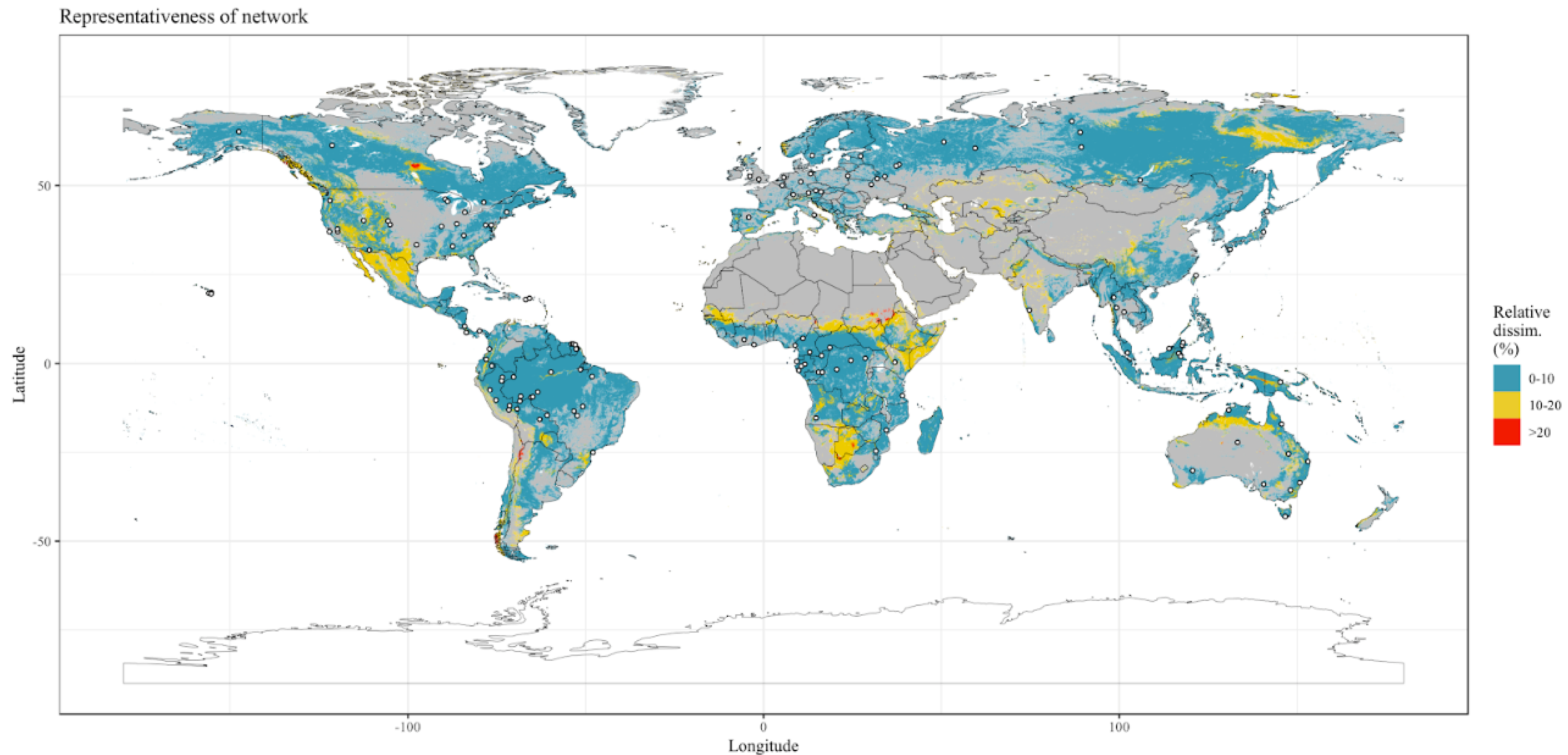
GEDI, ICESat-2, NISAR, and ESA BIOMASS teams are working on coordinated cal/val
Australia (TERN and others) have played a leadership role in biomass cal/val and open data

Proposed Biomass Validation Supersites



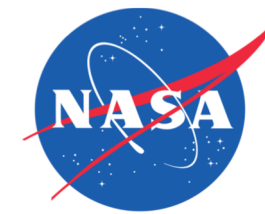
A subset of data rich Multi-Mission Sites that have been identified as useful for all missions

Where are the Spatial Gaps?



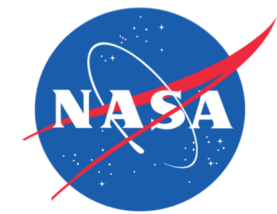
Labriere et al., in prep

CEOS WGCV Supersite and Biomass Meeting, Canberra, March 2020



Timeline

Timeline	Activities
Fall 2017	• Identify contributors • Develop draft protocol skeleton • Meet with writing groups
Winter 2017	• Finalize skeleton, writing groups / leads
2018	• Chapter drafts • Review paper on biomass validation
2019	• Protocol writing
Spring 2020	• Protocol completion and internal review
Summer 2020 (?)	• Two month public comment, protocol publication
October 2020	• Protocol & biomass site endorsement by CEOS



Conclusions

1. *Many* exciting new biomass-relevant data streams and products will soon be available
2. To avoid confusion in the user-community, transparent and consistent biomass product *validation is critical*
3. Several areas that require more research attention (e.g. better allometry)
4. Validation requires consistent reference datasets, *funding* for plot re-census, airborne and terrestrial laser scanning data
5. User-friendly and transparent tools for product inter-comparison and validation are required



Thank you to the many protocol co-authors!

lduncans@umd.edu

Follow GEDI on Twitter @GEDI_Knights

Follow Laura on Twitter @lauraduncanson

