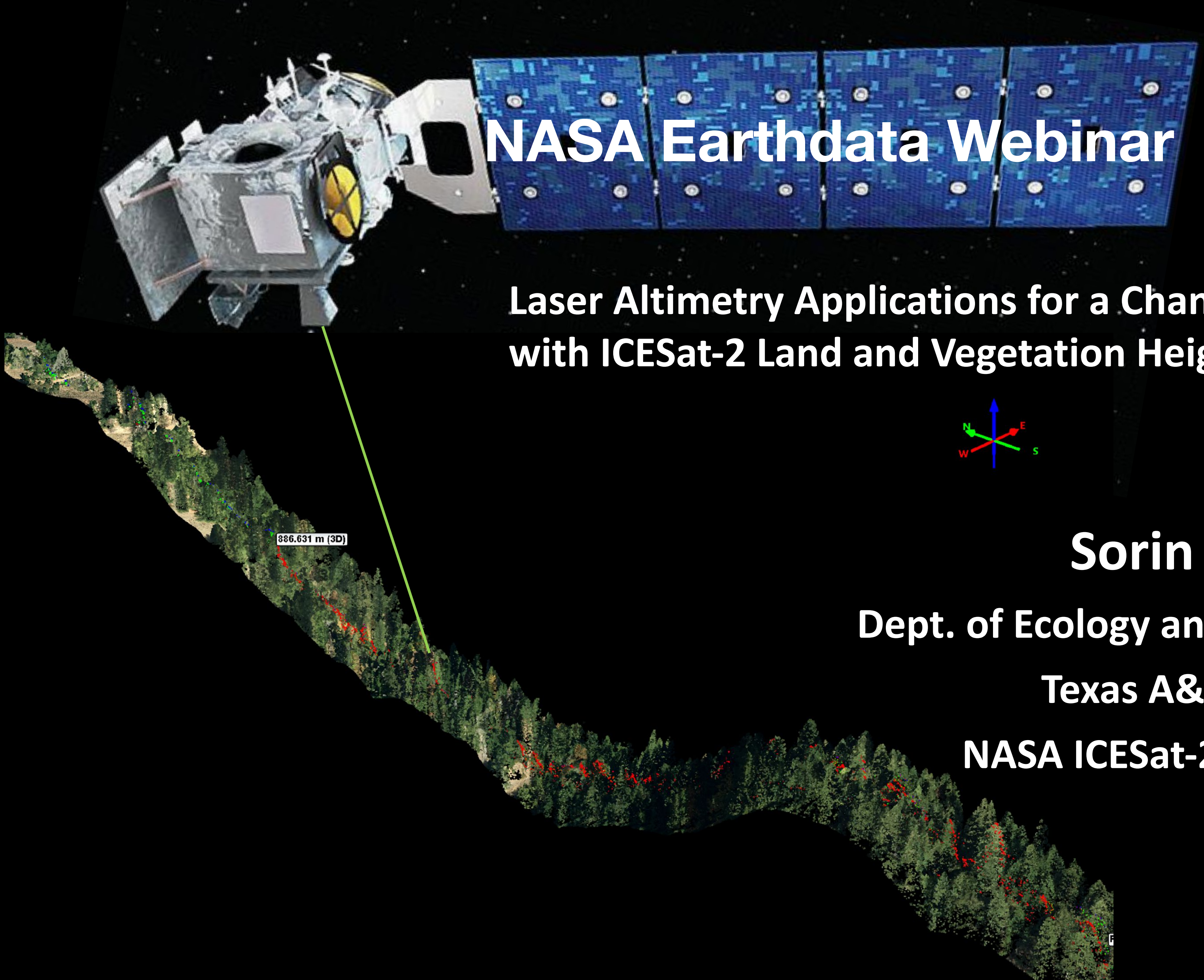
NASA Earthdata Webinar

Laser Altimetry Applications for a Changing World: Working with ICESat-2 Land and Vegetation Height Data

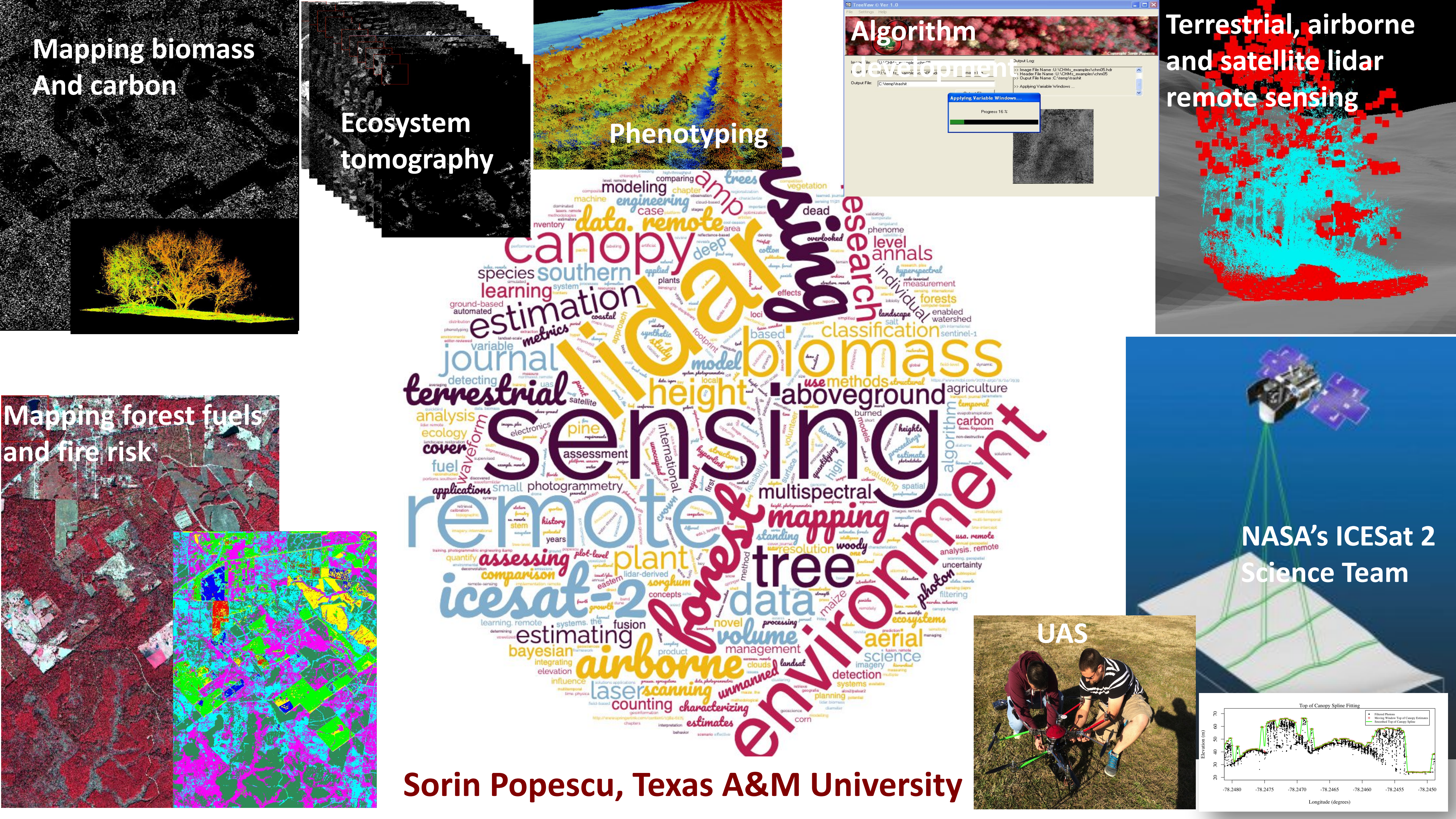


Sorin Popescu

Dept. of Ecology and Conservation Biology

Texas A&M University

NASA ICESat-2 Science Team PI

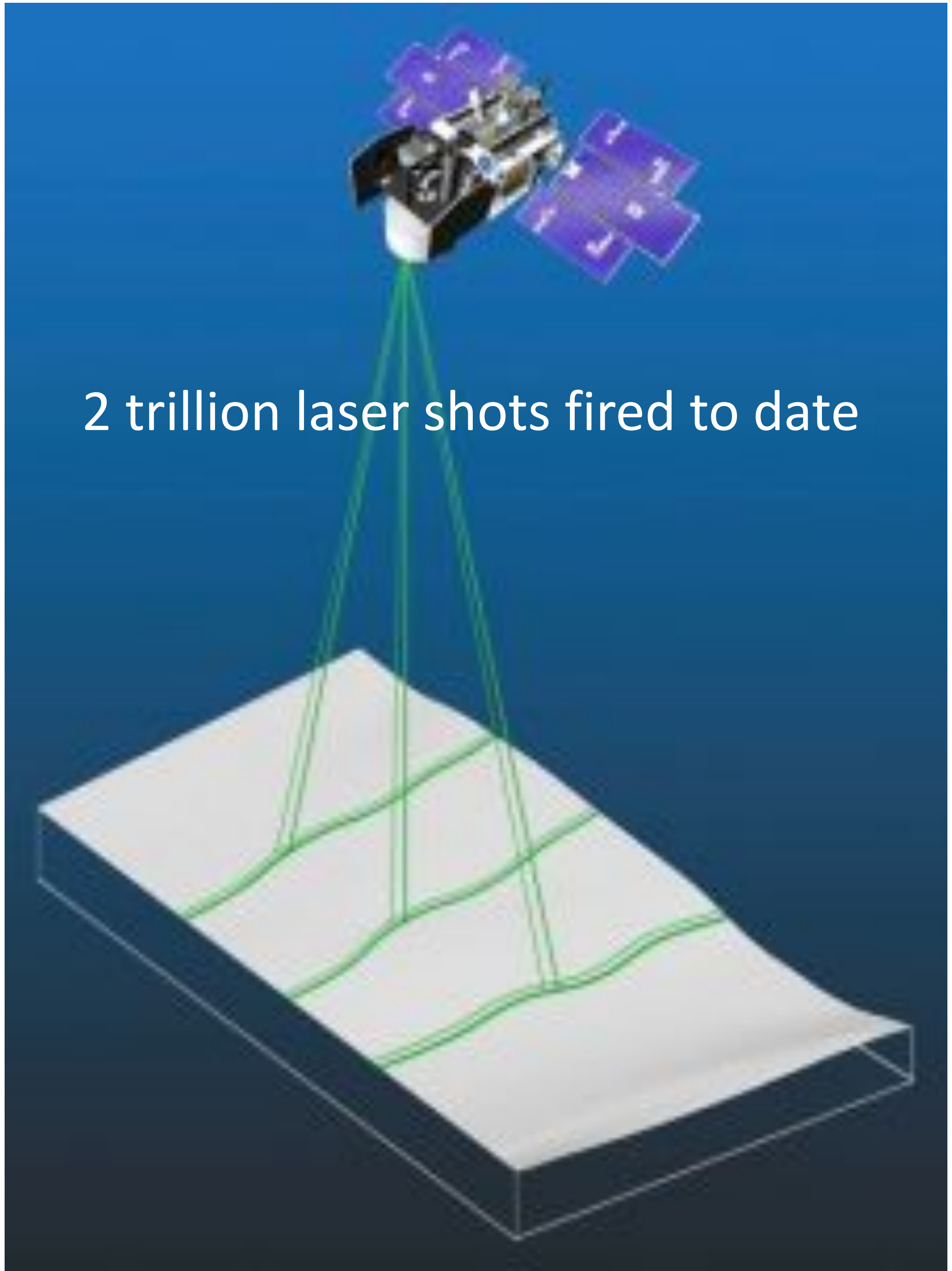

Mapping biomass
And carbon
Ecosystem
tomography
Phenotyping
Algorithm
development
Terrestrial, airborne
and satellite lidar
remote sensing
Mapping forest fuels
and fire risk
NASA's ICESat 2
Science Team
UAS
Top of Canopy Spline Fitting
Elevation (m)
Longitude (degrees)
sensing
remote
lidar
biomass
environment
forest
tree
canopy
icesat-2
airborne
aboveground
height
estimation
terrestrial
journal
mapping
multispectral
data
plant
research
imaging
Sorin Popescu, Texas A&M University

ICESat 2 – since Sept 15, 2018
Spaceborne photon-counting lidar

http://icesat.gsfc.nasa.gov/icesat2/

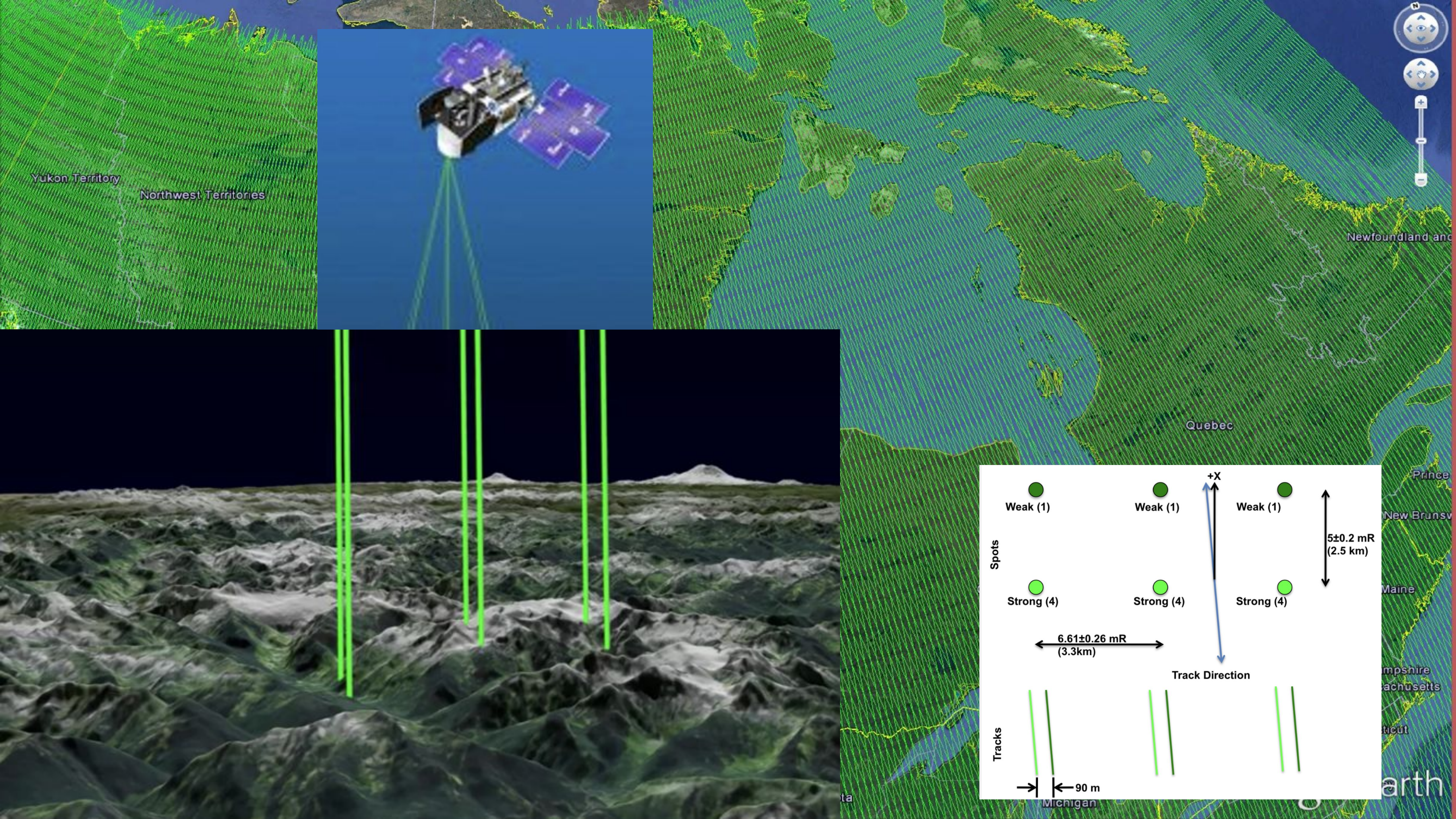
Science Objectives:

- **Measure melting ice sheets and investigate how this effects sea level rise,**
- **Measure and investigate changes in the mass of ice sheets and glaciers,**
- **Estimate and study sea ice thickness,**
- **Measure the height of vegetation in forests and other ecosystems worldwide.**



Why should you care about canopy height?

- Forests are the major terrestrial carbon storage and sink ecosystems.
- Canopy height is one of the strong predictors or vegetation biomass/carbon
- The forest canopy is the functional interface between 90% of Earth's terrestrial biomass and the atmosphere (source)
- Forest canopies are home to an estimated 50% of terrestrial biodiversity (source)
- ATL-08 is the most downloaded ICESat-2 product

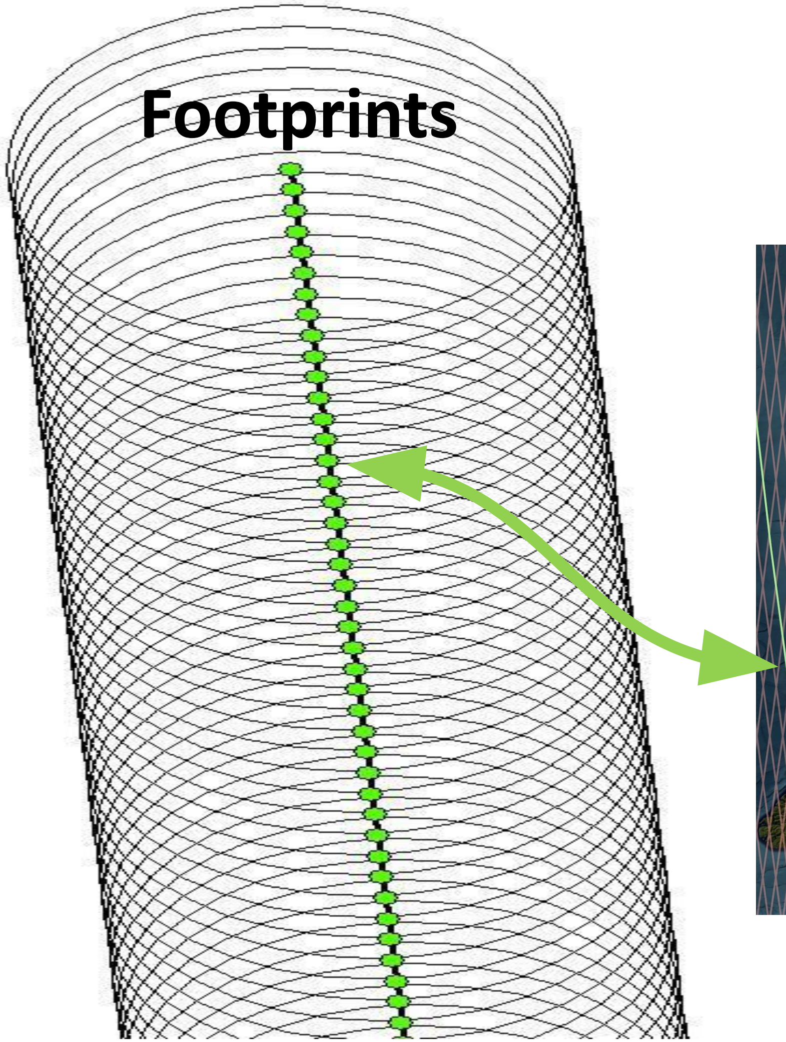


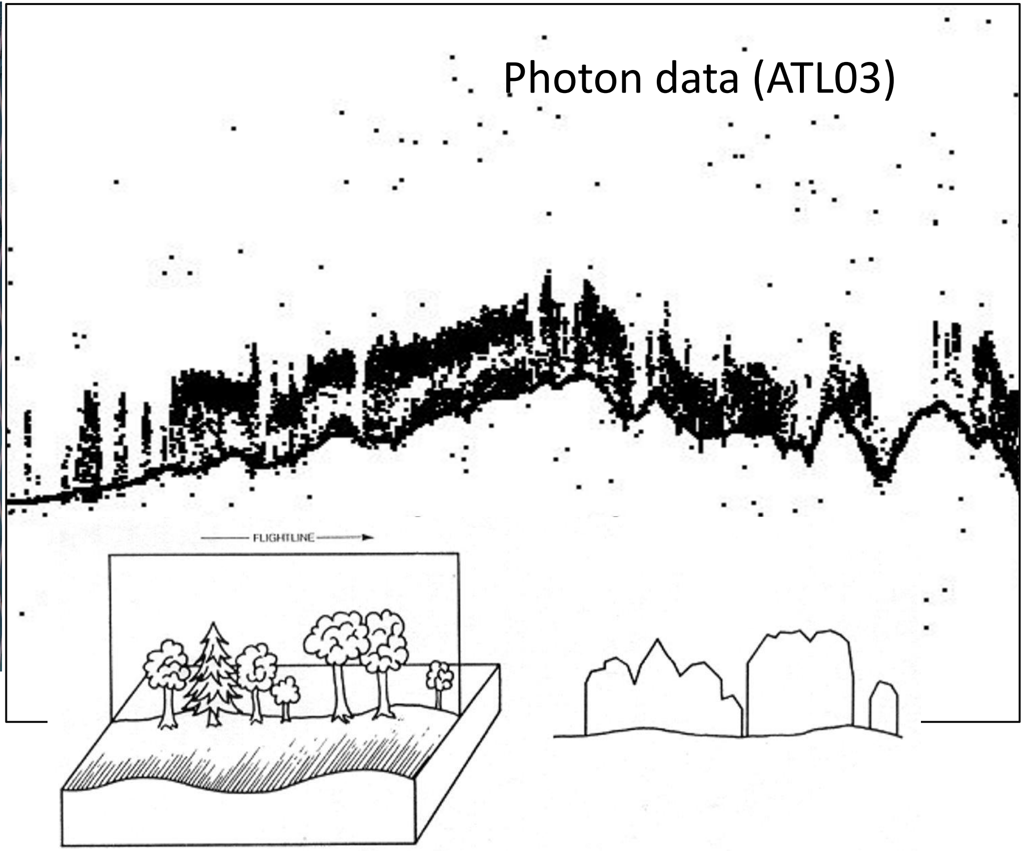
Yukon Territory
Northwest Territories
Newfoundland and
Quebec
Prince
New Brunsw
Maine
mpshire
achusetts
ticut
Michigan
+X
Weak (1)
Weak (1)
Weak (1)
Spots
Strong (4)
Strong (4)
Strong (4)
5±0.2 mR
(2.5 km)
6.61±0.26 mR
(3.3km)
Track Direction
Tracks
90 m

ICESAT 2 tracks over New Zealand

10 kHz laser pulses
500 km orbit altitude

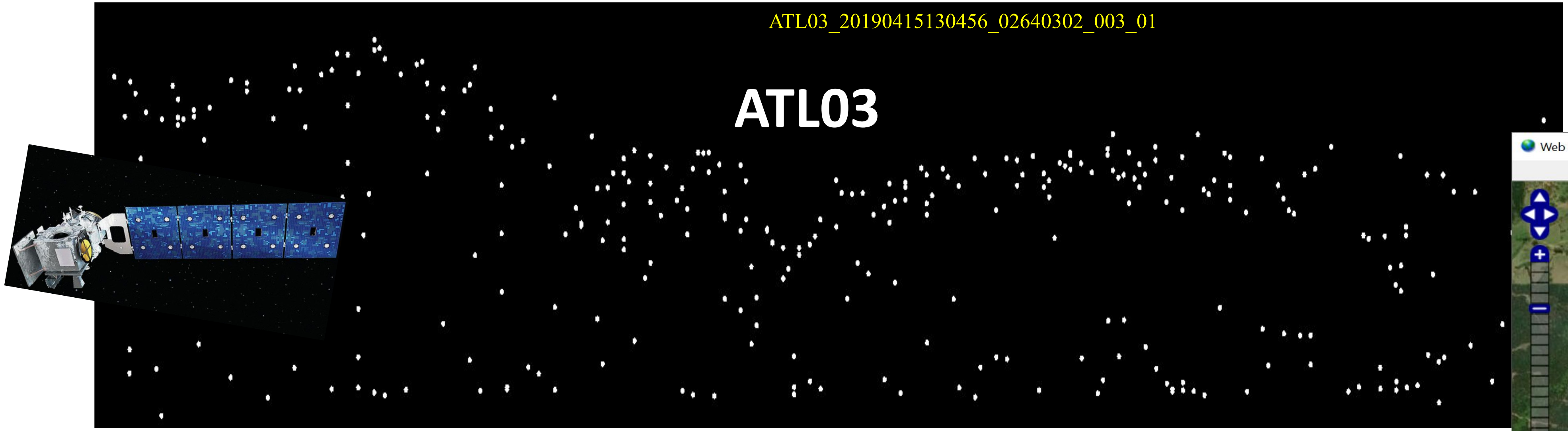
13-14 m footprints spaced 70 cm along track; 3.3 km beam separation; 90-m offset strong vs. weak beams

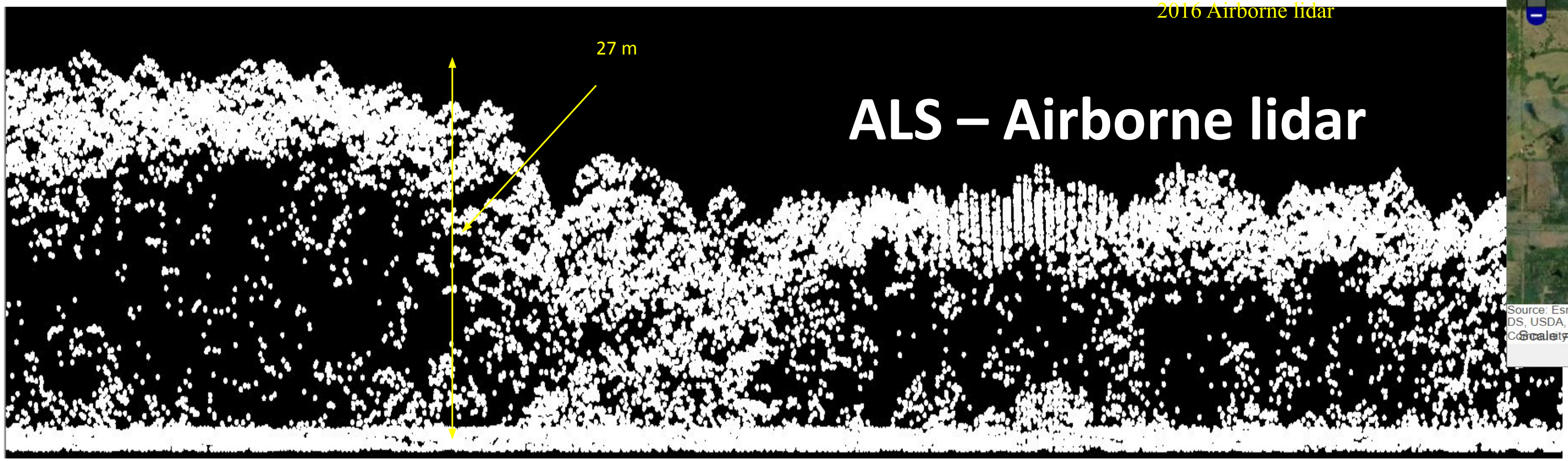


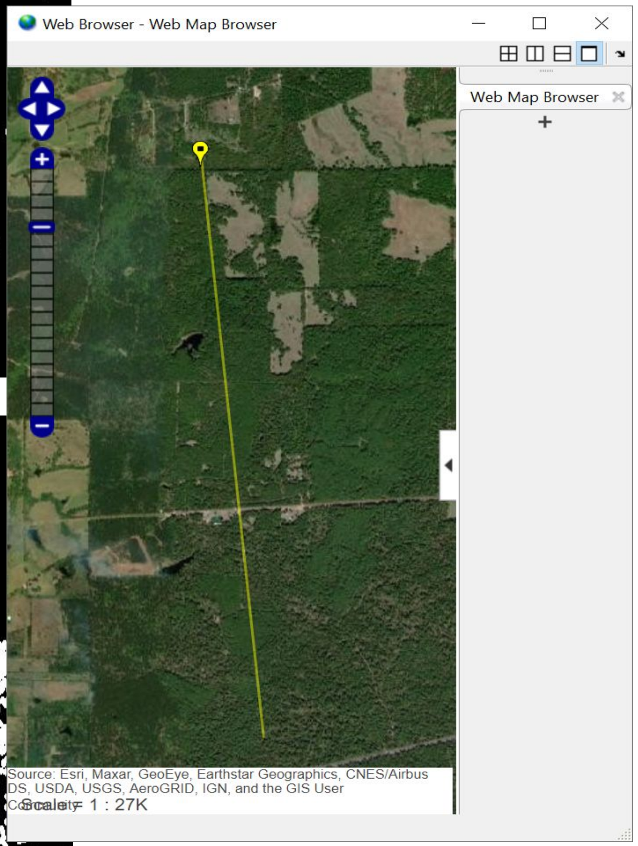


Canopy profile area (Nelson, 1984)

Examples of ICESat-2 data

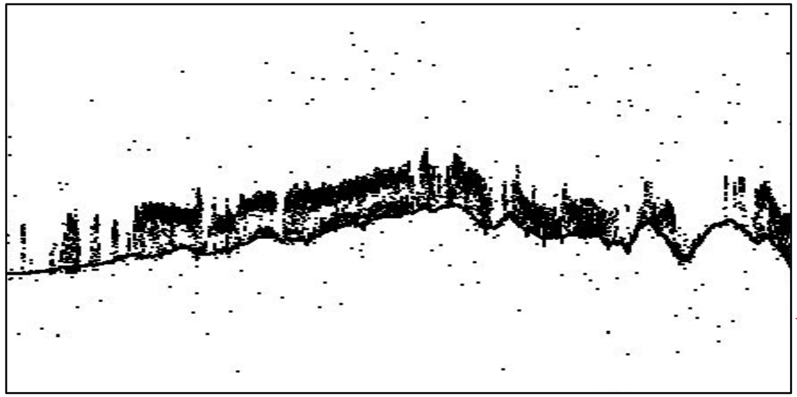


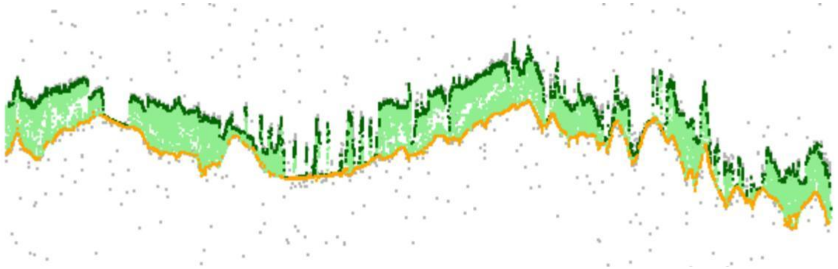




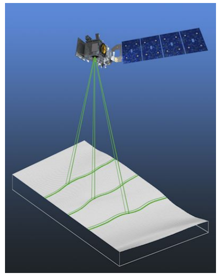
Web map link

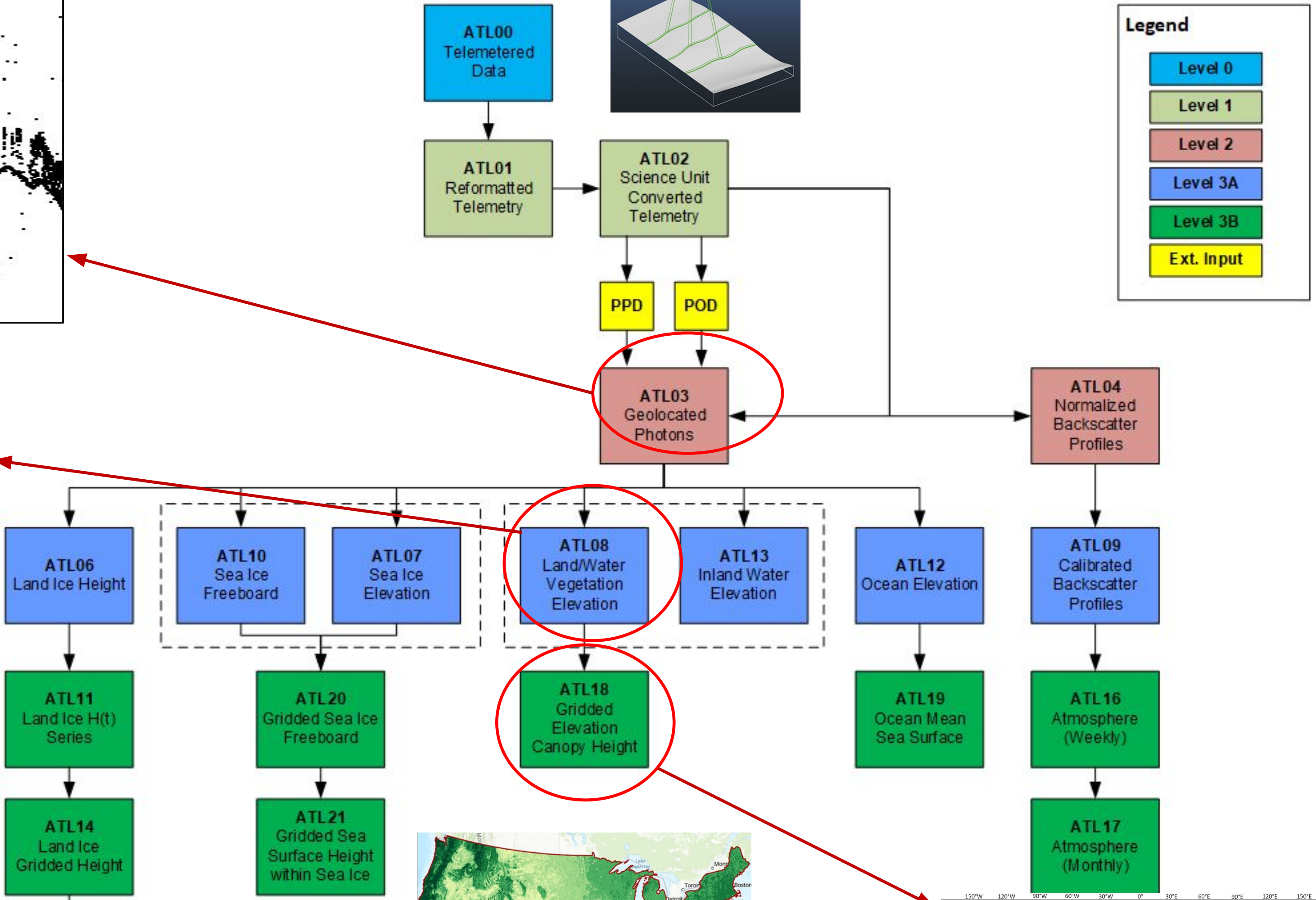
ICESat-2 data products

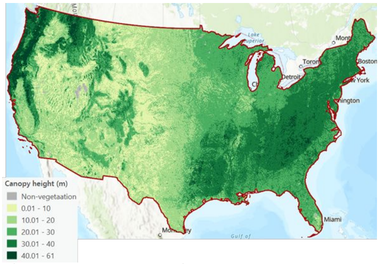


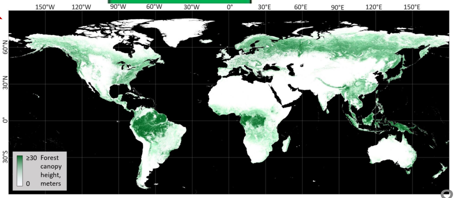


Canopy and terrain heights in 100m segments









https://nsidc.org/data/icesat-2/data-sets

ATL08 - L3A Land and Vegetation Height, Version 6

- Contains along-track heights above the WGS84 ellipsoid for the ground and canopy surfaces.
- The canopy and ground surfaces are processed in ***fixed 100 m*** data segments, which typically contain more than 100 signal photos.
- Data provided as granules (files, HDF5) that span about 1/14th of an orbit.

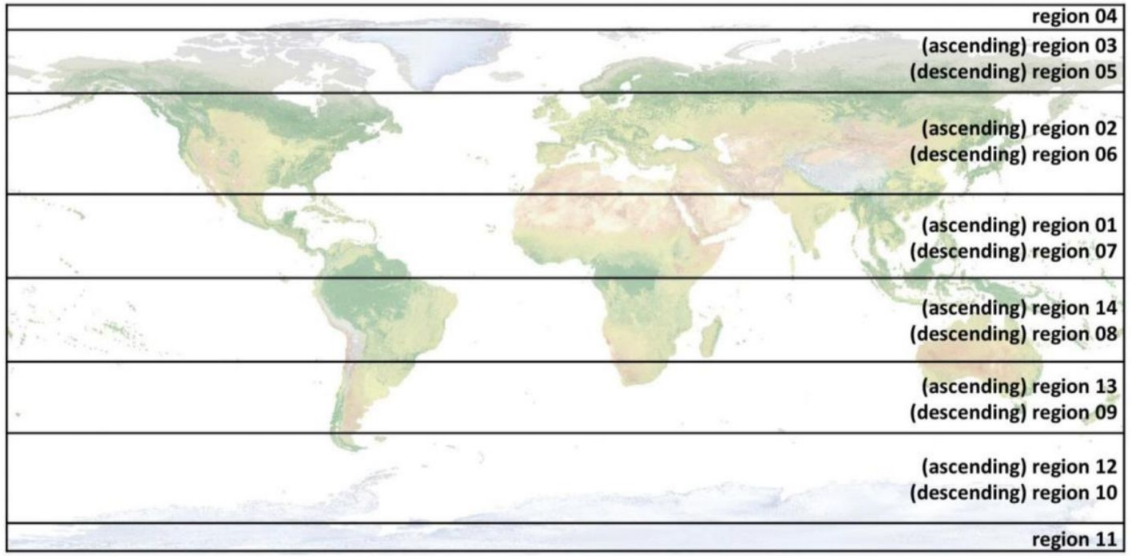
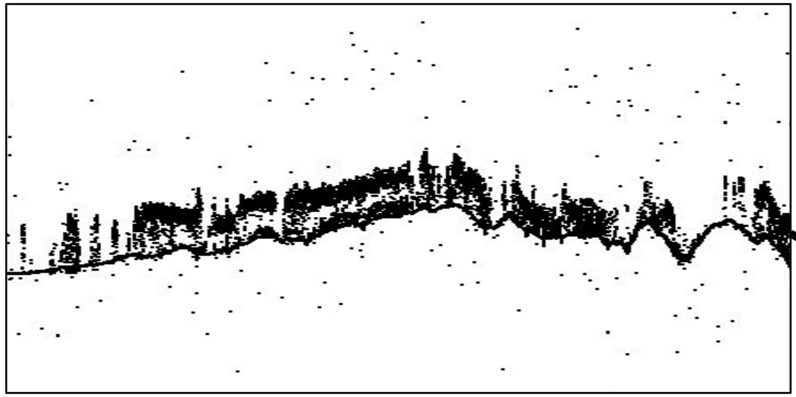


Figure 1. ATL08 region/granule boundaries.

Photon classification



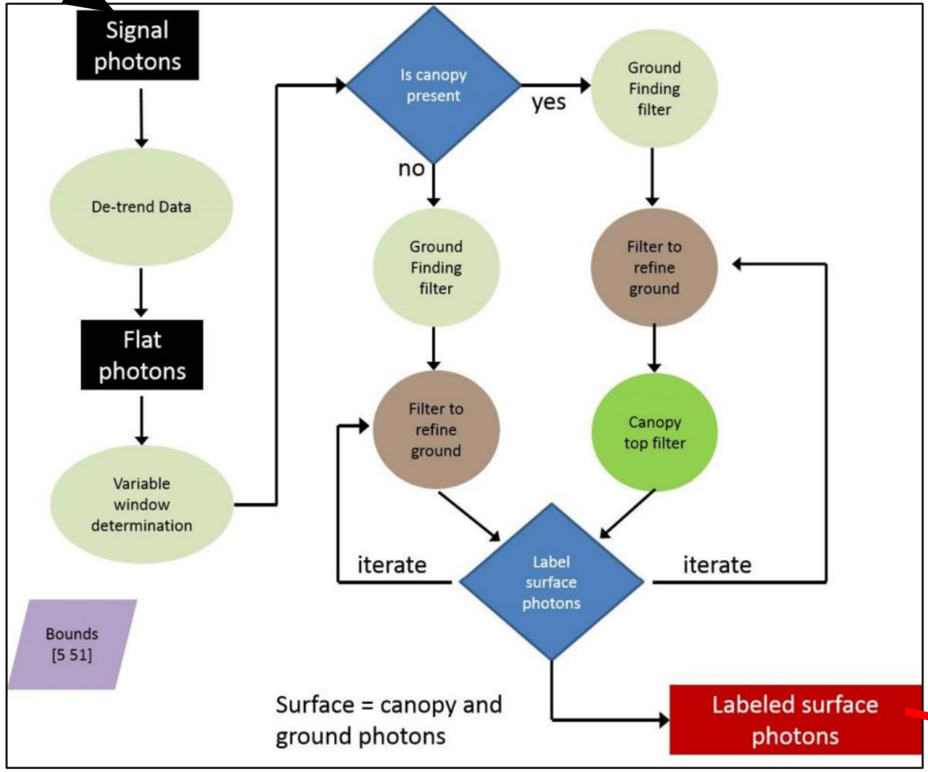
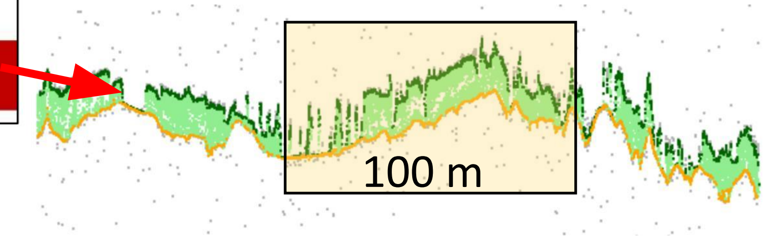


Figure 5. Flowchart of ATL08 Surface Finding.

Photon classes

- Ground
- Canopy
- Top of canopy

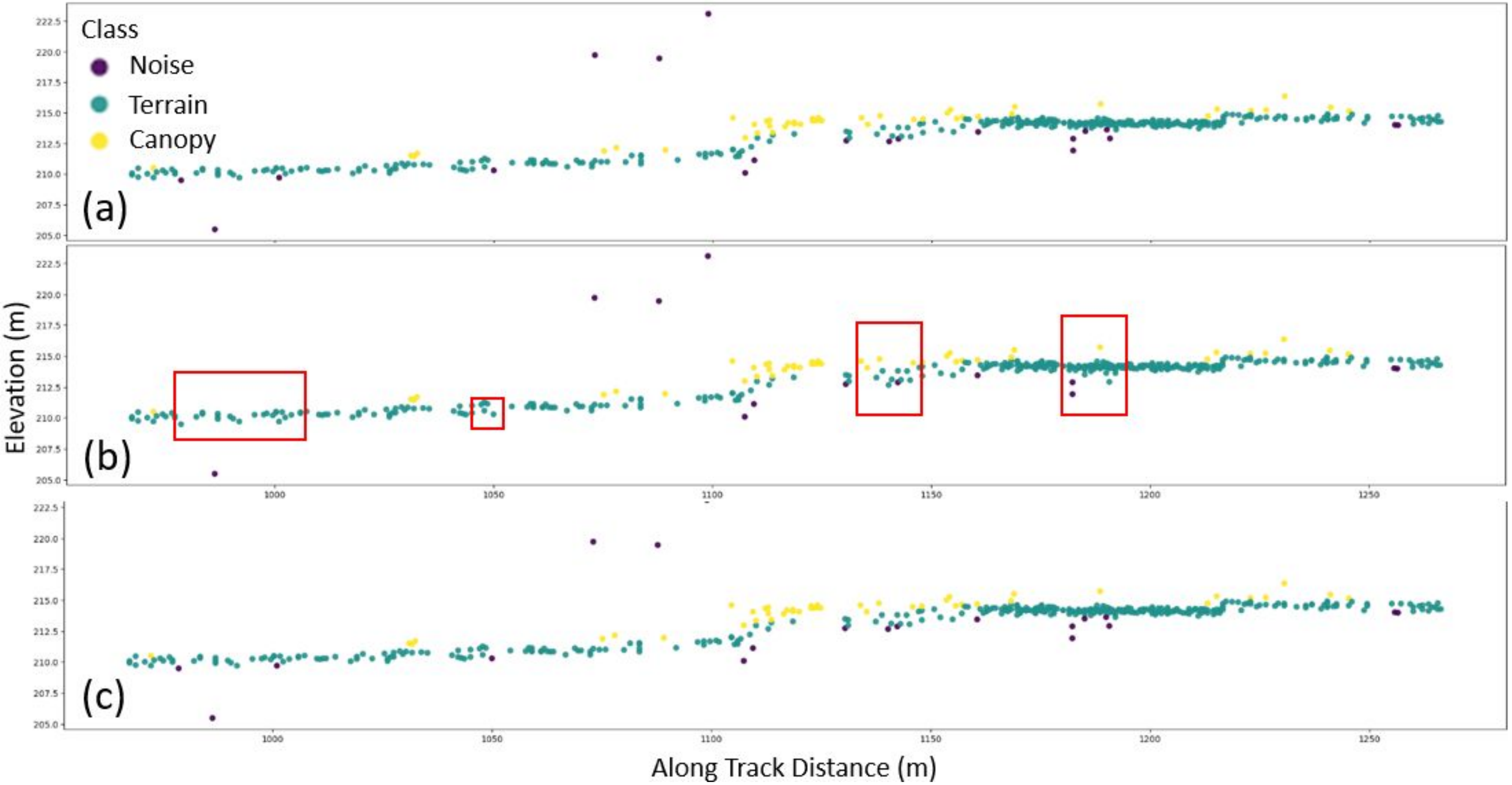


Vegetation parameters

Differential, Regressive, and Gaussian Adaptive Nearest Neighbor (DRAGANN)

Other photon classification approaches and YAPC

- **Random Forest reclassification result**



Visualization of photon classifications for different models for site CA_A:

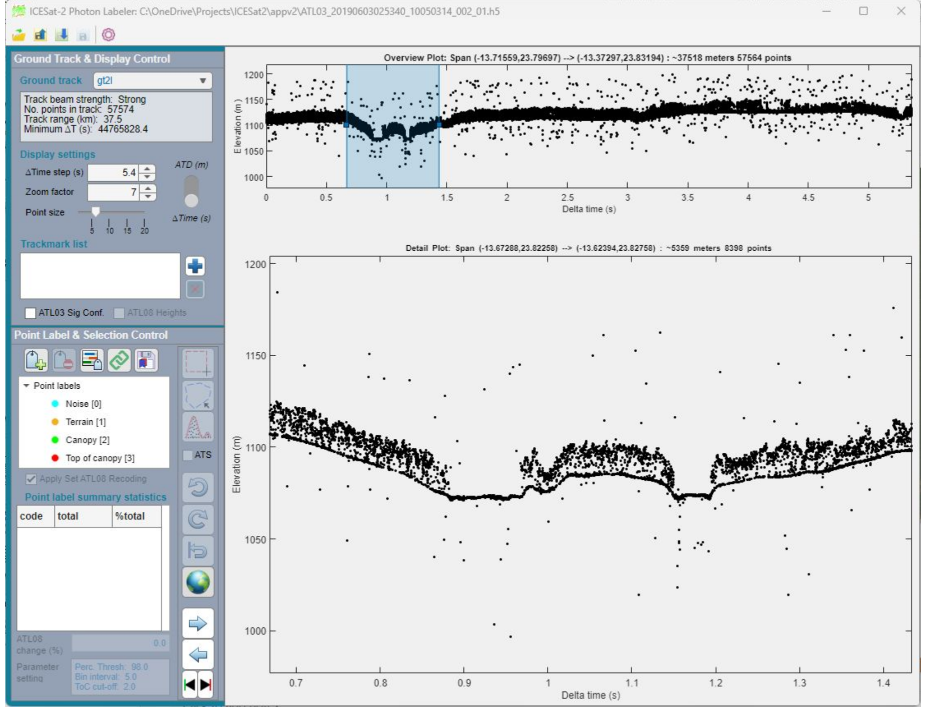
(a) RF1
(b) RF2
(c) ATL08 data

Different classifications are highlighted in red.

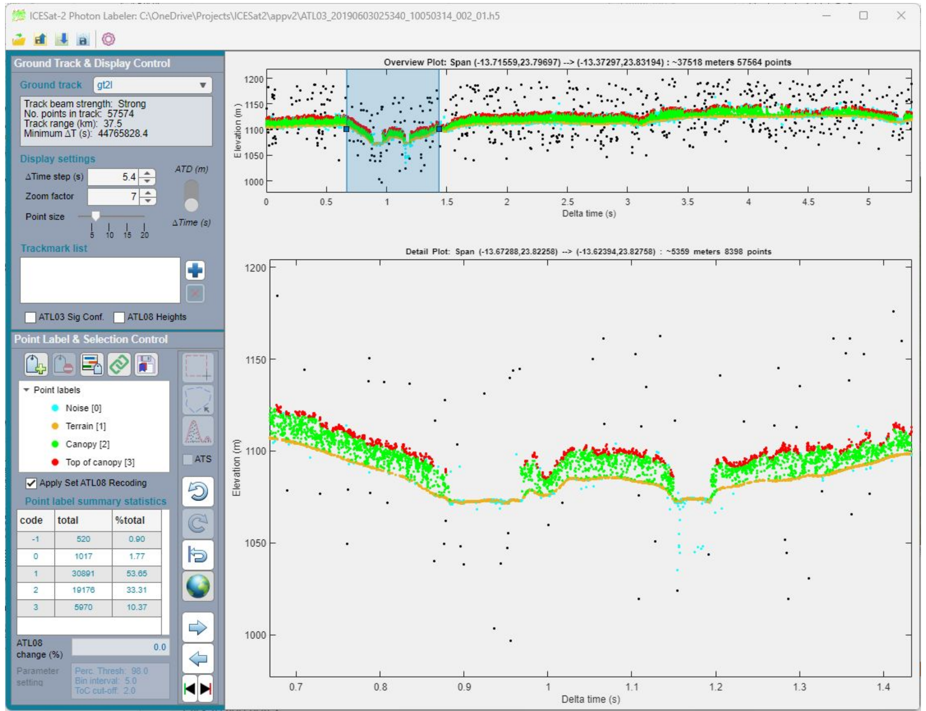
Source: Mei-Kuei Lu, TAMU

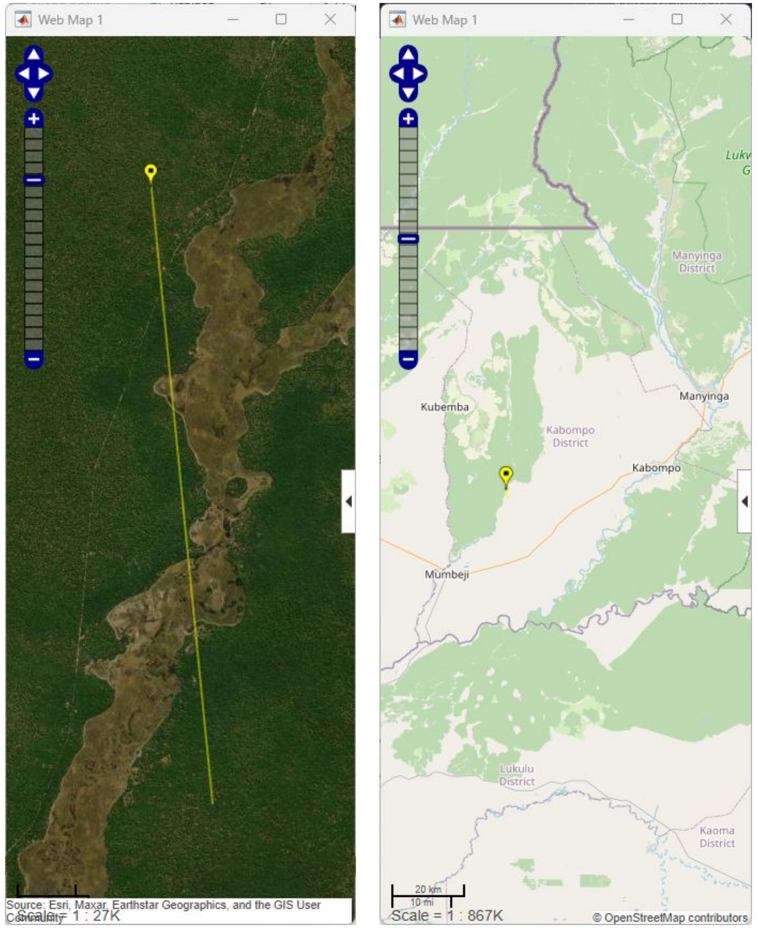
Data examples

Raw ICESat-2 ATL03 point cloud



Classified ICESat-2 ATL03 point cloud

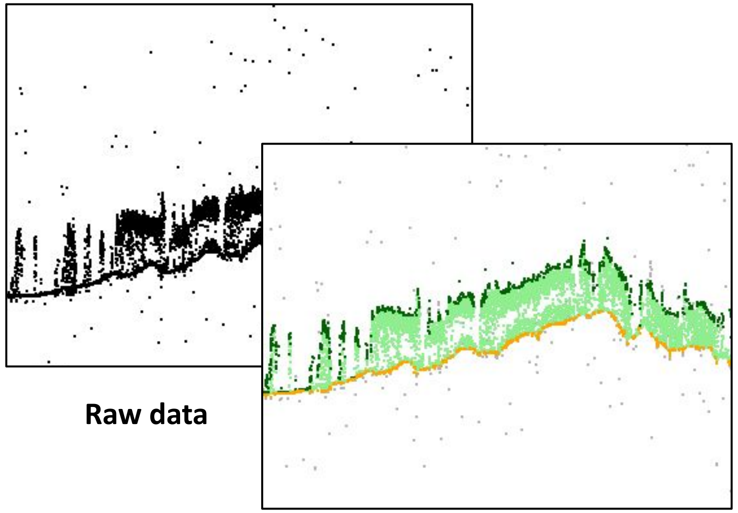




Web maps showing track segment

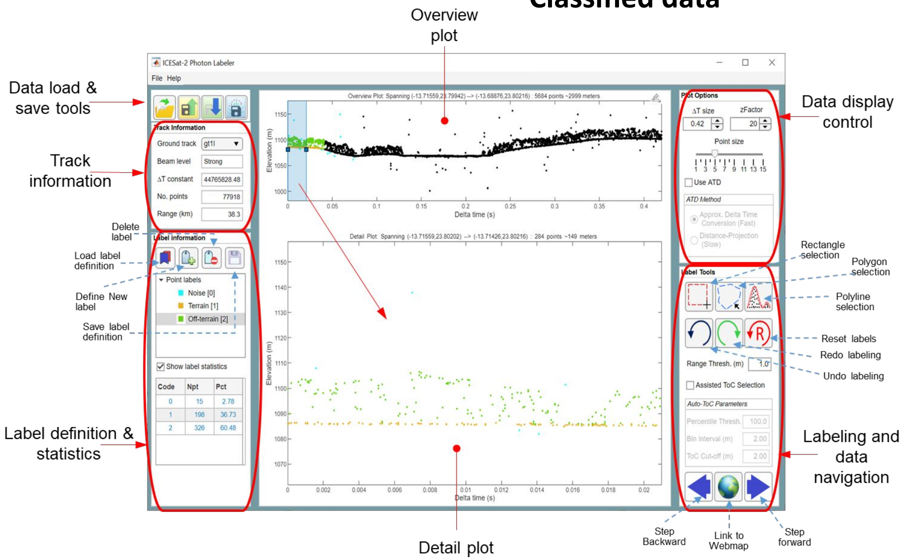
LASERS Lab ICESat-2 software tools. https://lasers.tamu.edu/

- Filtering and classification of photons
- Visualization and manual labeling of photons
- Miscellaneous routines for working with ICESat-2 data
  - Format conversion
  - Height metric extraction
  - Track generation
  - Custom-length ATL08 segment generation, e.g., 30m



Raw data

Classified data



PhotonLabeler

https://github.com/Oht0nger/PhoLabeler

Malambo, L.; Popescu, S. PhotonLabeler: An Inter-Disciplinary Platform for Visual Interpretation and Labeling of ICESat-2 Geolocated Photon Data. Remote Sens. 2020, 12, 3168.

Ice, Cloud, and Land Elevation Satellite 2 (ICESat-2)

Algorithm Theoretical Basis Document (ATBD) for Land - Vegetation Along-Track Products (ATL08)

Contributions by Land/Vegetation SDT Team Members and ICESat-2 Project Science Office

(Amy Neuenschwander, Katherine Pitts, Benjamin Jelley, John Robbins, Jonathan Markel, Sorin Popescu, Ross Nelson, David Harding, Dylan Pederson, Brad Klotz, and Ryan Sheridan)

ATBD prepared by Amy Neuenschwander

01 July 2022
(This ATBD Version corresponds to release 006 of the ICESat-2 ATL08 data)

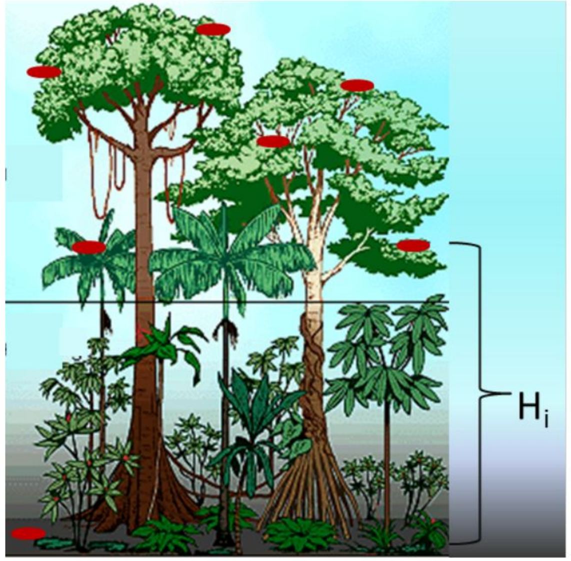


Figure 2.4. Illustration of canopy photons (red dots) interaction in a vegetated area. Relative canopy heights, H_i, are computed by differencing the canopy photon height from an interpolated terrain surface.

Table 2.2. Summary table of canopy parameters on ATL08.

Group	Data type	Description	Source
segment_id_beg	Integer	First along-track segment_id number in 100-m segment	ATL03
segment_id_end	Integer	Last along-track segment_id number in 100-m segment	ATL03
canopy_h_metrics_abs	Float	Absolute (H##) canopy height metrics calculated at the following percentiles: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95.	computed
canopy_h_metrics	Float	Relative (RH##) canopy height metrics calculated at the following percentiles:	computed

Table 2.2. Summary table of canopy parameters on ATL08.

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canopy_h_metrics	Float	Relative (RH##) canopy height metrics calculated at the following percentiles: 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95.	computed
h_canopy_abs	Float	98% height of all the individual absolute canopy heights (height above WGS84 ellipsoid) for segment.	computed
h_canopy	Float	98% height of all the individual relative canopy heights (height above terrain) for segment.	computed
h_canopy_20m	Float	98% height of all the individual relative canopy heights (height above terrain) for 20m geosegment.	
h_mean_canopy_abs	Float	Mean of individual absolute canopy heights within segment	computed
h_mean_canopy	Float	Mean of individual relative canopy heights within segment	computed
h_dif_canopy	Float	Difference between h_canopy and canopy_h_metrics(50)	computed
h_min_canopy_abs	Float	Minimum of individual absolute canopy heights within segment	computed
h_min_canopy	Float	Minimum of individual relative canopy heights within segment	computed
h_max_canopy_abs	Float	Maximum of individual absolute canopy heights within segment. Should be equivalent to H100	computed
h_max_canopy	Float	Maximum of individual relative canopy heights within segment. Should be equivalent to RH100	computed
h_canopy_uncertainty	Float	Uncertainty of the relative canopy height (h_canopy)	computed
canopy_openness	Float	STD of relative heights for all photons classified as canopy photons within the segment to provide inference of canopy openness	computed
toc_roughness	Float	STD of relative heights of all photons classified as top of canopy within the segment	computed
h_canopy_quad	Float	Quadratic mean canopy height	computed
n_ca_photons	Integer4	Number of canopy photons within 100 m segment	computed
n_toc_photons	Integer4	Number of top of canopy photons within 100 m segment	computed
centroid_height	Float	Absolute height above reference ellipsoid associated with the centroid of all signal photons	computed
canopy_rh_conf	Integer	Canopy relative height confidence flag based on percentage of ground and canopy photons within a segment: 0 (<5% canopy), 1 (>5% canopy, <5% ground), 2 (>5% canopy, >5% ground)	computed
subset_can_flag	Integer	Quality flag indicating the canopy photons populating the 100 m segment statistics are derived from less than 100 m worth of photons	computed
photon_rate_can	Float	Photon rate of canopy photons within each 100 m segment	computed
photon_rate_can_nr	Float	Noise removed photon canopy rate within each 100 m segment	computed
can_noise	integer	Number of noise photons calculated that fall within the canopy height for each 100 m segment based on ATL03 background rate parameters	computed

Validation of canopy heights and terrain elevation

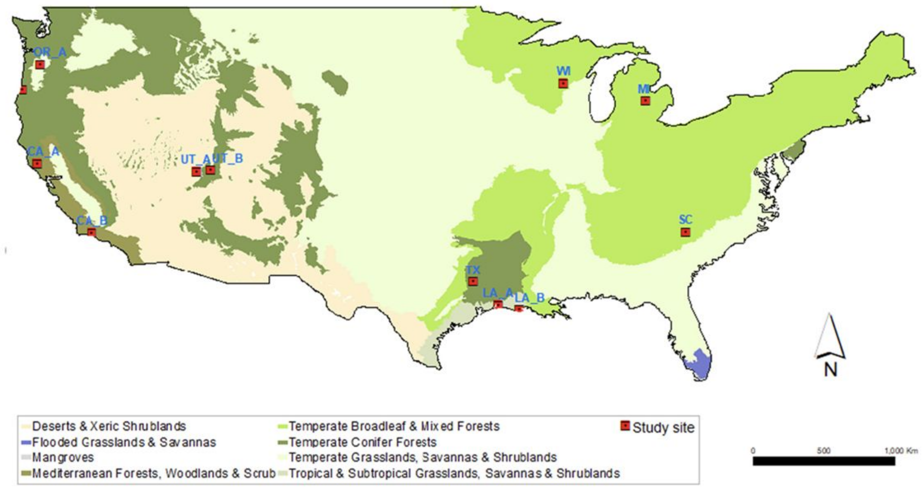

Fig. 1. Study sites across the contiguous United States on RESOLVE Ecoregions 2017 base map (https://ecoregions2017.appspot.com/)(Dinerstein et al., 201

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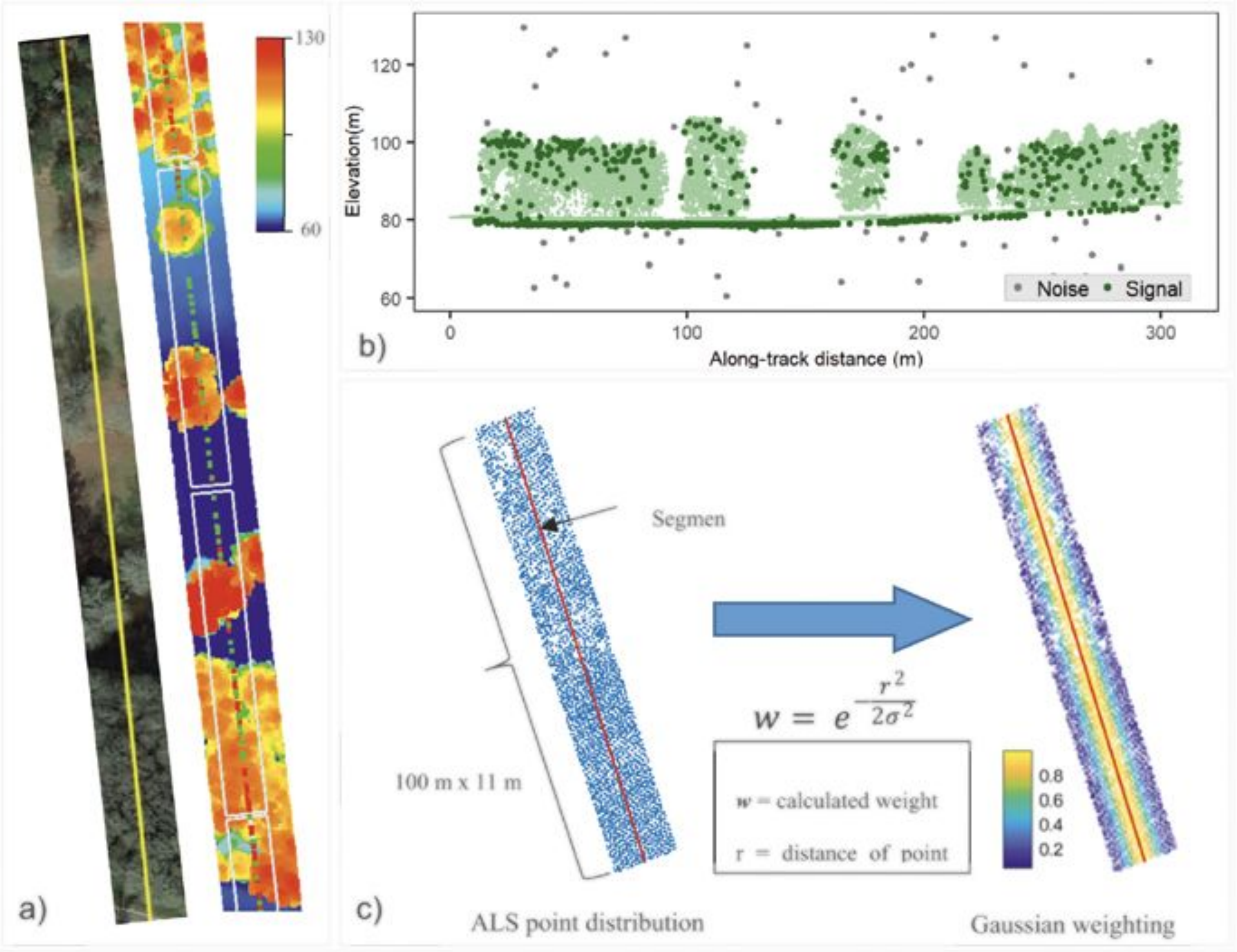
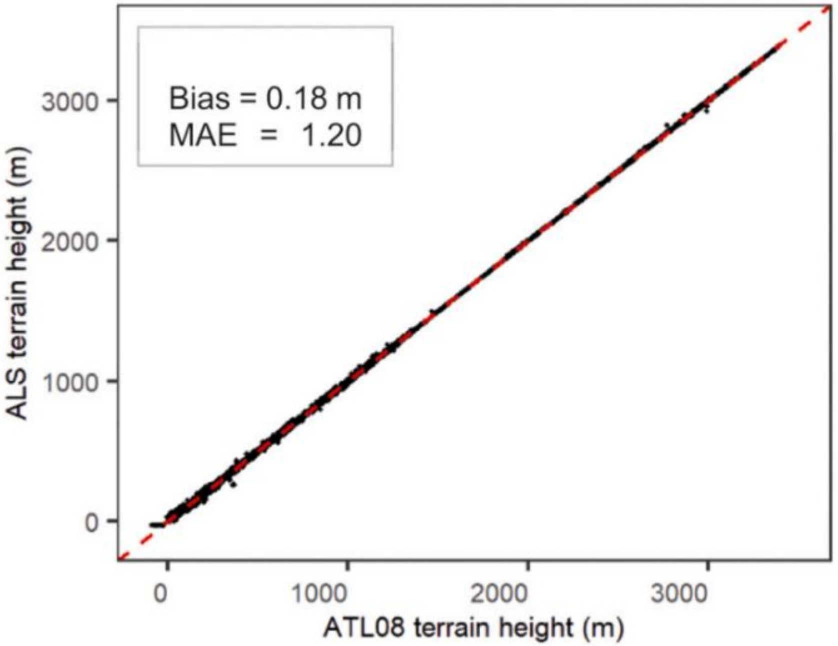
Assessing the agreement of ICESat-2 terrain and canopy height with airborne lidar over US ecozones

Lonesome Malambo*, Sorin C. Popescu



Validation with ALS datasets



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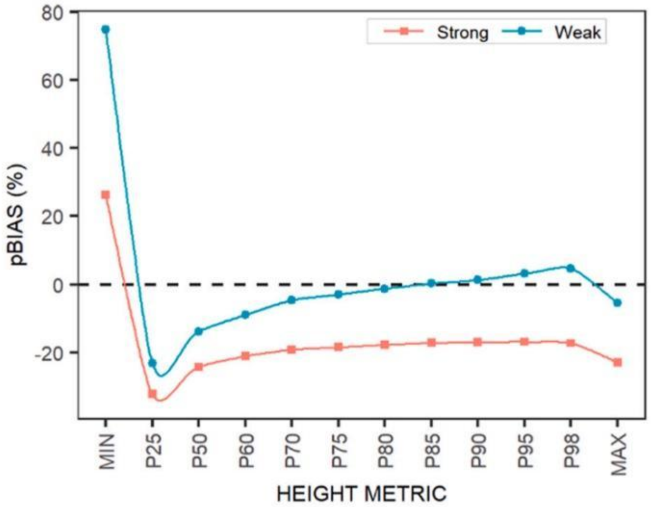
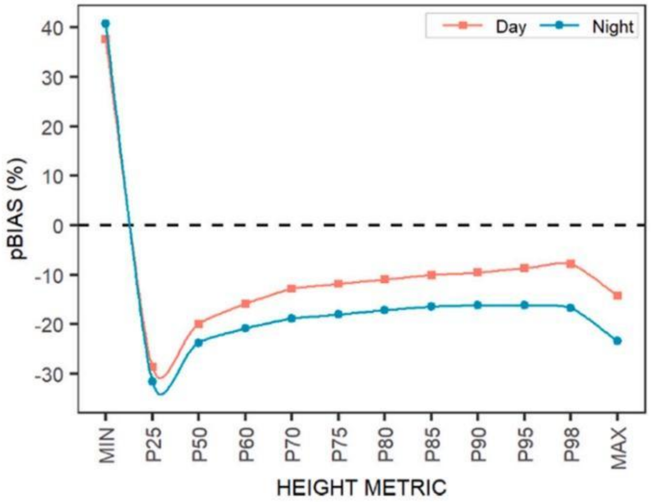
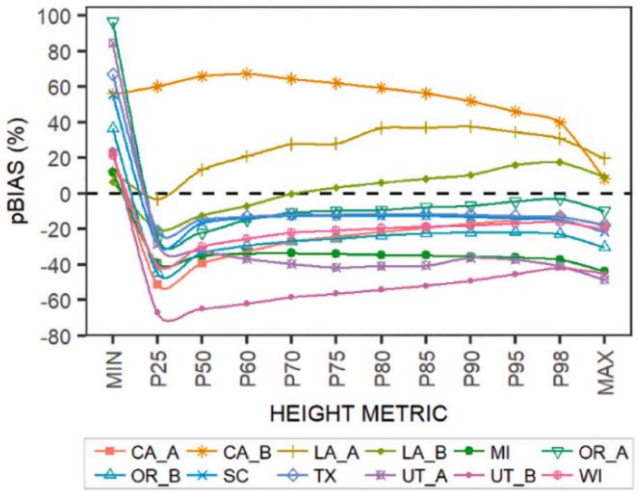
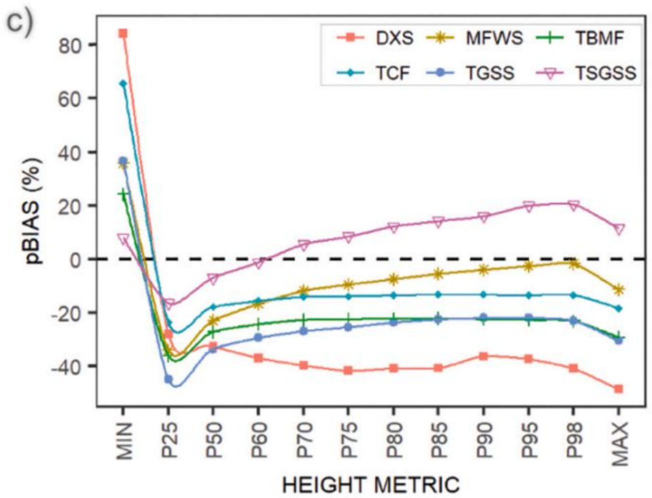


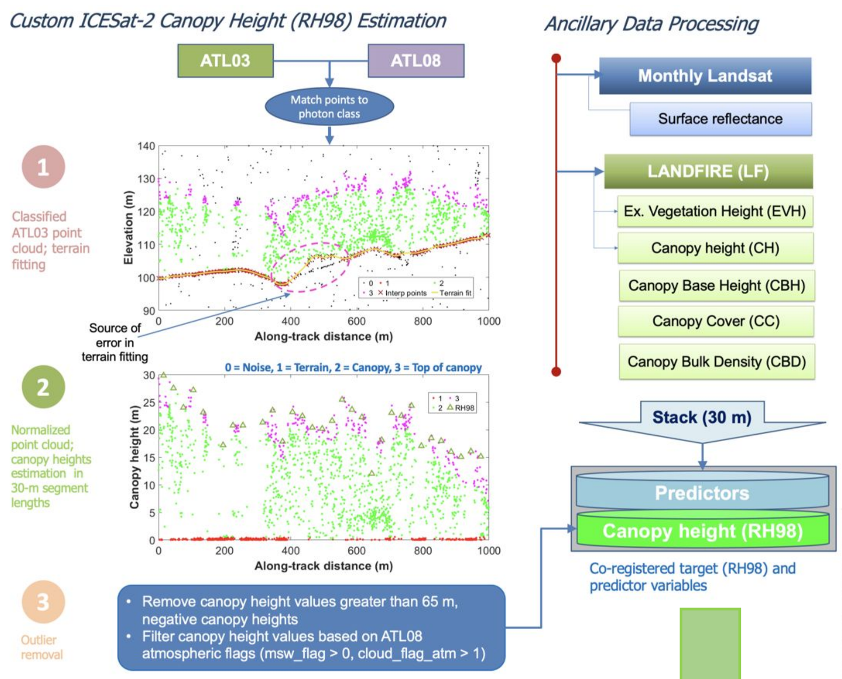


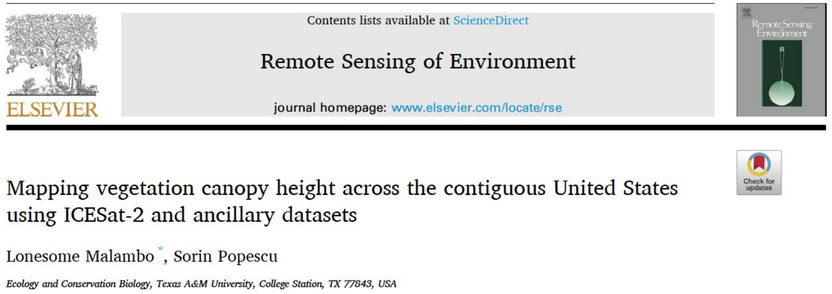
L. Malambo and S.C. Popescu





From transects to a wall-to-wall maps of canopy height

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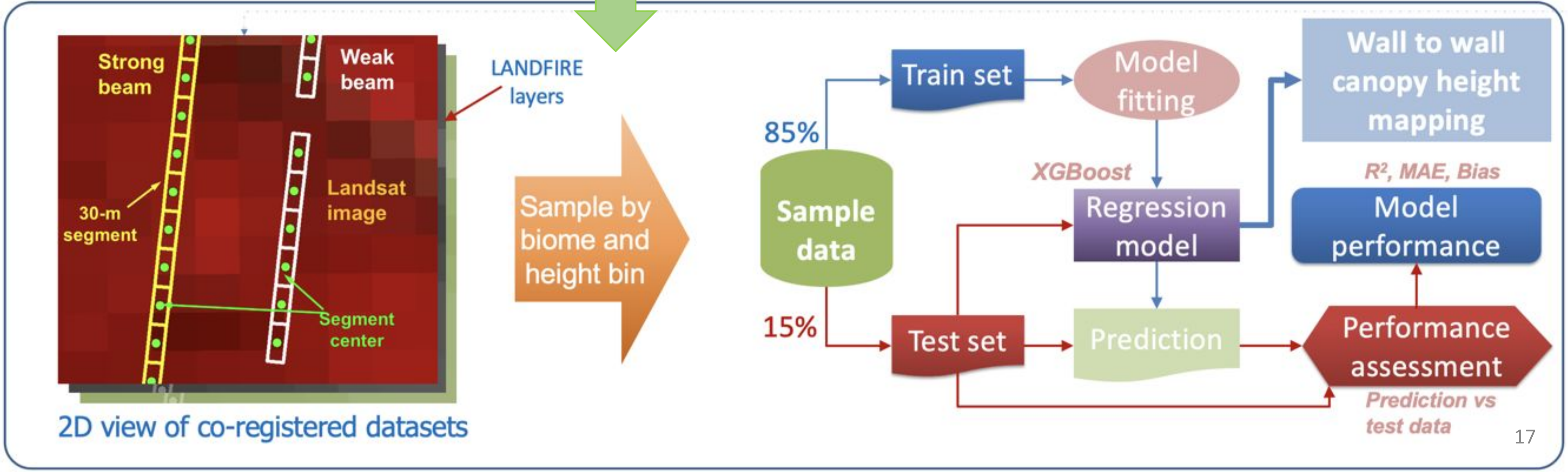
Mapping vegetation canopy height across the contiguous United States using ICESat-2 and ancillary datasets

Lonesome Malambo*, Sorin Popescu

Ecology and Conservation Biology, Texas A&M University, College Station, TX 77843, USA

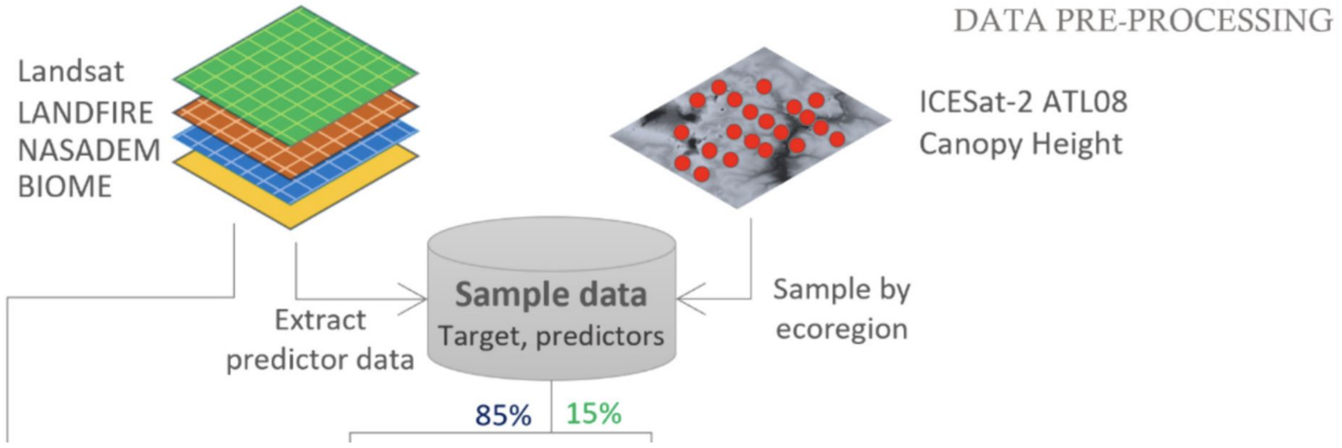


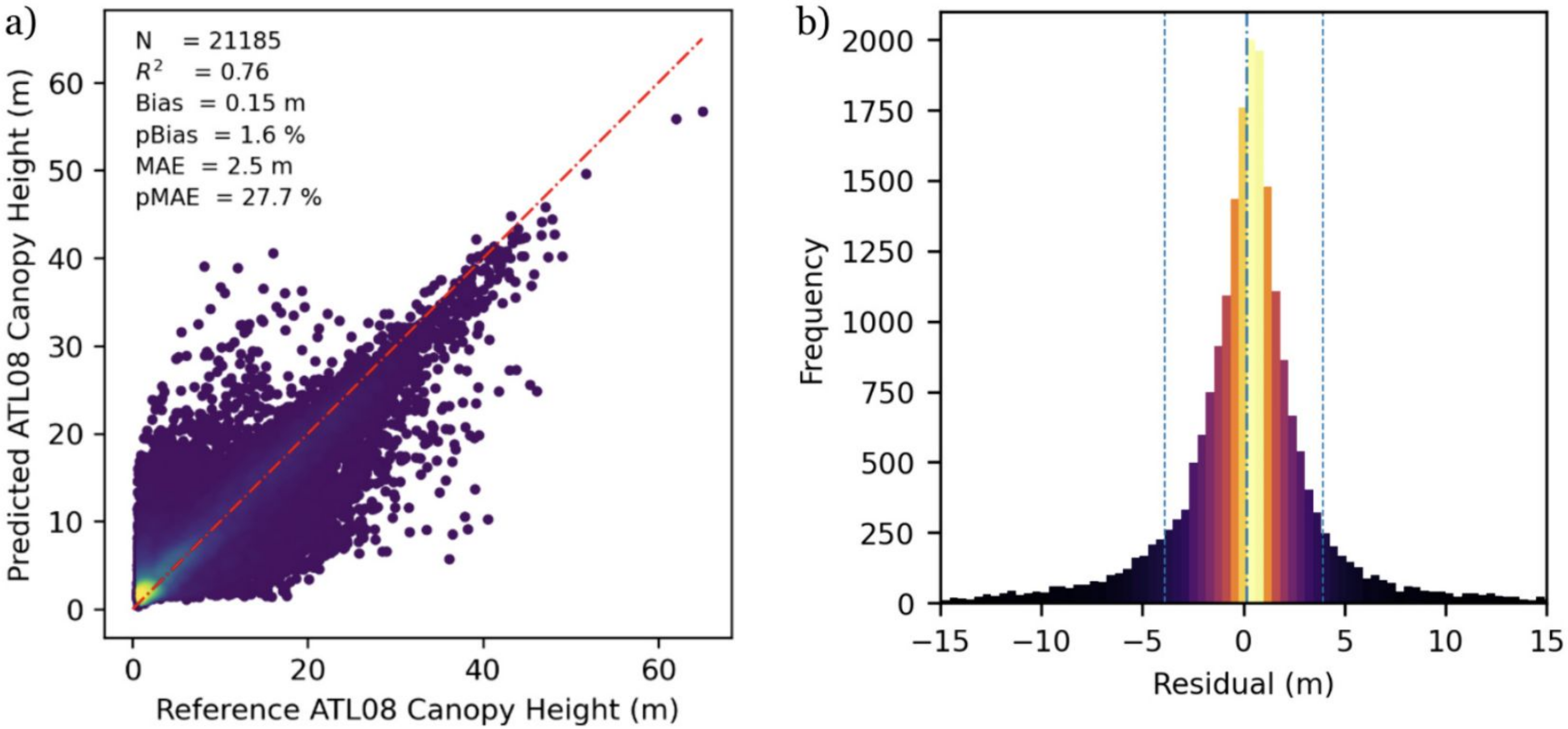
Sampling of ATL08 canopy heights

Summary of samples selected by biome.

Biome	Biome code	No. samples selected		
		Total	Training	Test
Deserts & Xeric Shrublands	DXS	14,482	12,310	2172
Flooded Grasslands & Savannas	FGS	7718	6560	1158
Mediterranean Forests, Woodlands & Scrub	MFWS	7077	6015	1062
Mangroves	MGV	5307	4511	796
Temperate Broadleaf & Mixed Forests	TBMF	28,508	24,232	4276
Temperate Conifer Forests	TCF	29,492	25,068	4424
Temperate Grasslands, Savannas & Shrublands	TGSS	34,934	29,694	5240
Tropical & Subtropical Coniferous Forests	TSCF	6075	5164	911
Tropical & Subtropical Grasslands, Savannas & Shrublands	TSGSS	7636	6491	1145
Overall		141,229	120,045	21,184

Model performance with hold-out data





Variable importance

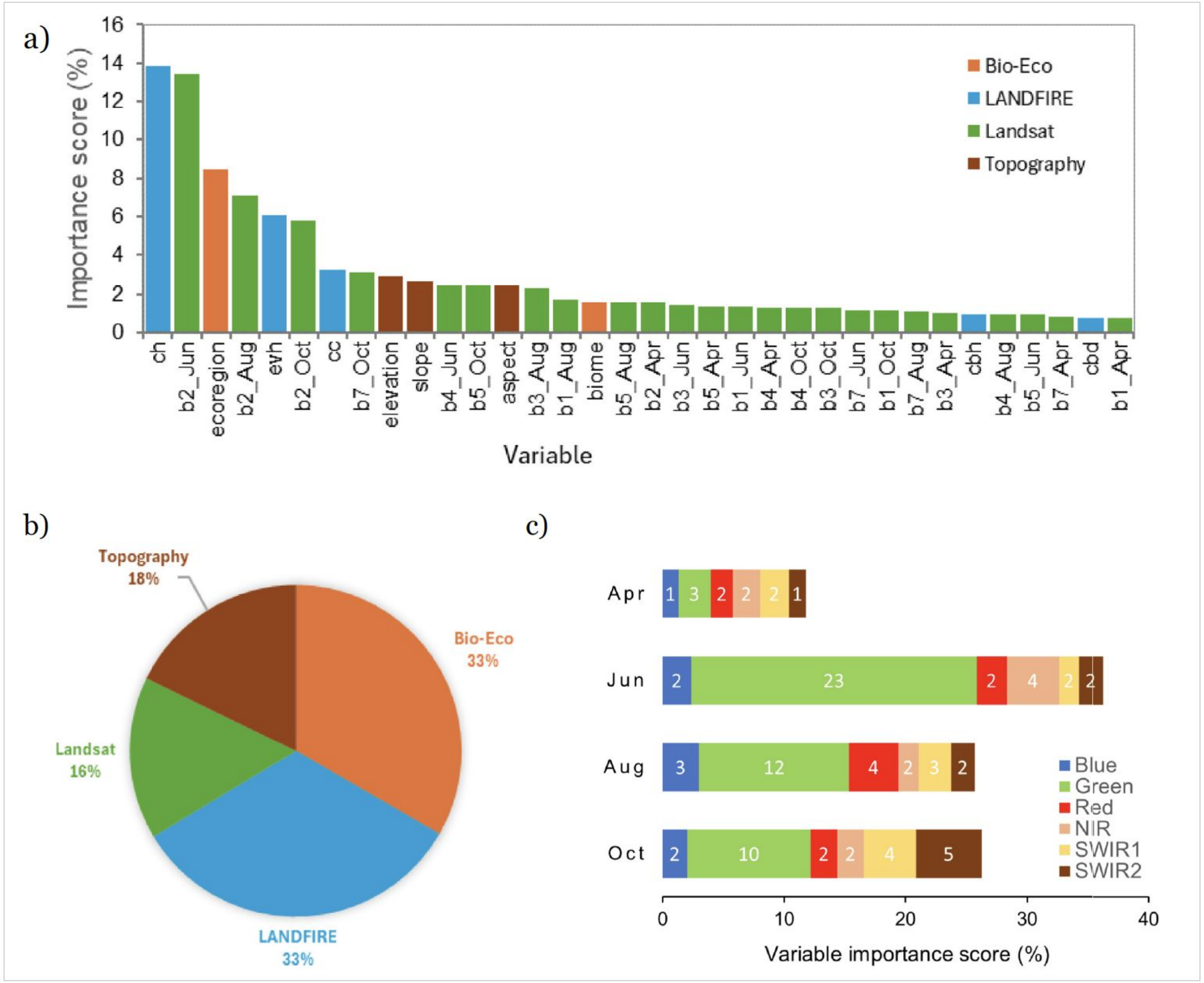


Fig. 7. Variable importance assessment for the fitted canopy height regression model: a) Individual variable importance ranking. The variables (predictors) are grouped into four themes or sources (Landsat reflectance, LANDFIRE, Biome-Ecoregion (Bio-Eco) and Topography) and colour-coded accordingly, b) Overall variable importance contribution by data source, c) Landsat variable importance ranking by month and spectral band.

Validation locations per biomes in the US

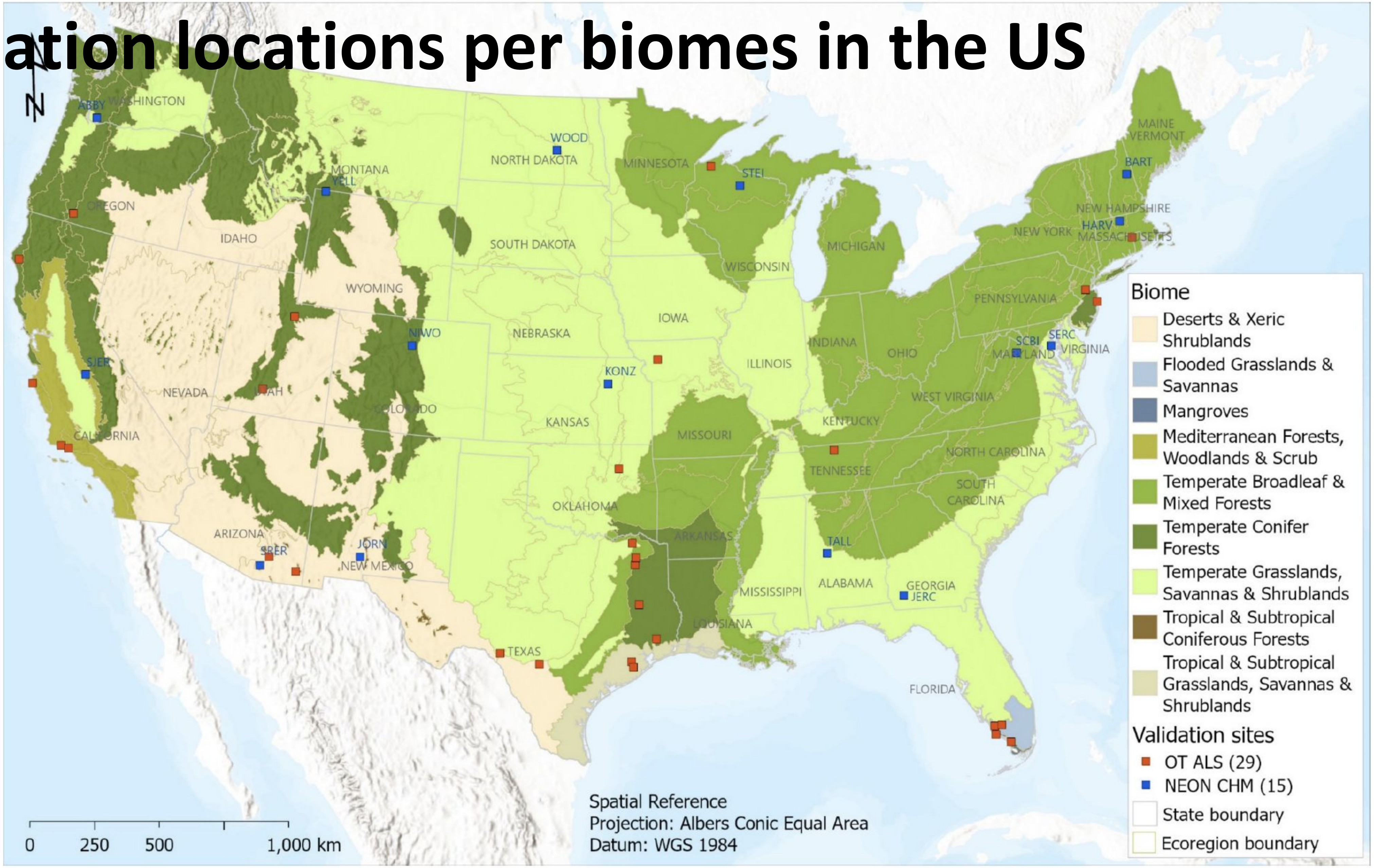


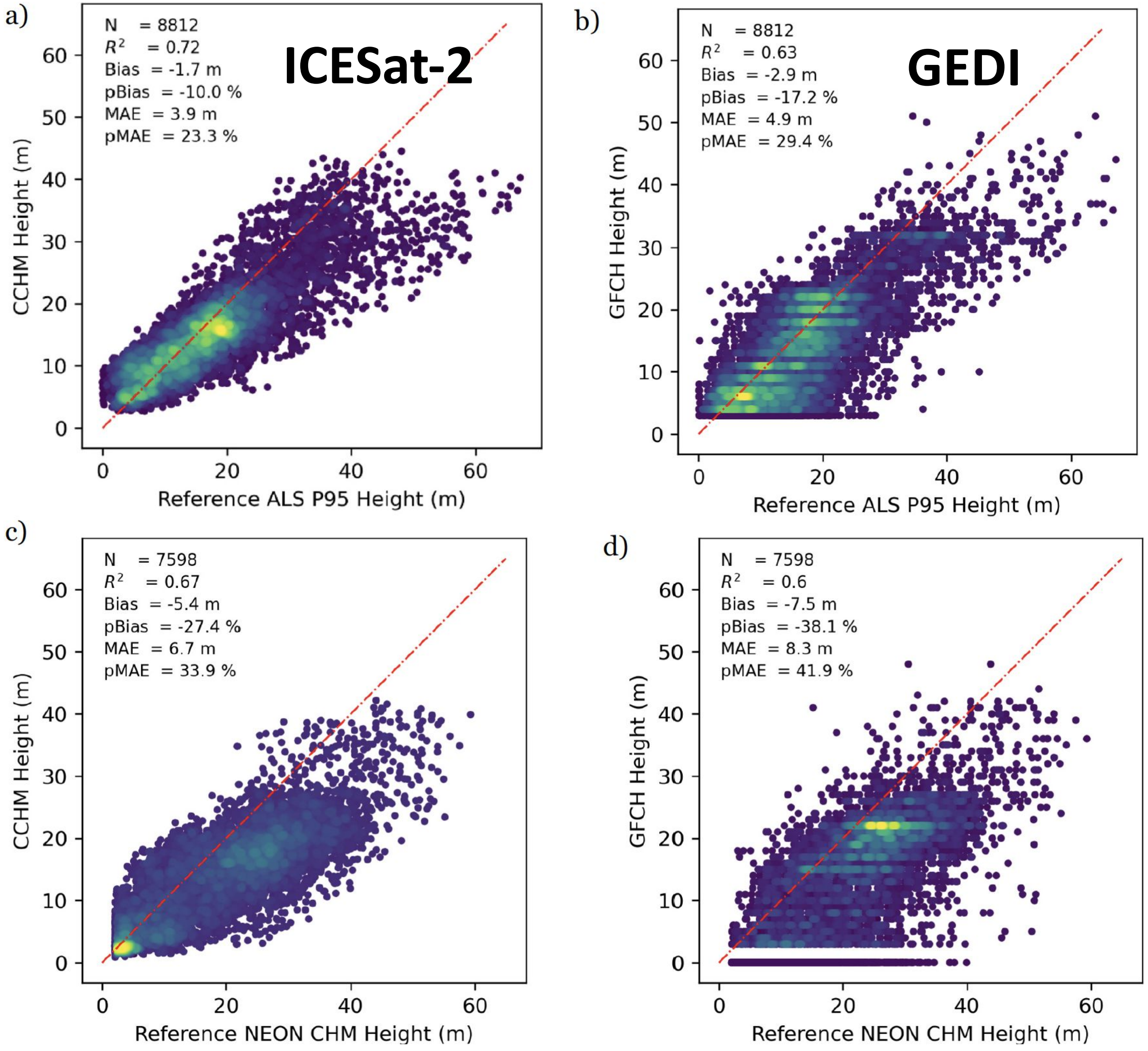
Fig. 2. Map of the contiguous United States depicting the distribution of major vegetation biomes and a network of validation sites applied in the canopy height modeling assessments. Biome theme based on the RESOLVE Ecoregions 2017 base map (Dinerstein et al., 2017).

Validation with airborne lidar datasets
CCHM (ICESat-2) vs GEDI global canopy height map

(Potapov et al., 2020)

- Open Topography ALS

- NEON CHM



CCHM (ICESat-2) and GFCH (GEDI – Potapov et al., 2020) per biomes

Table 8
Comparison of CCHM and GFCH canopy heights with NEON canopy height models. Biome codes are defined as follows: DXS (Deserts & Xeric Shrublands), MFWS (Mediterranean Forests, Woodlands & Scrub), TBMF (Temperate Broadleaf & Mixed Forests), TCF (Temperate Conifer Forests) and TGSS (Temperate Grasslands, Savannas & Shrublands).

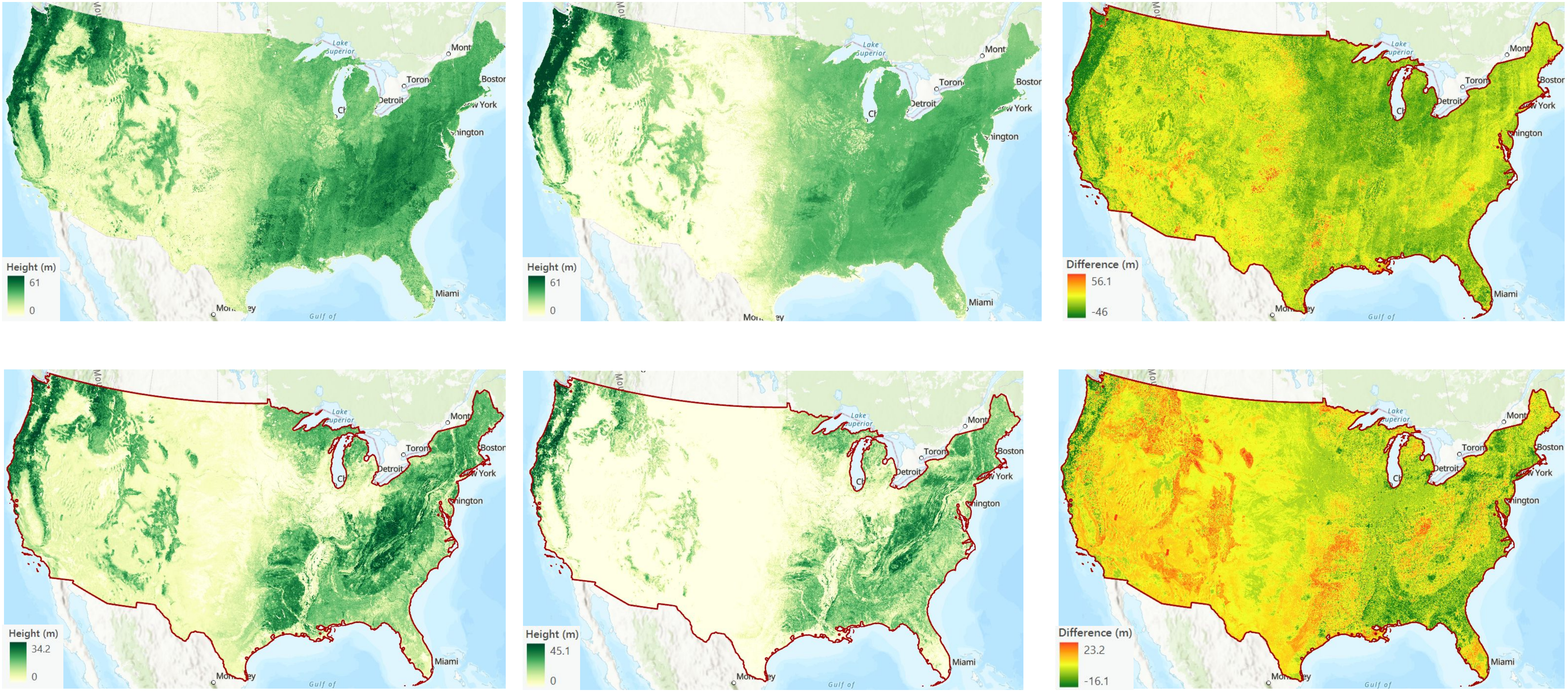
			CCHM					GFCH				
Site	Biome	N	R2	Bias (m)	pBias (%)	MAE (m)	pMAE (%)	R2	Bias (m)	pBias (%)	MAE (m)	pMAE (%)
SRER	DXS	534	0.59	−0.8	−16.8	1.5	31.3	0.47	−4.1	−87.1	4.1	88.6
SJER	MFWS	525	0.36	−5.0	−44.7	5.2	46.5	0.22	−10.2	−90.5	10.2	90.5
BART	TBMF	590	0.15	−7.0	−29.4	7.1	30.1	0.10	−5.5	−23.1	6.1	25.7
HARV	TBMF	583	0.27	−7.9	−29.4	8.2	30.6	0.24	−7.5	−28.0	7.8	29.2
SCBI	TBMF	581	0.61	−6.0	−21.5	6.9	24.9	0.51	−7.5	−27.1	8.1	29.4
STEI	TBMF	594	0.47	−4.4	−21.4	5.2	25.4	0.32	−4.0	−19.4	5.4	26.3
ABBY	TCF	539	0.63	−5.9	−20.7	8.2	28.7	0.48	−6.6	−23.2	9.6	33.5
NIWO	TCF	595	0.32	1.5	10.9	4.1	29.9	0.35	−2.2	−16.1	4.1	30.2
YELL	TCF	596	0.15	−4.4	−29.4	7.0	47.2	0.11	−8.2	−55.6	9.5	64.0
JERC	TGSS	508	0.45	−8.2	−39.2	8.9	42.7	0.30	−10.6	−51.2	11.0	53.1
KONZ	TGSS	586	0.53	−3.0	−27.0	4.2	37.7	0.31	−9.0	−81.1	9.1	81.3
SERC	TGSS	561	0.56	−12.1	−42.7	12.6	44.2	0.47	−14.7	−51.8	14.8	52.3
TALL	TGSS	597	0.21	−9.0	−31.2	9.4	32.5	0.26	−9.2	−31.9	9.5	32.7
WOOD	TGSS	173	0.11	−1.8	−33.4	2.9	53.9	0.09	−5.2	−97.0	5.2	97.1

CCHM vs GEDI/GLAD map

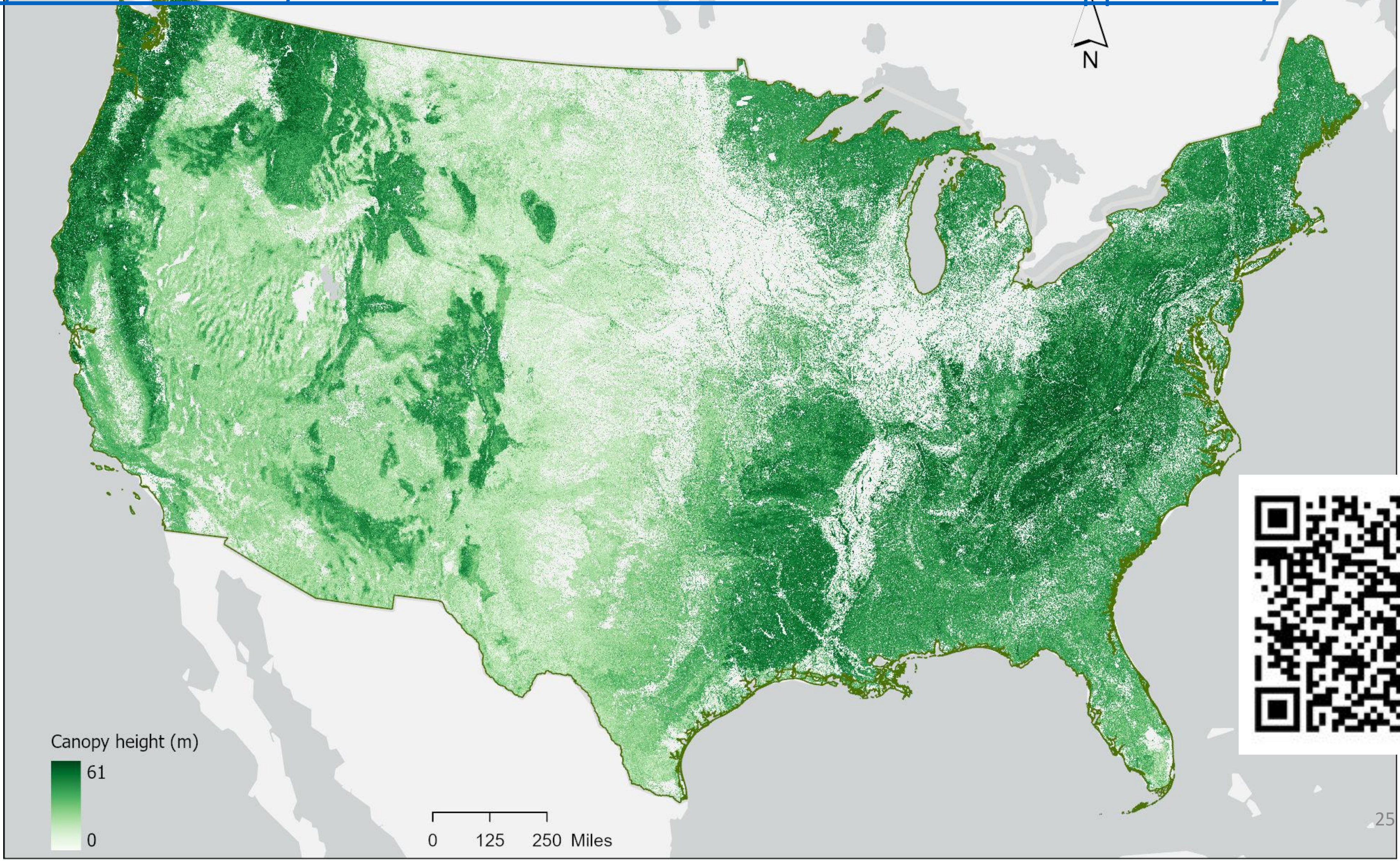
CCHM | **GEDI/GLAD** | **CCHM – GEDI/GLAD**

MAXIMUM

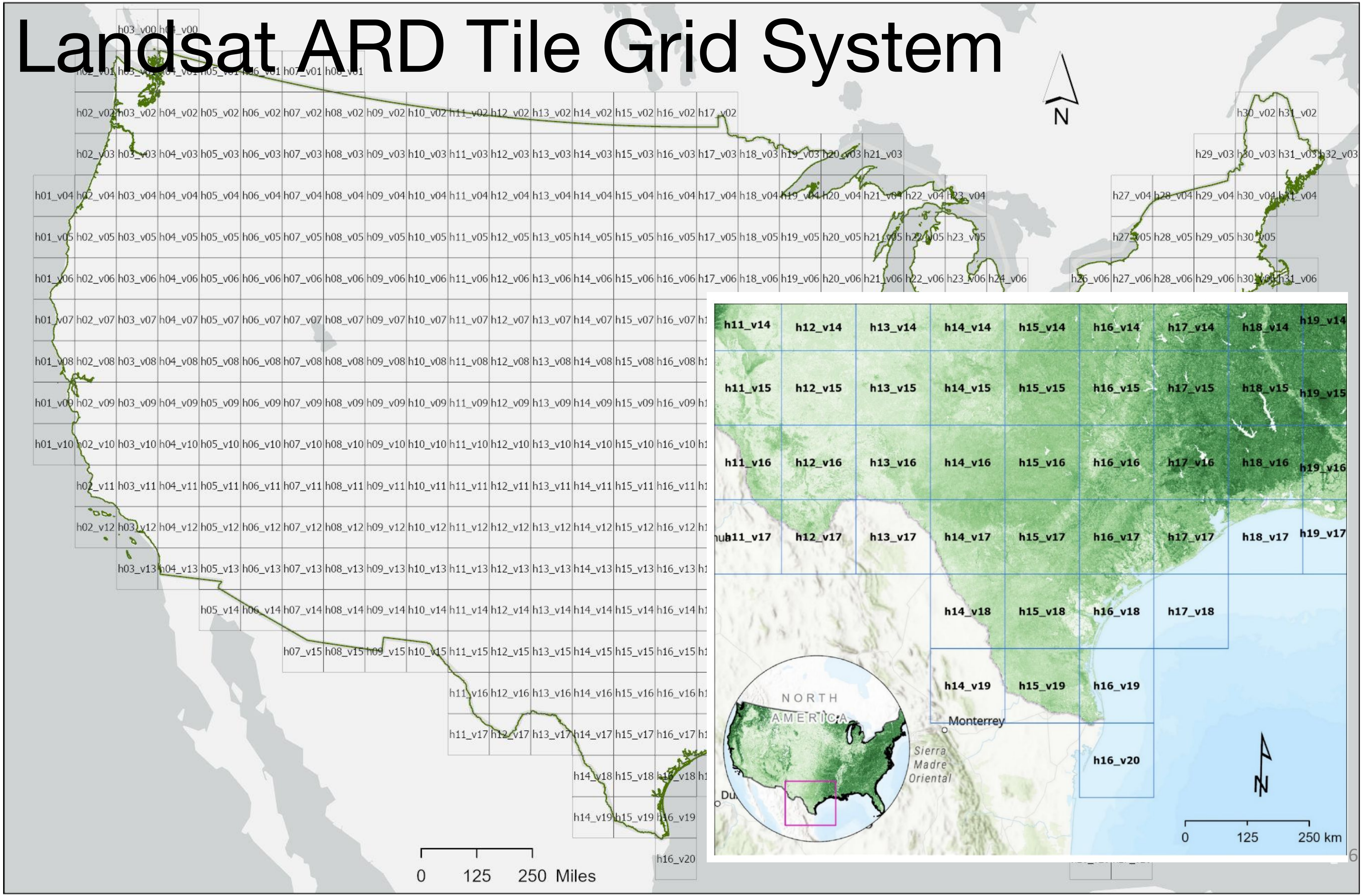
MEAN



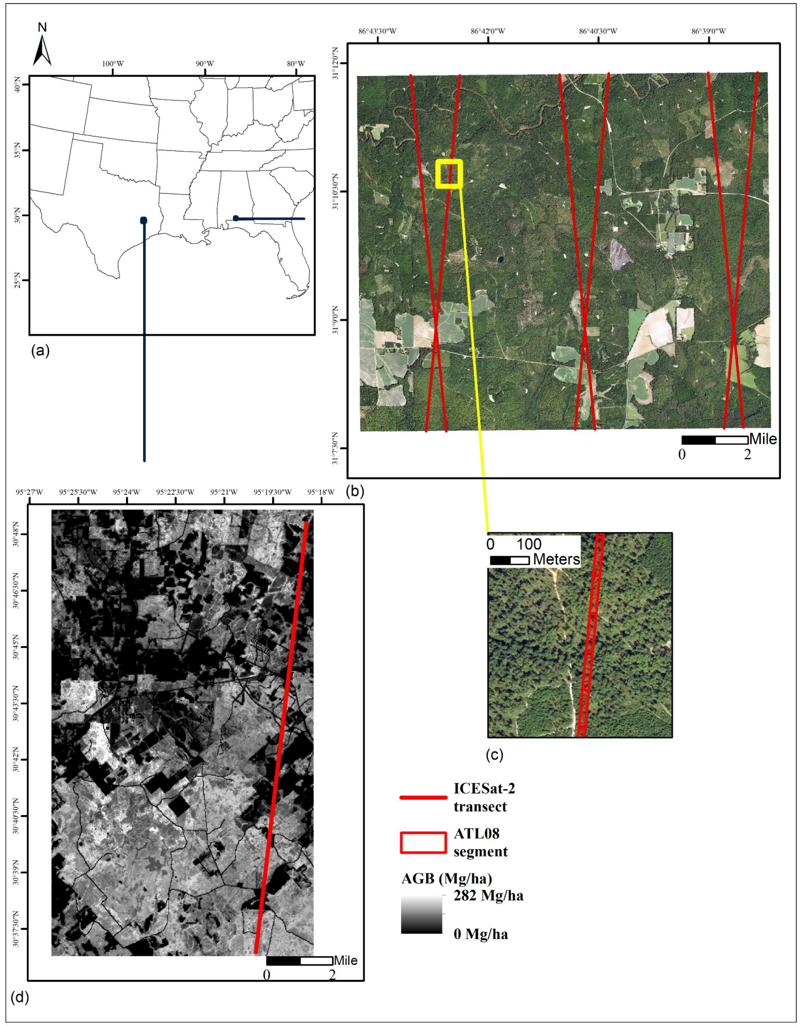
Original CCHM and GEDI/GLAD rasters aggregated at 2 km grid cell https://lasers.tamu.edu/ice-cloudand-land-elevation-satellite-icesat-2-applications/



Landsat ARD Tile Grid System



Mapping canopy cover with ICESat-2 for Southern US Forests



1. Percentage of photons above 2 m:

$$\frac{(number\ of\ photons > 2\ m)}{(total\ number\ of\ photons)}\ x\ 100\% \qquad (2)$$

2. Percentage of photons above 4.6 m:

$$\frac{(number\ of\ photons > 4.6\ m)}{(total\ number\ of\ photons)}\ x\ 100 \qquad (3)$$

3. Percentage canopy and top-of-canopy photons of the total number of canopy (inside canopy), top-of-canopy and ground photons:

$$\frac{(n\_ca\_photons + n\_toc\_photons)}{(n\_ca\_photons + n\_toc\_photons + n\_te\_photons)}\ x\ 100\% \qquad (4)$$

4. Percentage top-of-canopy photons of the number of top-of-canopy and ground photons:

$$\frac{n\_toc\_photons}{(n\_toc\_photons + n\_te\_photons)}\ x\ 100\% \qquad (5)$$

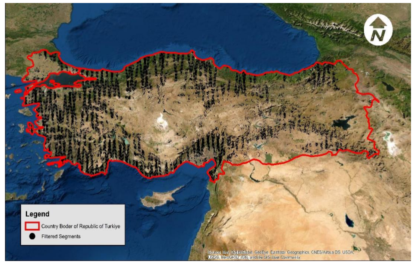
5. Percentage canopy of the number of canopy and ground photons:

$$\frac{n\_ca\_photons}{(n\_ca\_photons + n\_te\_photons)}\ x\ 100\% \qquad (6)$$

6. Mean of #3, #4, #5 above (7)

Narine, L., L. Malambo, and S. Popescu. 2022. Characterizing canopy cover with ICESat-2: A case study of southern forests in Texas and Alabama, USA. *Remote Sensing of Environment.*

Other gridded maps with ICESat-2
Map of canopy cover in Turkey

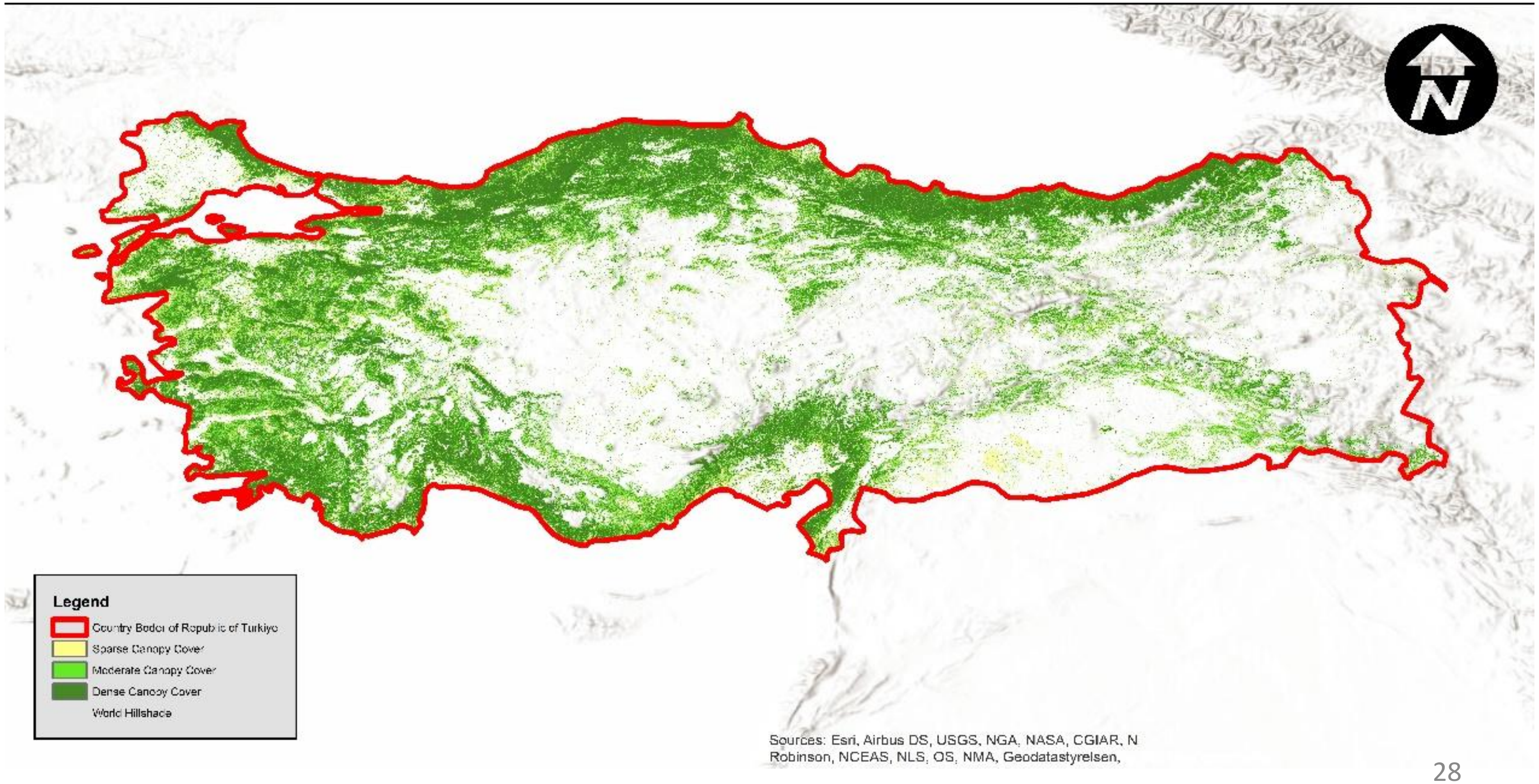


ICESat-2 for Canopy Cover Estimation at Large-Scale on a Cloud-Based Platform

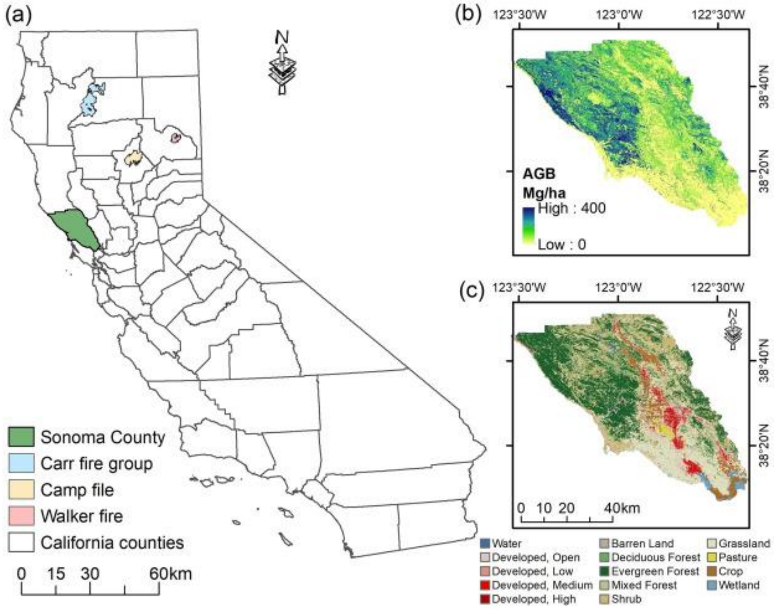
by Emre Akturk [1,2], Sorin C. Popescu [1,*] and Lonesome Malambo [1]

[1] Department of Ecology and Conservation Biology, Texas A&M University, College Station, TX 77843, USA
[2] Department of Forest Engineering, Faculty of Forestry, Kastamonu University, Kastamonu 37150, Türkiye
[*] Author to whom correspondence should be addressed.

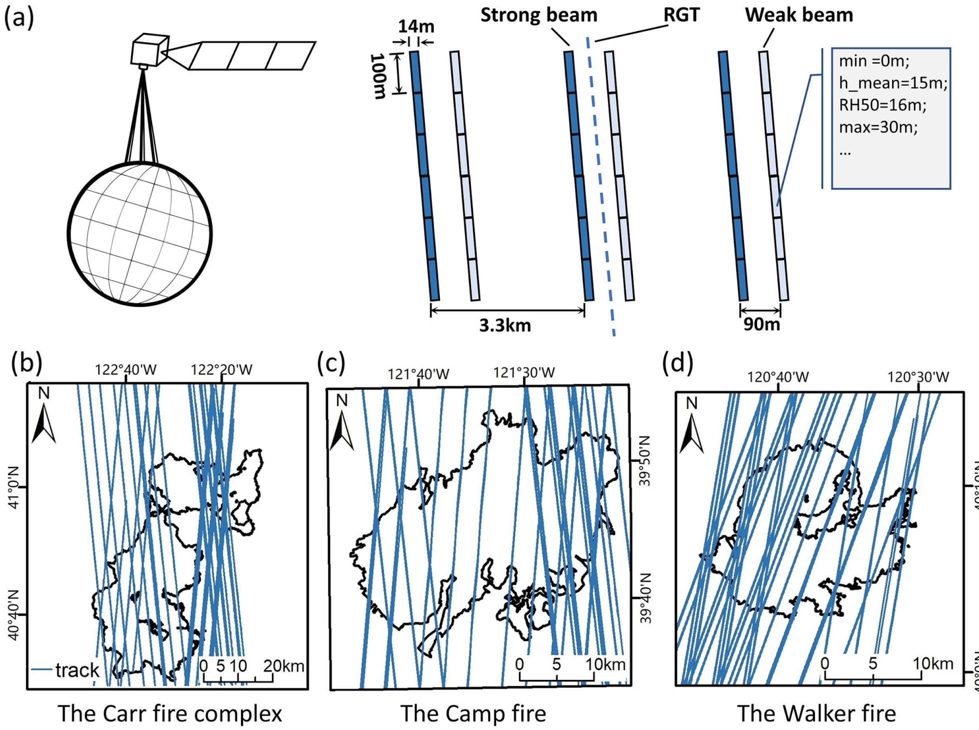
Sensors **2023**, *23*(7), 3394; **https://doi.org/10.3390/s23073394**

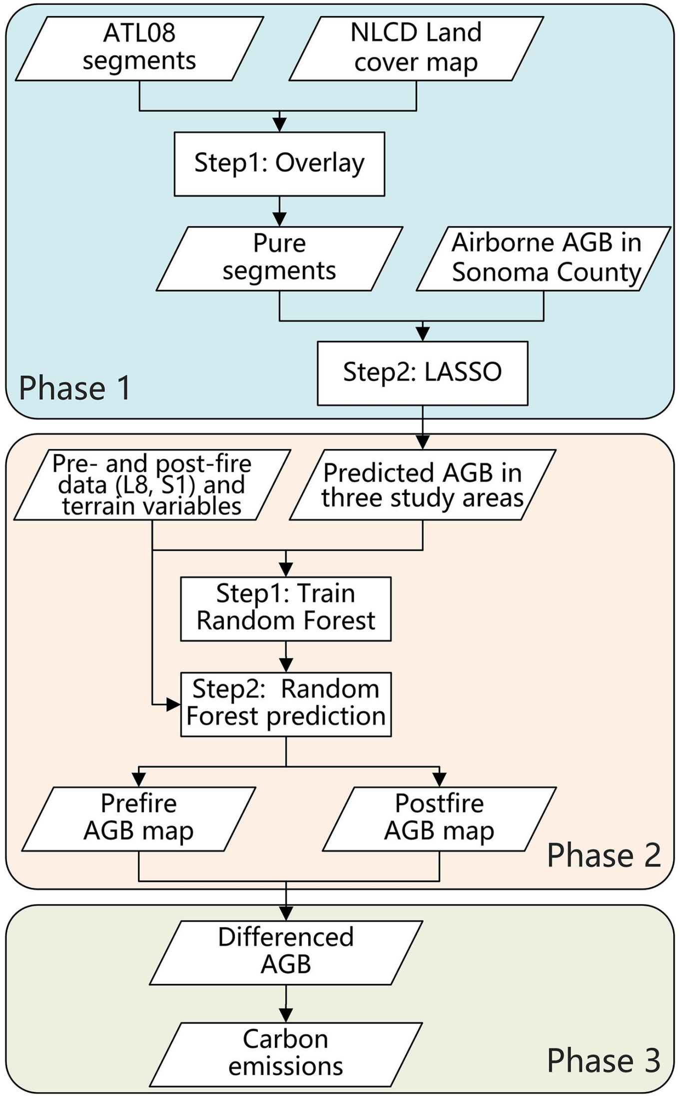


Estimation of biomass burning emissions by integrating ICESat-2, Landsat 8, and Sentinel-1 data



Reference biomass map from Dubayah et al, 2017





Meng Liu * and Sorin Popescu. *Remote Sens. Environ.* **2022**. https://doi.org/10.1016/j.rse.2022.113172

Mapping biomass

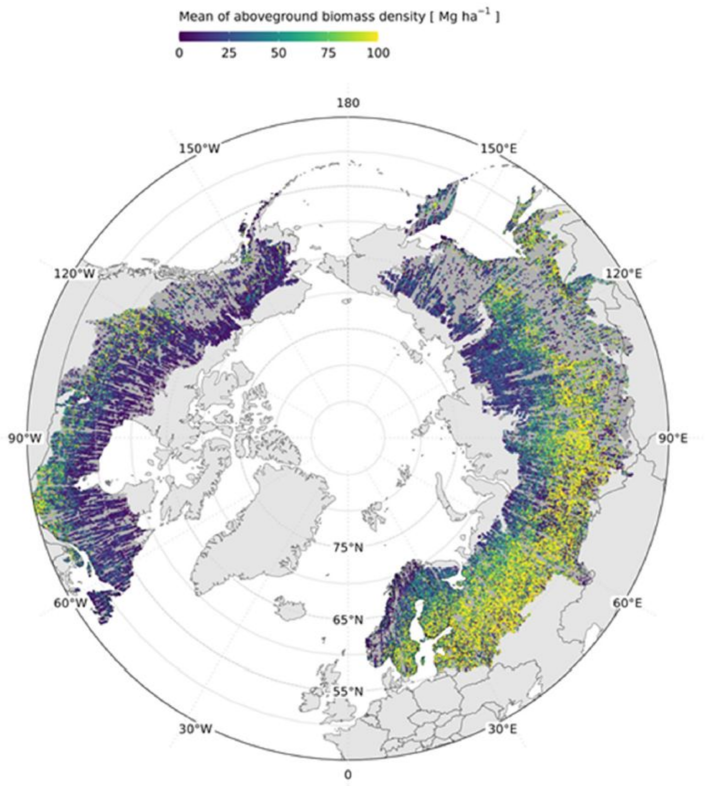


Fig. 1 … rea.

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Towards global spaceborne lidar biomass: Developing and applying boreal forest biomass models for ICESat-2 laser altimetry data

A. Neuenschwander [a,*], L. Duncanson [b], P. Montesano [c], D. Minor [b], E. Guenther [a], S. Hancock [d], M.A. Wulder [e], J.C. White [e], M. Purslow [d], N. Thomas [c], A. Mandel [f], T. Feng [b], J. Armston [b], J.R. Kellner [g], H.E. Andersen [h], L. Boschetti [i], P. Fekety [j], A. Hudak [k], J. Pisek [l], N. Sánchez-López [k], K. Stereńczak [m]

P. Varvia et al.

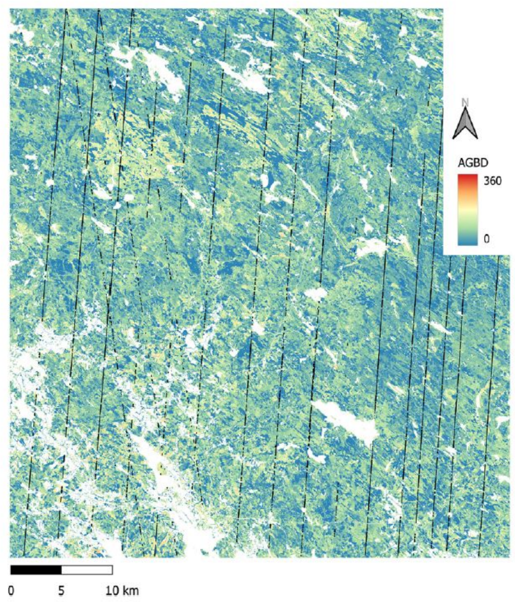

Fig. 7. 15 m resolution AGBD [Mg/ha] map of the Nurmes area produced using the reference ALS and Sentinel-2 model. ICESat −2 tracks shown in black.

Remote Sensing of Environment 311 (2024) 114249

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Estimation of boreal forest biomass from ICESat-2 data using hierarchical hybrid inference

Petri Varvia [a,*], Svetlana Saarela [b], Matti Maltamo [a], Petteri Packalen [c], Terje Gobakken [b], Erik Næsset [b], Göran Ståhl [d], Lauri Korhonen [a]

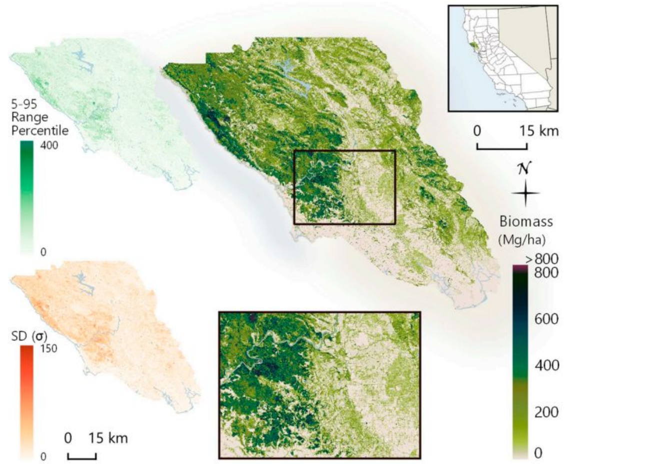

Fig. 1. A Sonoma County-wide 30 m ALS biomass map was used as the biomass reference map for this study. The 90th percentile and standard deviations of biomass from a model bootstrapping are shown on the left.

Remote Sensing of Environment 242 (2020) 111779

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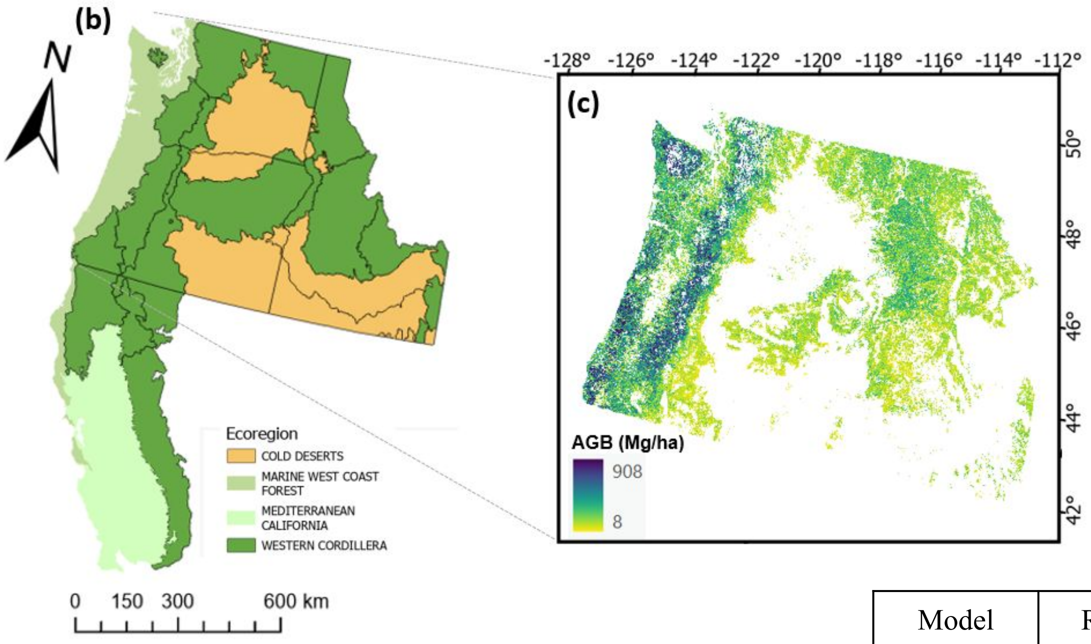
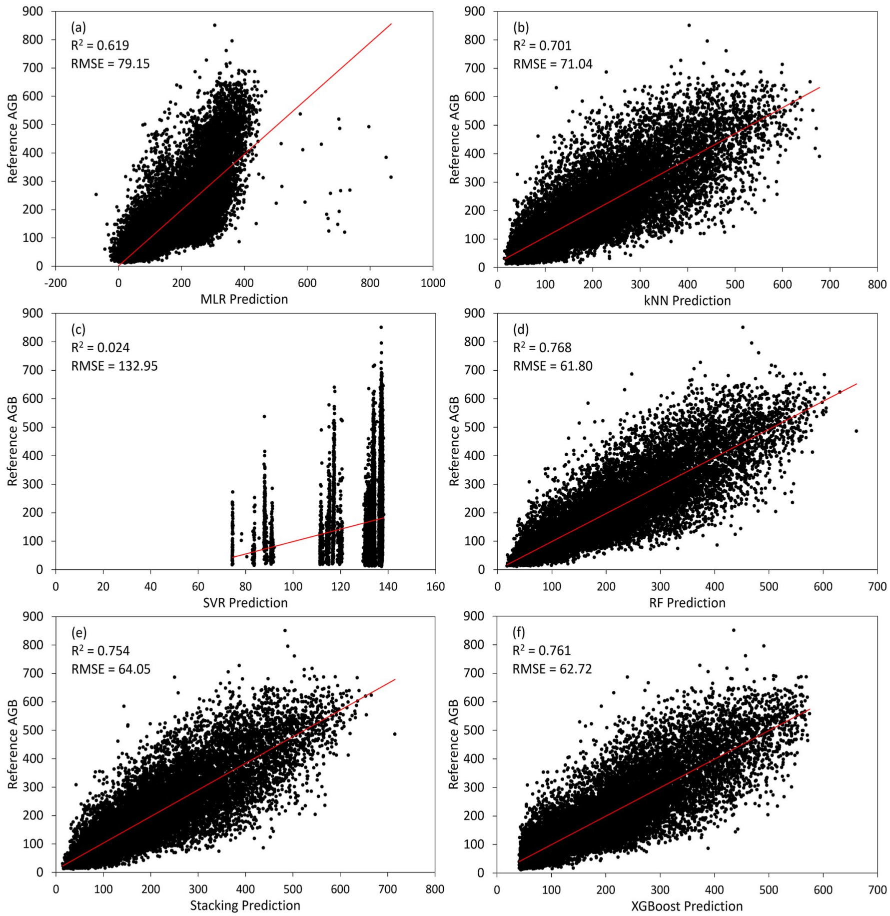
Biomass estimation from simulated GEDI, ICESat-2 and NISAR across environmental gradients in Sonoma County, California

Laura Duncanson [a,b,*], Amy Neuenschwander [c], Steven Hancock [a,d], Nathan Thomas [b,e], Temilola Fatoyinbo [b], Marc Simard [f], Carlos A. Silva [a], John Armston [a], Scott B. Luthcke [g], Michelle Hofton [a], James R. Kellner [h,i], Ralph Dubayah [a]

Mapping biomass



Model	RMSE	R^2	Ranking
RF	61.8	0.768	1
MLR	79.15	0.62	5
SVR	132.95	0.02	6
kNN	71.04	0.7	4
Stacking	64.05	0.754	3
XGBoost	62.72	0.761	2

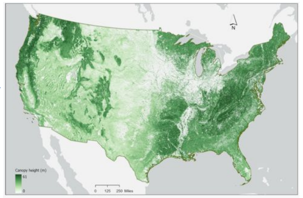


Source: Mei-Kuei Lu, TAMU

A Look ahead

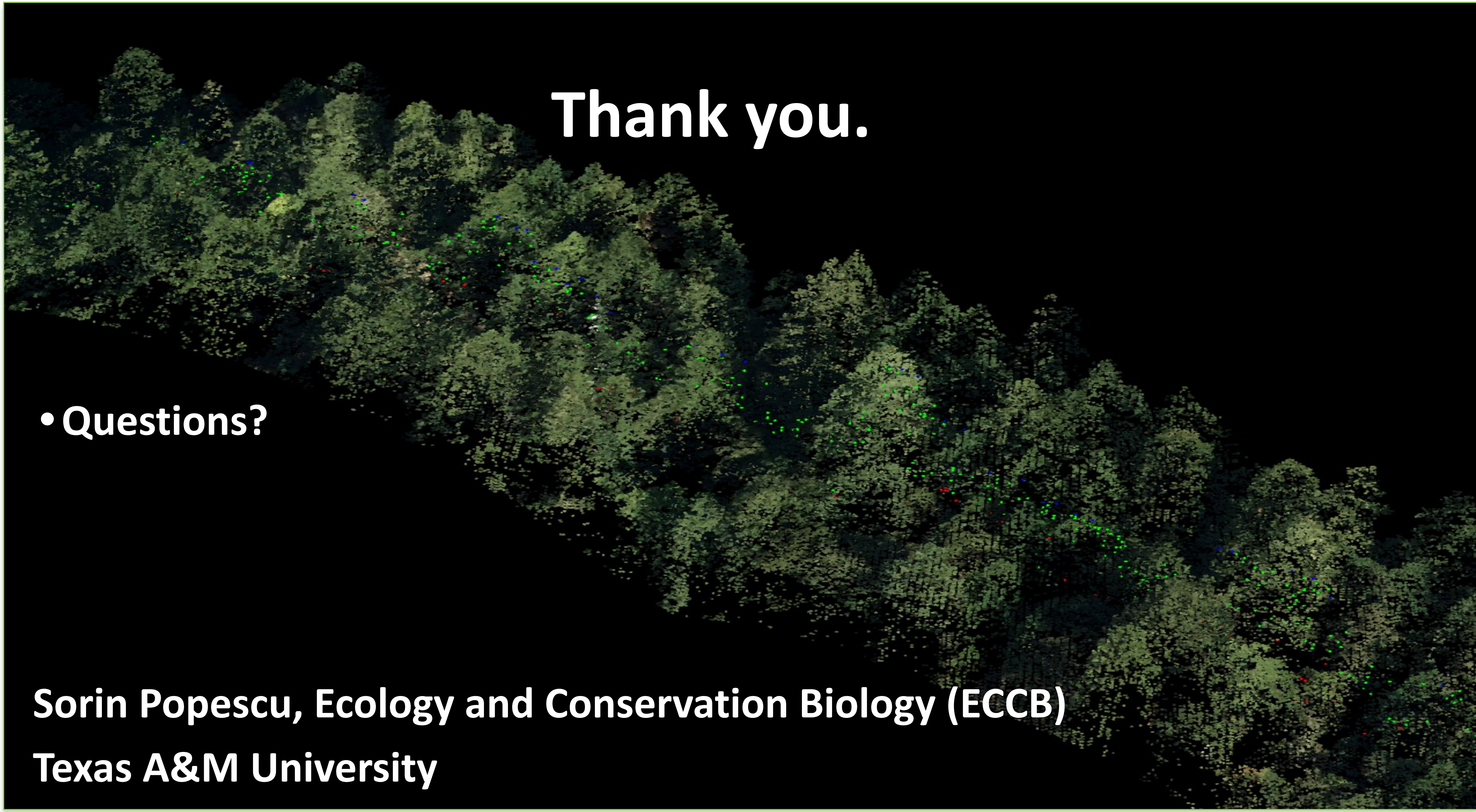
Biomass

Global canopy height map



Canopy cover

Change analysis over 5 years



Thank you.

- Questions?

Sorin Popescu, Ecology and Conservation Biology (ECCB)

Texas A&M University