Inferring Vegetation Canopy Information Using Combined Lidar and Radar Interferometry Data

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Terrestrial Ecology Program Site Review

Goddard Space Flight Center

March 17, 2004

Project Objectives

- To obtain a semi-empirical model relating InSAR measured parameters to canopy parameters which can be generated from spaceborne lidars. These parameters include canopy height and biomass.

- To use joint InSAR and lidar data products to generate corrections to InSAR measured heights, thus improving the usefulness of InSAR topographic maps.

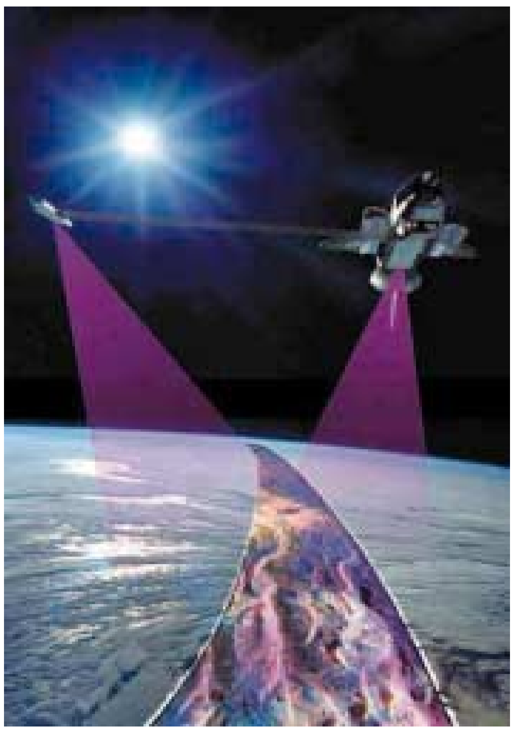
- To verify and assess the accuracy of the proposed algorithms using test sites exhibiting a variety of canopy types.

- To use the SRTM data, in conjunction with data from VCL or ICESat, to prove the feasibility of spaceborne estimation of vegetation canopy, including canopy height and biomass, parameters for many vegetation canopy types.

SRTM & ICESat Elevation Data

<u>Shuttle Radar Topography Mission</u>

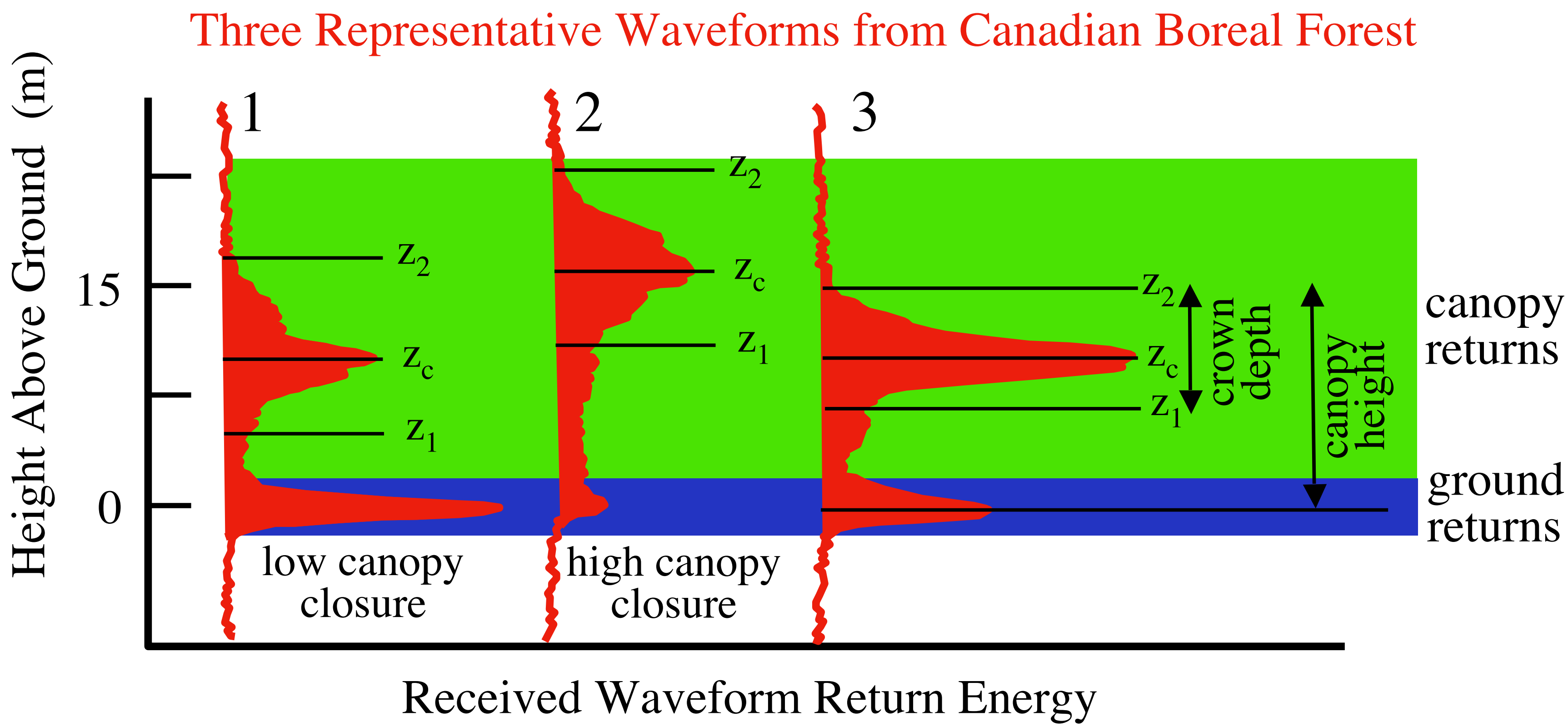
C- and X-band radar interferometry
Correlation: height distribution of scatterers
Radar phase center elevation
Phase center vertical accuracy ~10 m
Spatial resolution ~ 100 m
DEM: US 30 m grid; non-US 90 m grid



<u>ICE, Cloud and land Elevation Satellite</u>

NIR (1064 nm) lidar backscatter
Waveform: height distribution of surfaces
Lowest, highest, & average elevations
Vertical accuracy ~ 0.2 m
Spatial resolution ~ 100 m x 50 m
Profile: 175 m along-track sampling

Canopy Structure Information from ICESat Waveforms

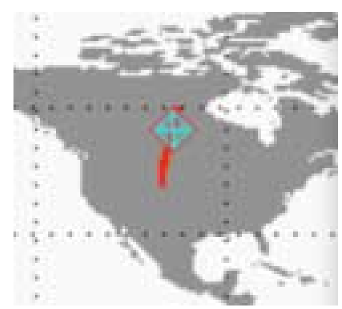


Canopy Height = Distance from Start of Signal to Last Peak, z_2

Crown Depth = Width of Upper Part of Canopy Return, $z_2 - z_1$

Roughness of Outer Canopy = Leading Edge Slope from z_2 to z_c

$$\textbf{Canopy Closure} \sim \frac{\textbf{Canopy Return Energy}}{\textbf{Total Return Energy}}$$



Interferometric Correlation

- The interferometric correlation for single pass systems can be written as the product of three terms $\gamma = \gamma_g \gamma_{snr} \gamma_v$

  where g_g is the geometric correlation, g_{snr} is the SNR correlation and g_v is the volumetric correlation.

- The geometric correlation is a function of the baseline, surface slopes, how the signals are processed and the impulse response function. By carefully tracking what is done to the signals in the processing this term can be computed and compensated.

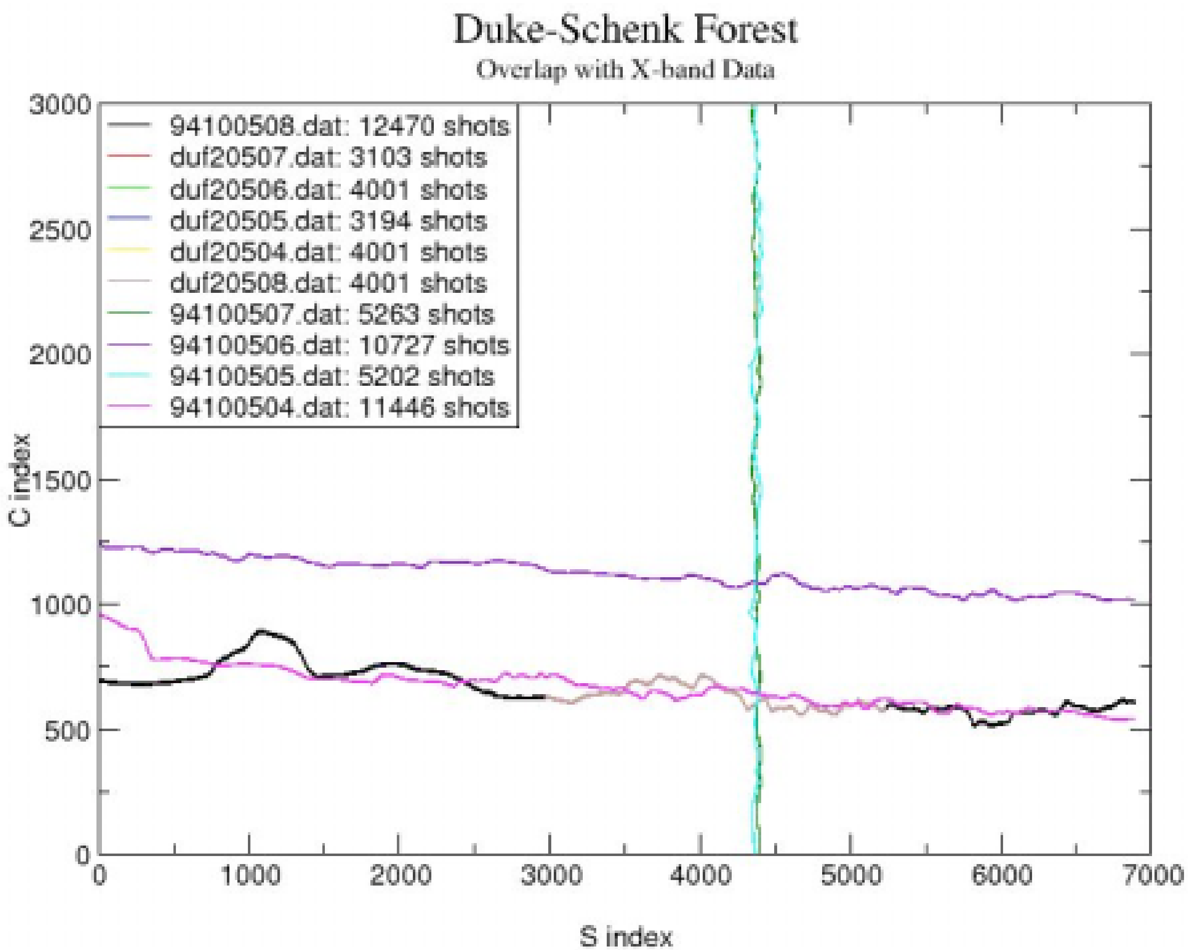
- The SNR correlation measures the reduction in signal similarity due to thermal and other noise sources such as ISLR noise. By measuring or estimating the amount of thermal and other noise sources this term can be computed and estimated.

- The volumetric correlation is related to the vertical distribution of scatterers within a resolution element and is the quantity of interest
  - A method to use SRTM, GeoSAR and TOPSAR correlation data and determine penetration from the scatterer standard deviation was developed for this project.

SLICER & GeoSAR Comparison: Duke Forest

- SLICER: airborne waveform lidar
- GeoSAR: airborne X-band and P-band Interferometric SAR
- The SLICER data was projected to the GeoSAR SCH coordinate system and the coregistered data sets were compared.
- In order to assess the impact of incidence angle variations, the GeoSAR swath was divided into 4 subswaths of approximately 4 km width.
- Canopy characteristics thought to influence the penetration of radiation were computed from the SLICER waveform:
  - Canopy height (maximum elevation minus ground elevation)
  - Laser scatterer standard deviation
  - Relative canopy closure (canopy return energy / total return energy)
- Radar scatterer properties were computed from the GeoSAR X-band and P-band correlation data:
  - "Canopy height" (X-band elevation minus P-band elevation)
  - X-band scatterer standard deviation ("penetration")
  - X-band height bias (X-band elevation minus ground elevation from SLICER)

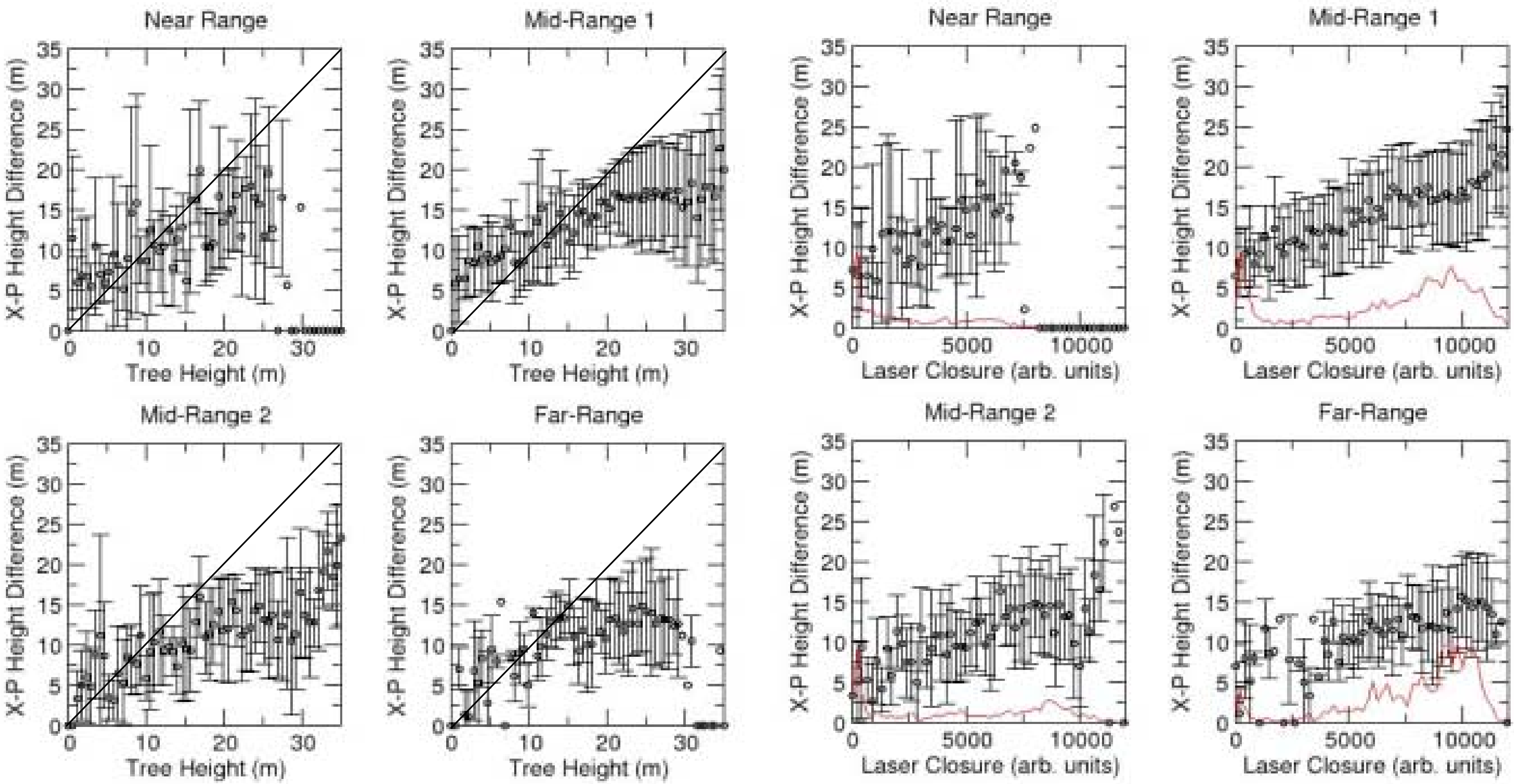
Duke Forest SLICER Overlap with GeoSAR



SLICER:
Airborne LIDAR
waveform profile with
contiguous 10 m footprints

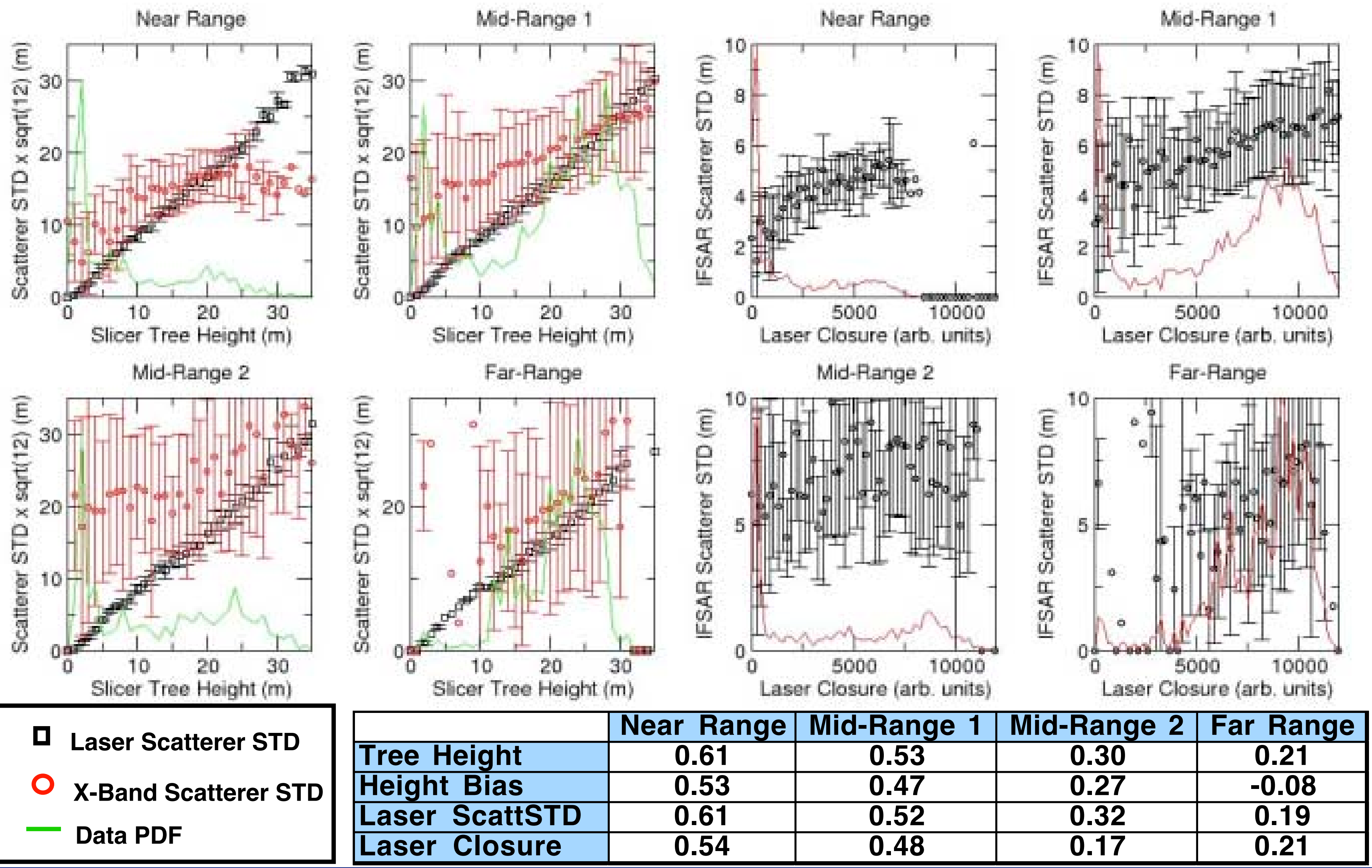
GeoSAR:
Airborne InSAR
X- and P-band height images
X ~ canopy top
P ~ ground

X-P Height Difference vs Lidar Height & Closure



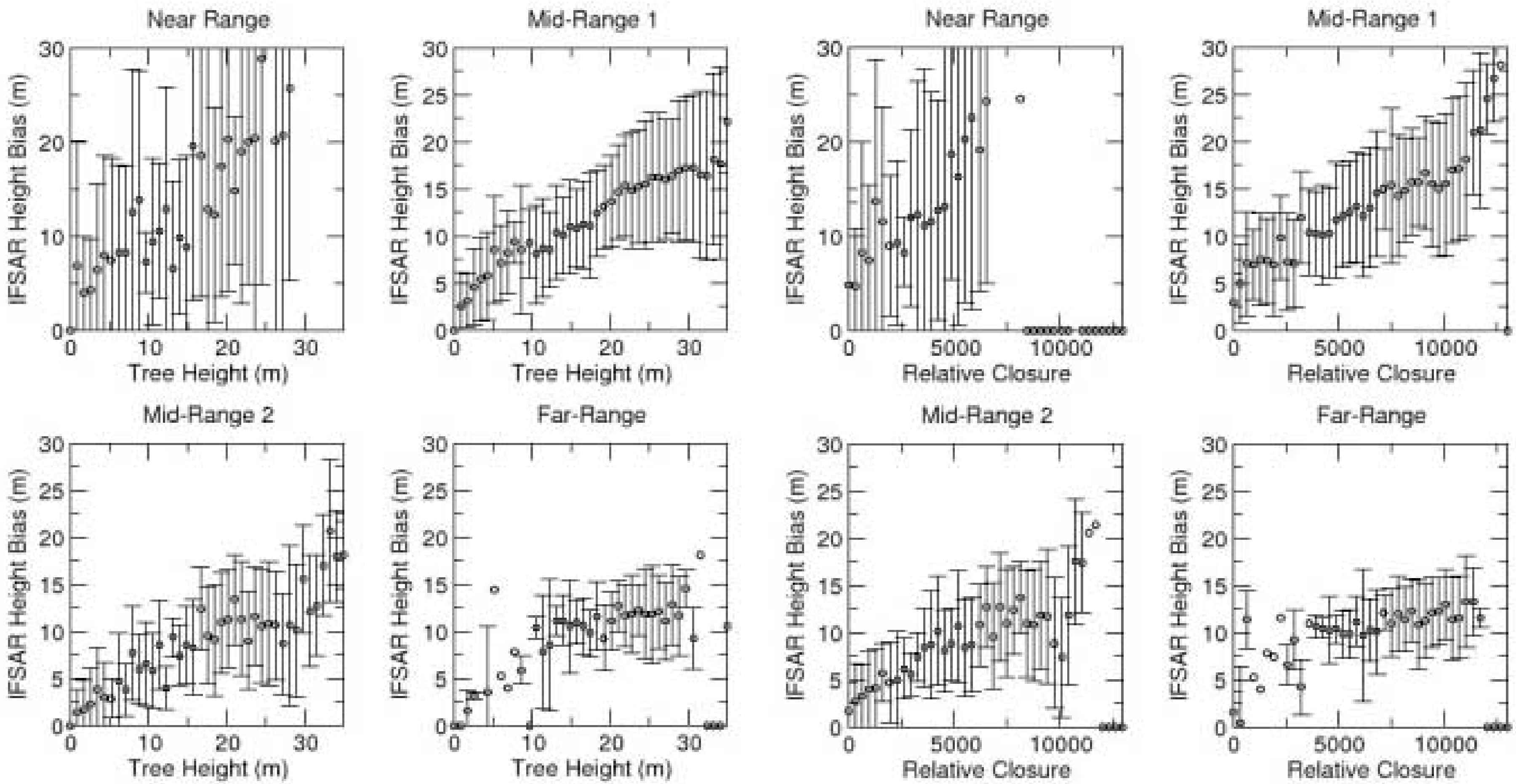
	Near Range	Mid-Range 1	Mid-Range 2	Far Range
Tree Height	0.39	0.47	0.48	0.31
Laser ScattSTD	0.38	0.43	0.46	0.22
Laser Closure	0.41	0.50	0.49	0.41

X Scatterer STD vs Lidar Height & Closure



	Near Range	Mid-Range 1	Mid-Range 2	Far Range
Tree Height	0.61	0.53	0.30	0.21
Height Bias	0.53	0.47	0.27	-0.08
Laser ScattSTD	0.61	0.52	0.32	0.19
Laser Closure	0.54	0.48	0.17	0.21

X Height Bias vs Lidar Height & Closure

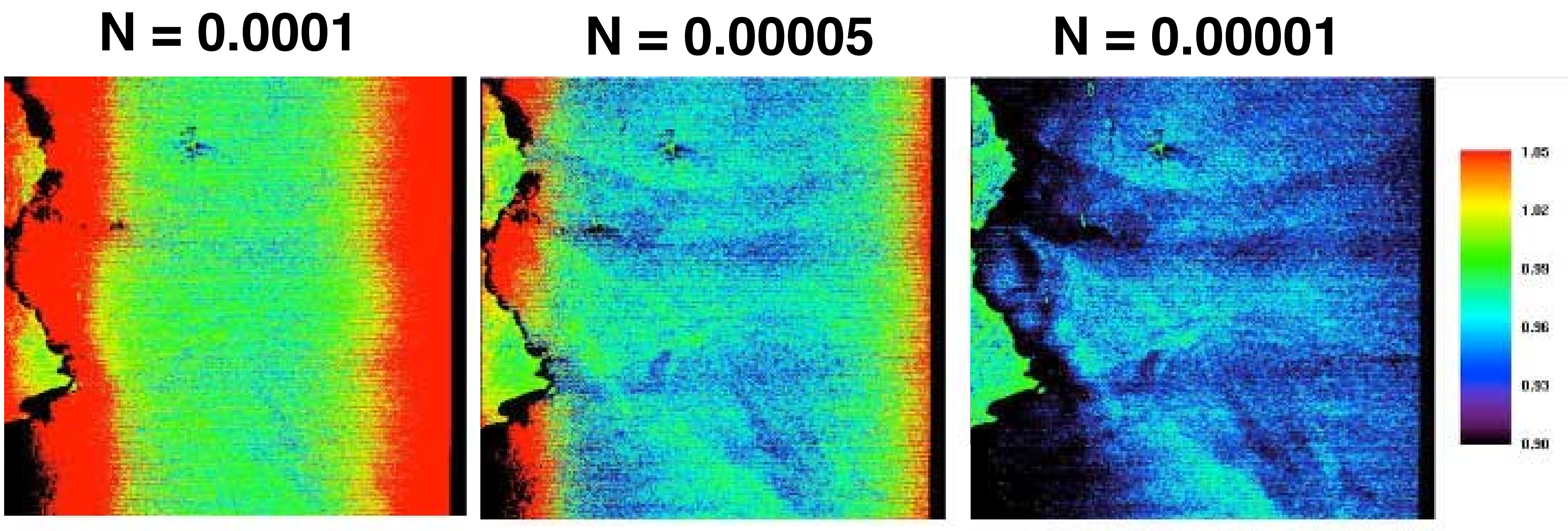


Correlation				
	Near Range	Mid-Range 1	Mid-Range 2	Far Range
Tree Height	0.50	0.59	0.62	0.28
Laser Closure	0.44	0.58	0.62	0.33

SRTM Geometric Correlation Correction

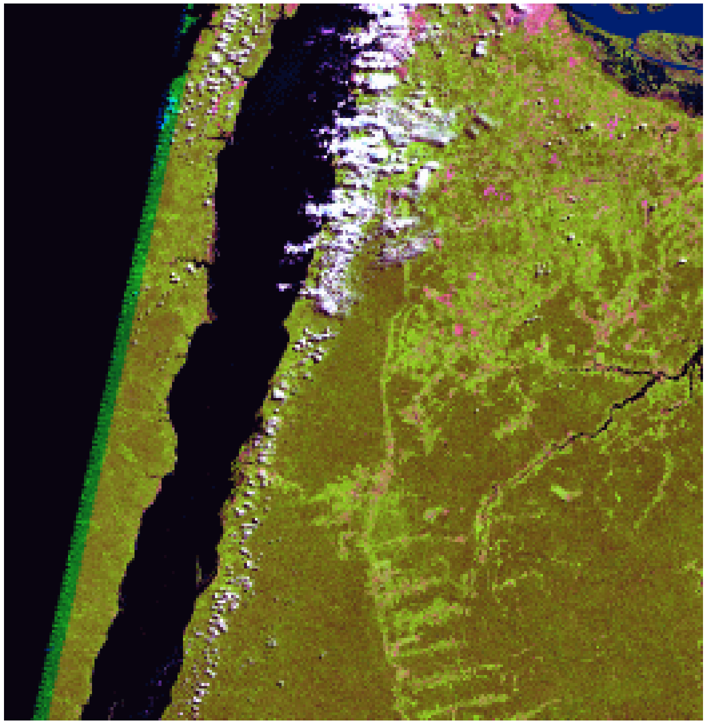
- Early versions of the SRTM processor (Case A, Case B data deliveries) did not correct for the geometric correlation
- The geometric correlation code modification was put in place to make the correlation data saved for SRTM and the Carbon Cycle task meaningful as the raw correlation data was contaminated by factors which were not available outside the processor
- In addition to the geometrically corrected correlation data, the format of the correlation file was modified to also output the total power, required for calibration of the noise correlation term.
- The first data delivery containing “corrected” correlation data was the North America delivery

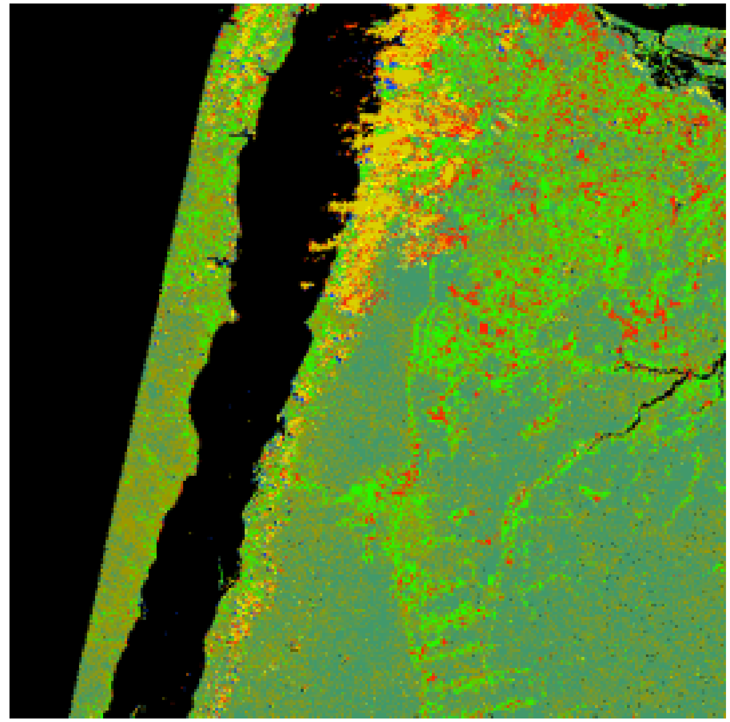
SRTM Thermal Noise Calibration



- Decorrelation data over ocean, with geometric correlation removed
- Thermal noise correction attempted using image power
- If decorrelation were caused by thermal noise, there is a level in the estimated thermal noise where the corrected correlation would be constant
- Since this level is not found, one concludes that additional decorrelation sources (ISLR sidelobe leakage?) play a significant role in the correlation

TM Based Classification for Tapajos, Brazil



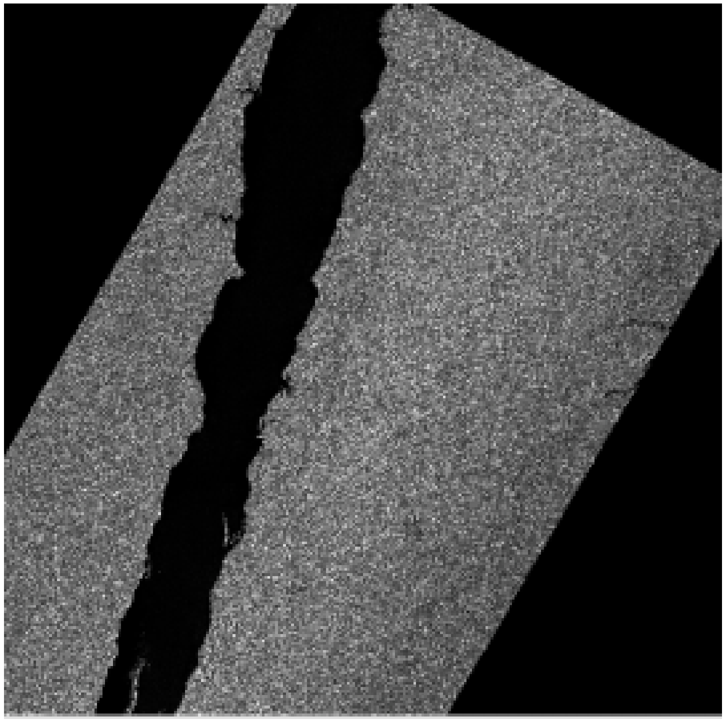


Landsat bands 5/4/3 for the Tapajos region of Brazil

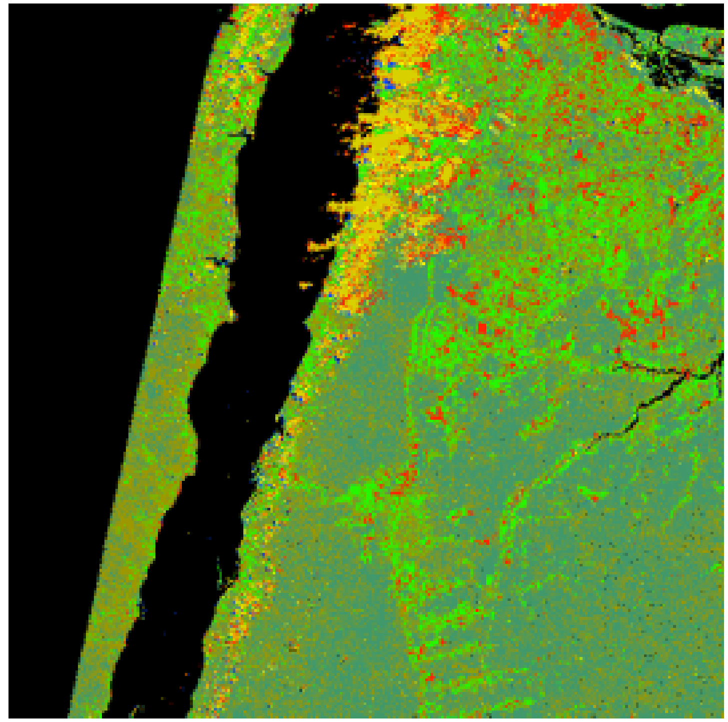
TM scene and classification courtesy of S. Saatchi, JPL

- Dense Forest
- Degraded Forest
- Secondary Forest
- Deforested
- Unclassified/water
- Clouds

SRTM Backscatter for Tapajos, Brazil

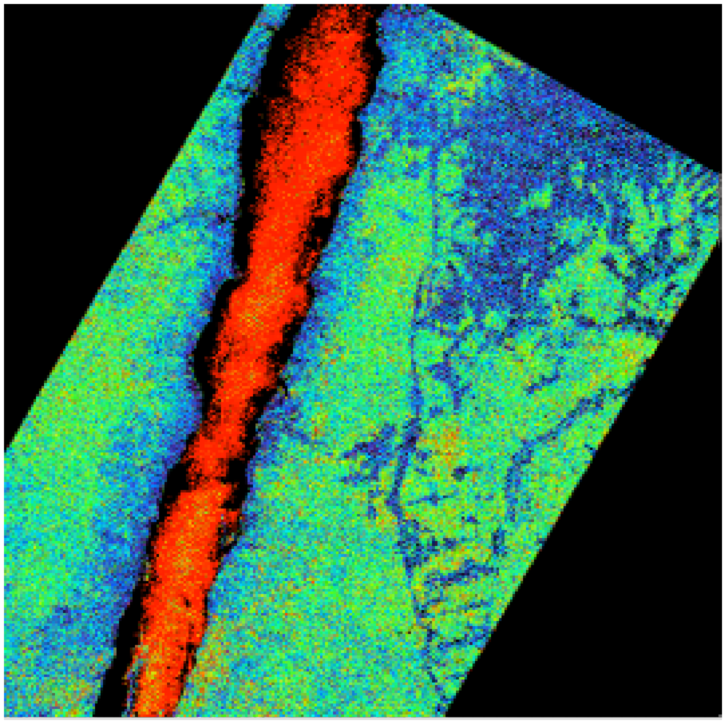


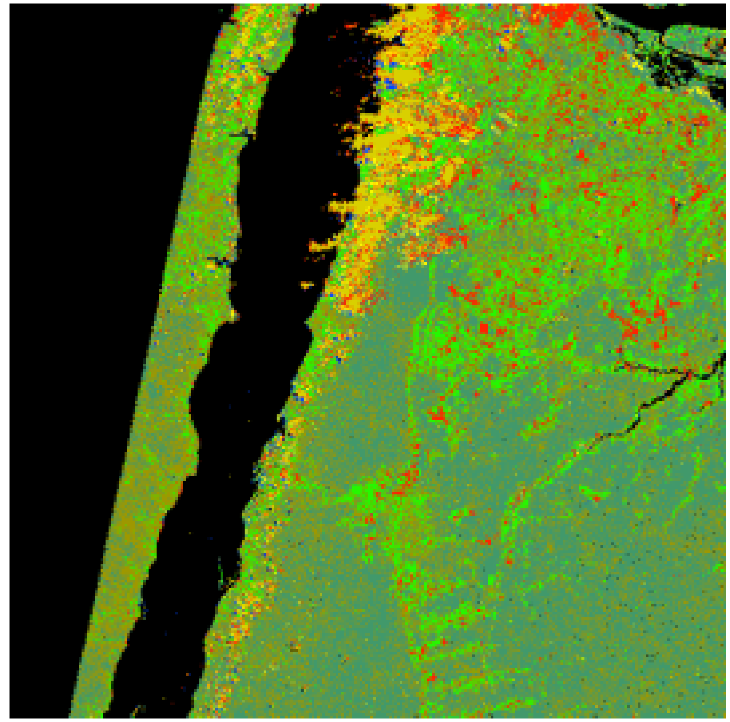
SRTM C-band
radar backscatter intensity



Dense Forest
Deforested
Degraded Forest
Unclassified/water
Secondary Forest
Clouds

SRTM Penetration for Tapajos, Brazil

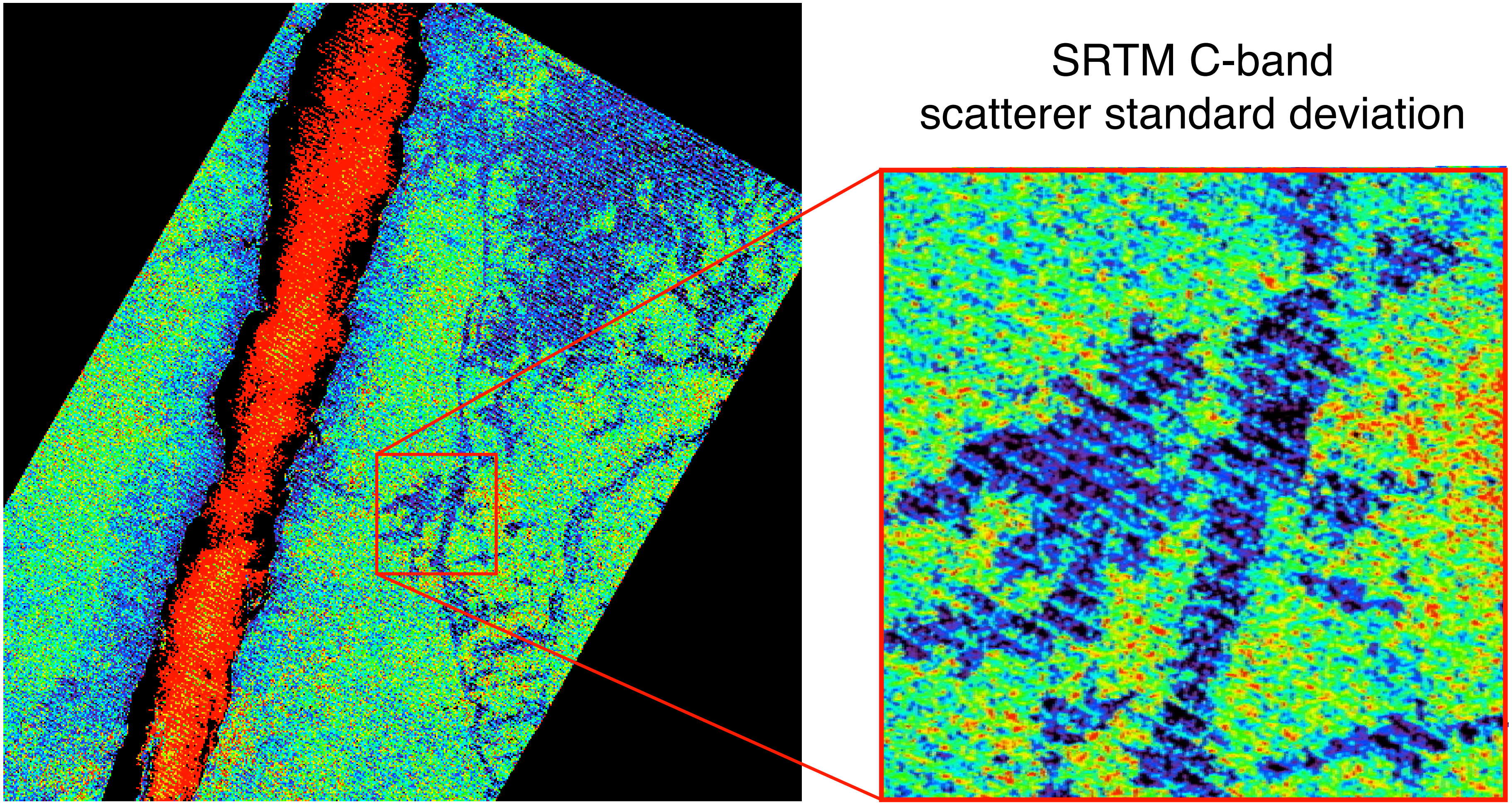




SRTM C-band
scatterer standard deviation

■	Dense Forest	■	Deforested
■	Degraded Forest	■	Unclassified/water
■	Secondary Forest	■	Clouds

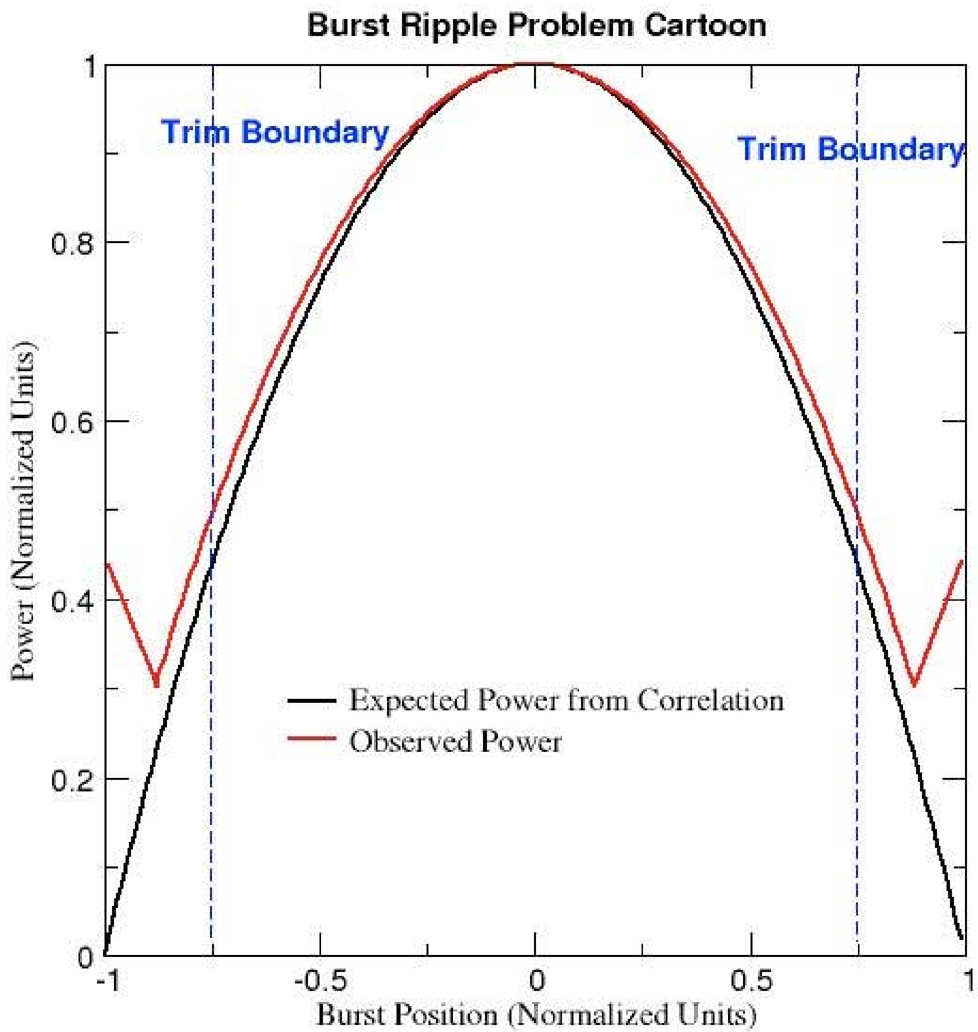
SRTM Miscalibration Ripples in Penetration Product



SRTM C-band
scatterer standard deviation

Although on a large scale, there is good agreement between penetration estimates and vegetation classes, on a pixel basis, there are substantial errors introduced by the calibration ripples.

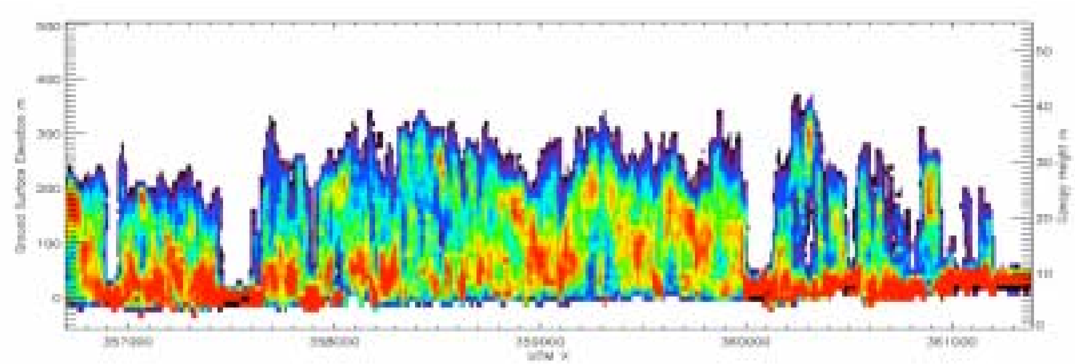
What is the source of the ripple problem?



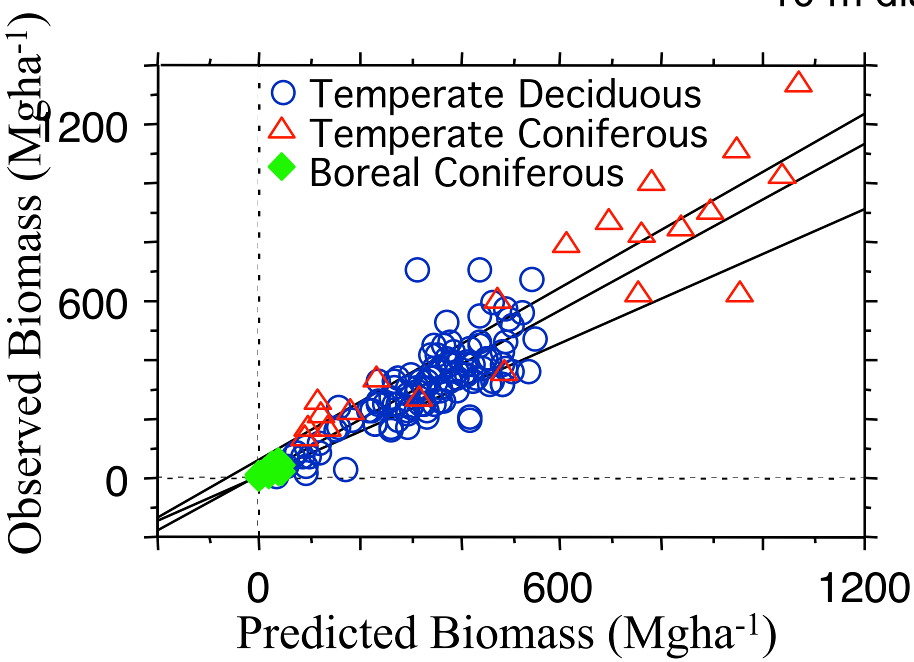
- After detailed examination of the SRTM processor data at various levels of interferogram formation, the correlation ripples were traced to a mismatch between the observed return power for a burst and the corresponding measured correlation
- At the burst edges, the power increased, while the correlation decreased! (opposite from expectation)
- The source of this discrepancy is still not understood
- Proposed solution: trim bursts so that anomalous regions are excluded
- Danger: data gaps may arise

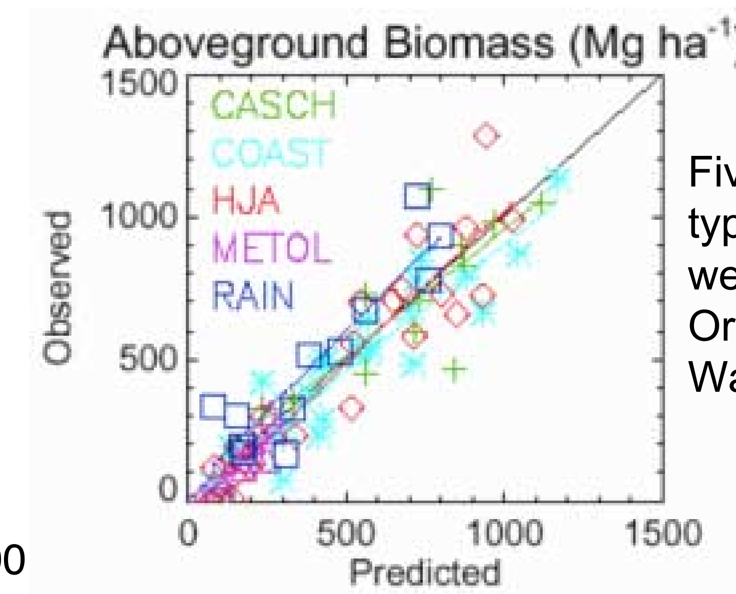
Waveform Estimation of Forest Above Ground Biomass

Based on regression of SLICER waveform indices and field observations of above ground forest biomass, mean height of the canopy squared is the best waveform-based predictor of biomass for a diverse set of forest types. The relationship is linear to high biomass levels, accounting for 80 to 90% of variance. Mean canopy height squared is a proxy for height x stem diameter (a measure of volume).



4.7 km SLICER waveform transect
10 m diameter footprints color-coded by plant density

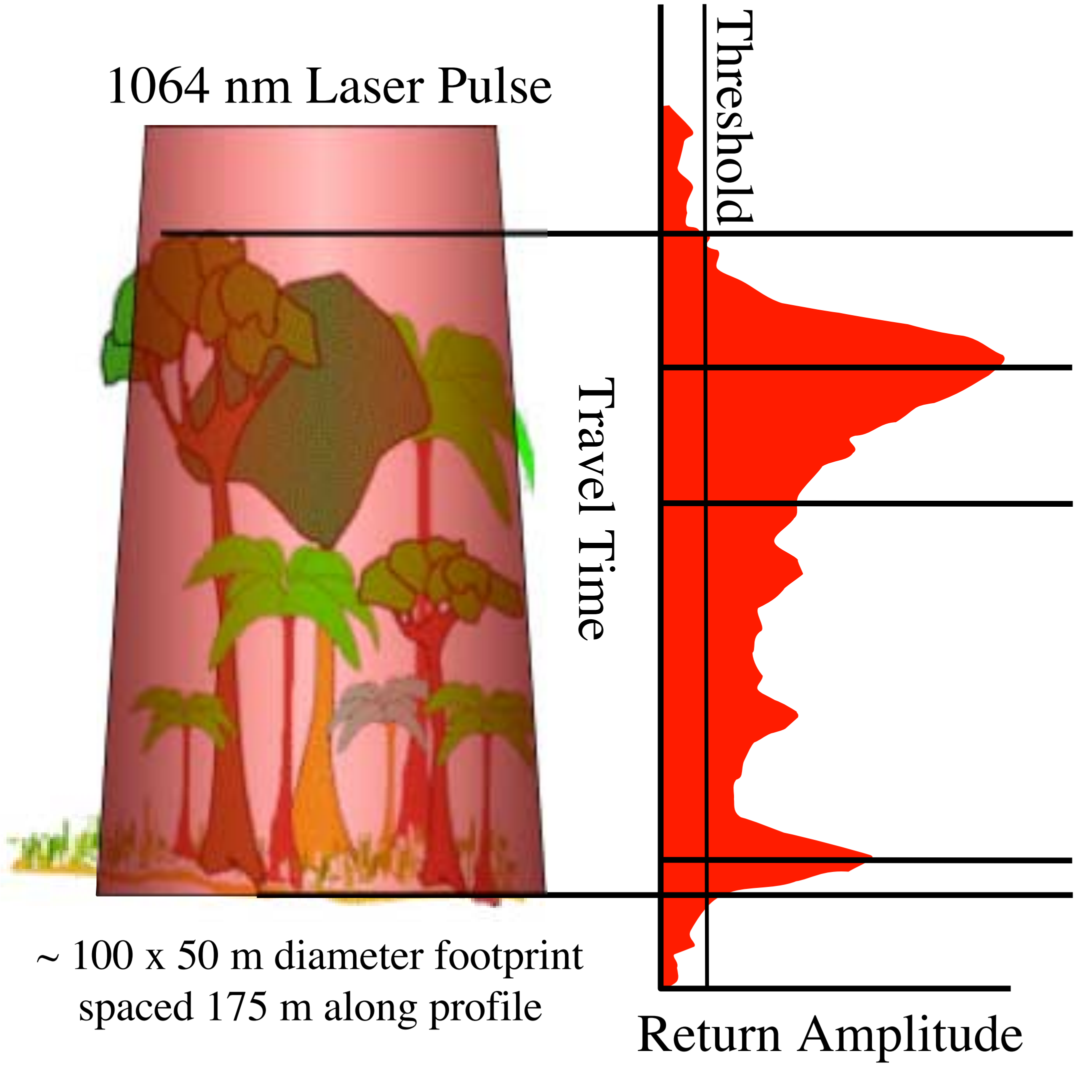




Five forest types in western Oregon and Washington

ICESat Waveform for Vegetated Landscape

Height Distribution of Reflected Laser Energy: 15 cm Vertical Sampling



ICESat Elevation Products

Signal Start
= highest detected elevation

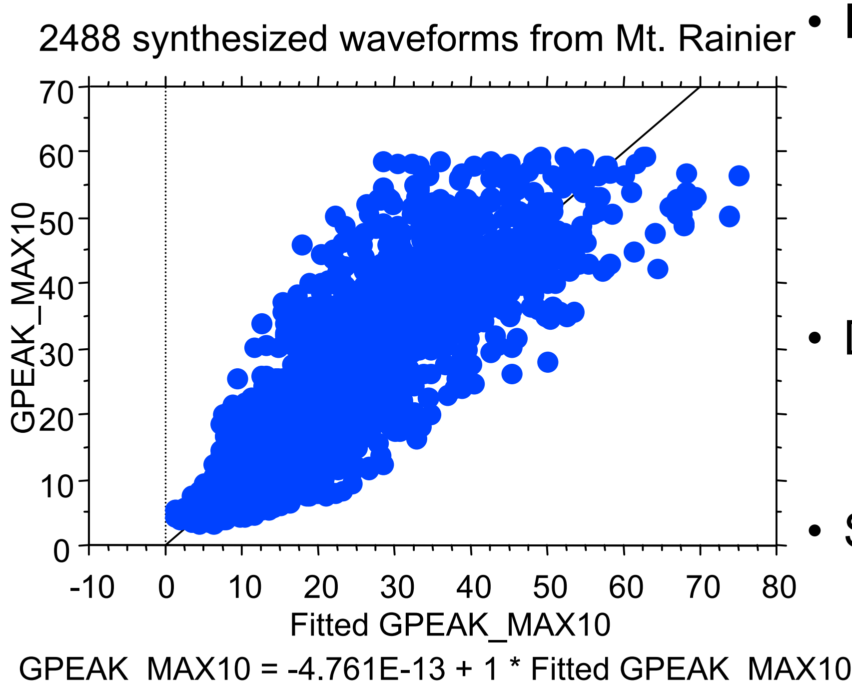
Gaussian Fit to Largest Peak
= standard "ice sheet" elevation

Centroid of Signal Start to End
= average detected elevation

Gaussian Fit to Last Peak
= ground elevation in flat areas

Signal End
= lowest detected elevation

Maximum Stand Height Retrieval from 75 m Waveforms



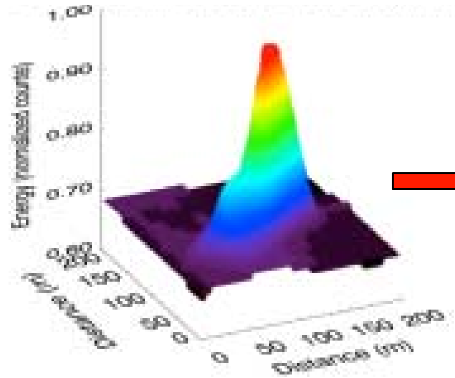
- Independent variables
  - synthesized from SLICER swath of 10 m footprints
  - 75 m waveform extent (EH)
  - range of ground elevations (ELEV_RANGE10)
  - range of canopy top elevations (TOPE_RANGE10)
- Dependent variable
  - maximum height of the 10 m waveforms (GPEAK_MAX10)
- Step-wise multiple regression
  - model explains 79.6% of variance
  - EH is the most important variable
  - range variables are each about half as important

Count	2448
Num. Missing	0
R	.892
R Squared	.796
Adjusted R Squared	.796
RMS Residual	3.738

	Coefficient	Std. Error	Std. Coeff.	F-to-Remove
Intercept	-1.092	.178	-1.092	37.680
EH	1.062	.012	2.814	7952.665
ELEV_RANGE10	-.516	.011	-1.211	2170.087
TOPE_RANGE10	-.500	.013	-1.191	1571.590

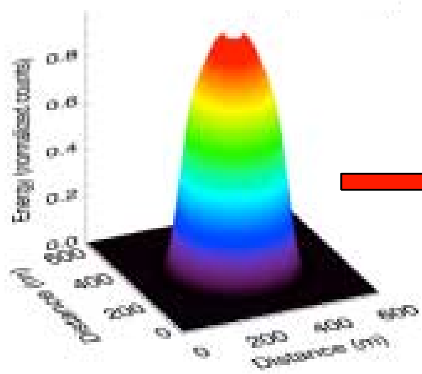
Validation of ICESat Waveforms

Laser Profiling Array (LPA) Image of Footprint Spatial Energy Pattern



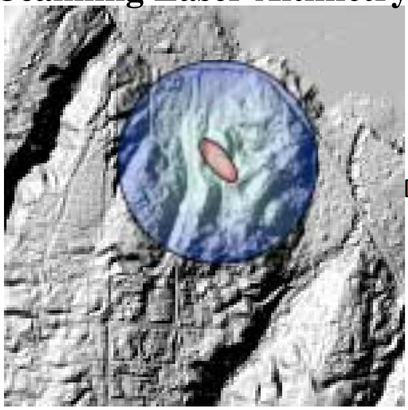
~ 120 m x 50 m full-width ellipse

1064 nm Receiver FOV Transmissivity



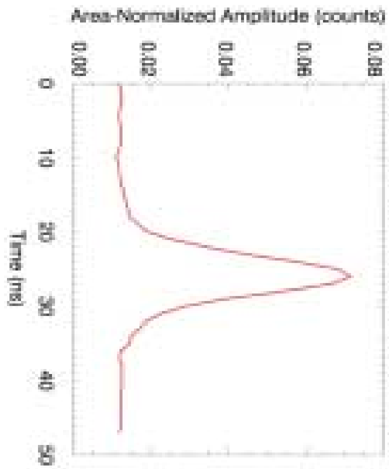
500 m full-width diameter

1.8 m DEM from Airborne Scanning Laser Altimetry

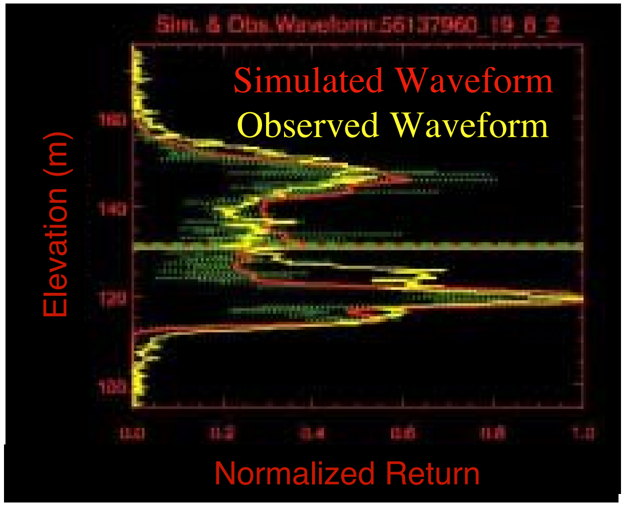


Spatial Convolution = Height Distribution of Reflected Laser Energy Within Footprint

Receiver Response for Transmit Pulse



Temporal Convolution = Simulated Waveform

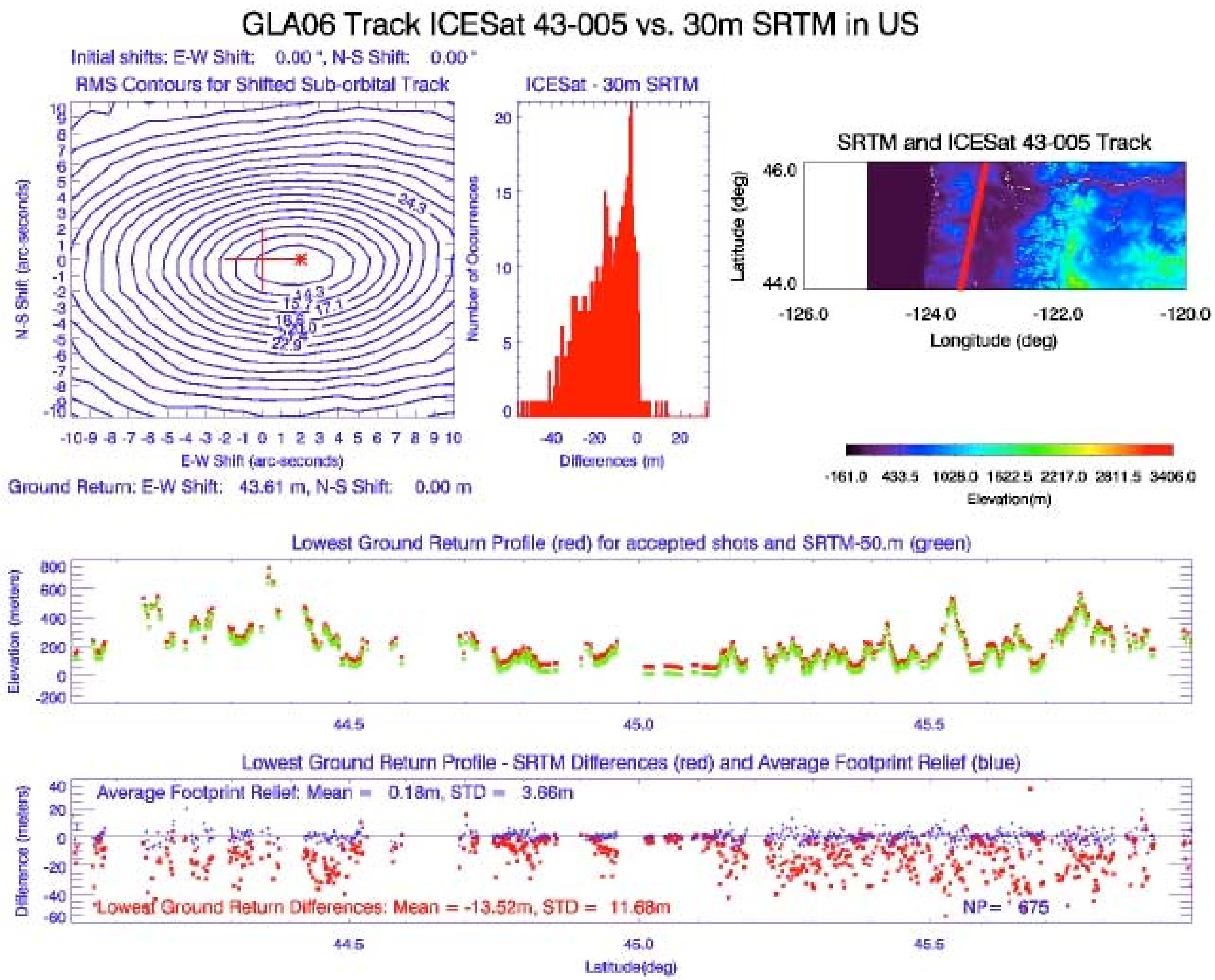


Identify Waveform Best Fit Location from Canopy DEM

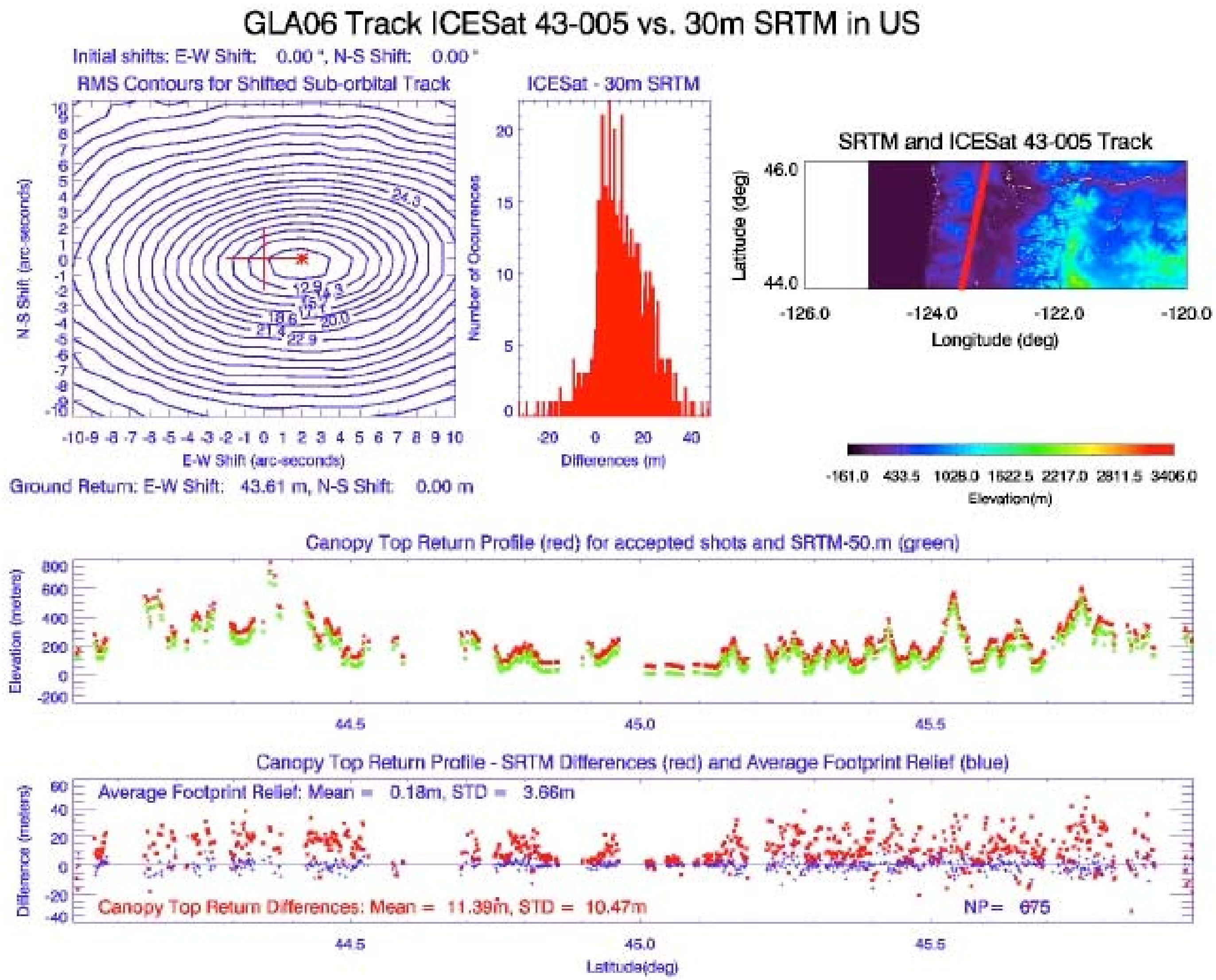
Comparison to high-resolution airborne laser mapping data demonstrates that ICESat waveforms provide detailed and accurate information on the within-footprint distribution of surface heights for forested landscapes

Simulation results by
Claudia Carabajal, NVI @ GSFC

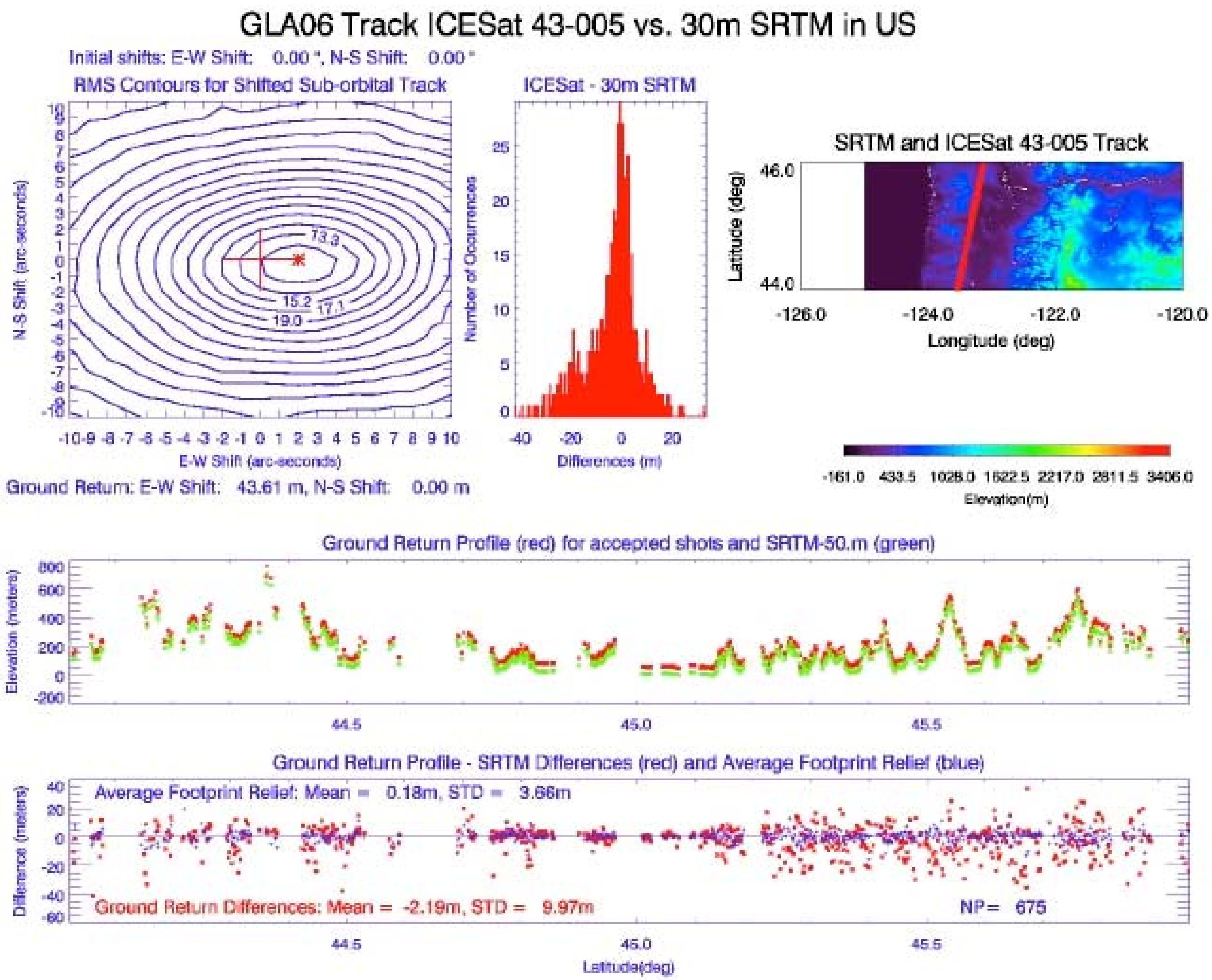
ICESat Signal End vs. SRTM DEM



ICESat Signal Start vs. SRTM DEM



ICESat Largest Peak vs. SRTM DEM



ICESat vs. SRTM Elevation Differences

ICESat 8-day Track 43 across Puget Lowland, Washington State

Latitude 48° - 49° very low relief / Latitude 46° - 48° low relief

Canopy Top

ICESat Track & Cycle	Mean (m)	STD (m)	ICESat Track & Cycle	Mean (m)	STD (m)
43-002	4.70	7.16	43-002	6.12	8.36
43-003	2.48	4.94	43-003	7.04	10.70
43-004	4.75	6.33	43-004	9.67	9.06
43-005	3.16	8.00	43-005	9.38	10.13
43-029	2.75	5.15	43-029	7.40	10.55
Mean	**3.57**	**6.32**	**Mean**	**7.92**	**9.76**
STD	**1.08**	**1.30**	**STD**	**1.54**	**1.01**

Largest Peak

ICESat Track & Cycle	Mean (m)	STD (m)	ICESat Track & Cycle	Mean (m)	STD (m)
43-002	-0.89	5.93	43-002	-0.85	7.24
43-003	-0.69	3.95	43-003	-2.59	7.74
43-004	0.22	5.73	43-004	-1.39	7.38
43-005	-2.18	6.46	43-005	-3.24	8.27
43-029	-1.10	3.88	43-029	-1.15	9.11
Mean	**-0.93**	**5.19**	**Mean**	**-1.84**	**7.95**
STD	**0.86**	**1.19**	**STD**	**1.02**	**0.76**

Lowest Ground

ICESat Track & Cycle	Mean (m)	STD (m)	ICESat Track & Cycle	Mean (m)	STD (m)
43-002	-3.85	6.77	43-002	-11.72	8.55
43-003	-3.02	4.52	43-003	-7.53	8.46
43-004	-3.05	6.61	43-004	-9.25	9.87
43-005	-4.93	7.30	43-005	-10.39	8.83
43-029	-2.35	4.45	43-029	-9.89	9.17
Mean	**-3.44**	**5.93**	**Mean**	**-9.76**	**8.98**
STD	**0.99**	**1.34**	**STD**	**1.54**	**0.57**

Conclusions

- GeoSAR X- and P-band InSAR canopy parameters are positively correlated with lidar-estimated canopy structure parameters measured by SLICER, but the correlations are not always linear, they are a function of radar incidence angle and vegetation cover type, and there is significant uncorrelated variance in the InSAR parameters.

- SRTM correlation ripples impart systematic errors in the C-band penetration product (scatterer standard deviation). On a large scale there is good agreement between penetration estimates and vegetation classes, but on a pixel basis there are substantial errors introduced by the calibration ripples. Efforts to identify the source and reduce the effect of the ripples are ongoing.

- Retrieval of maximum stand height (and therefore biomass) from lidar waveform large diameter waveforms can be achieved with reasonably high accuracy, especially if independent information is available on topographic relief as can be provided by SRTM (the correlation ripples do not impact the SRTM elevation data).