Comparison of Airborne LIDAR and SRTM C-Band Elevations for a Vegetated Landscape

David Harding
Laboratory for Planetary Geodynamics
NASA Goddard Space Flight Center

Shuttle Radar Topography Mission
Data Validation Workshop
Reston, VA
June 15, 2005

NASA SENH Project: Lidar Validation of SRTM Topography

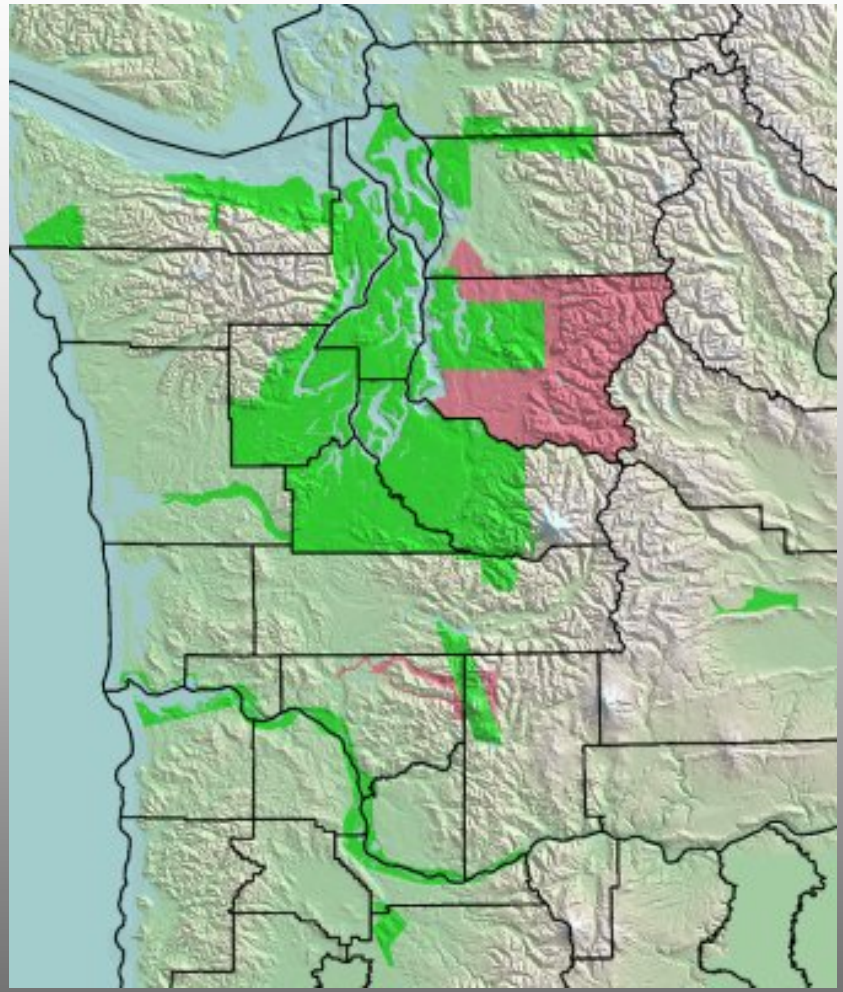
OBJECTIVES

- Establish empirical relationships between lidar elevation data and the SRTM C-band DEM as a function of geographic region, land cover type, and slope.
- Quantify systematic and random errors in the SRTM elevation data based on the distributions of lidar to SRTM elevation differences.
- Evaluate radar phase center elevation biases in vegetated regions utilizing the lidar capability to measure canopy vertical structure and the elevation of the underlying ground.

Overview

- **Description of Puget Sound Lidar Consortium data**
  - Classified lidar discrete-return point cloud
  - Lidar highest surface (canopy top) and bald Earth DEMs
  - 1.8 m grid spacing
  - Availability
- **Registration and resampling of SRTM to Lidar DEM**
- **Analysis of Lidar DEM vs. up-sampled SRTM differences**
  - As a function of lidar canopy height, ground slope and azimuth
- **Future Work**
  - Elevation differences a function of canopy openness and roughness derived from point cloud

Puget Sound Lidar Consortium (PSLC)



Puget Sound Lidar Consortium

Other public surveys (limited canopy data)

Public-domain high-resolution topography

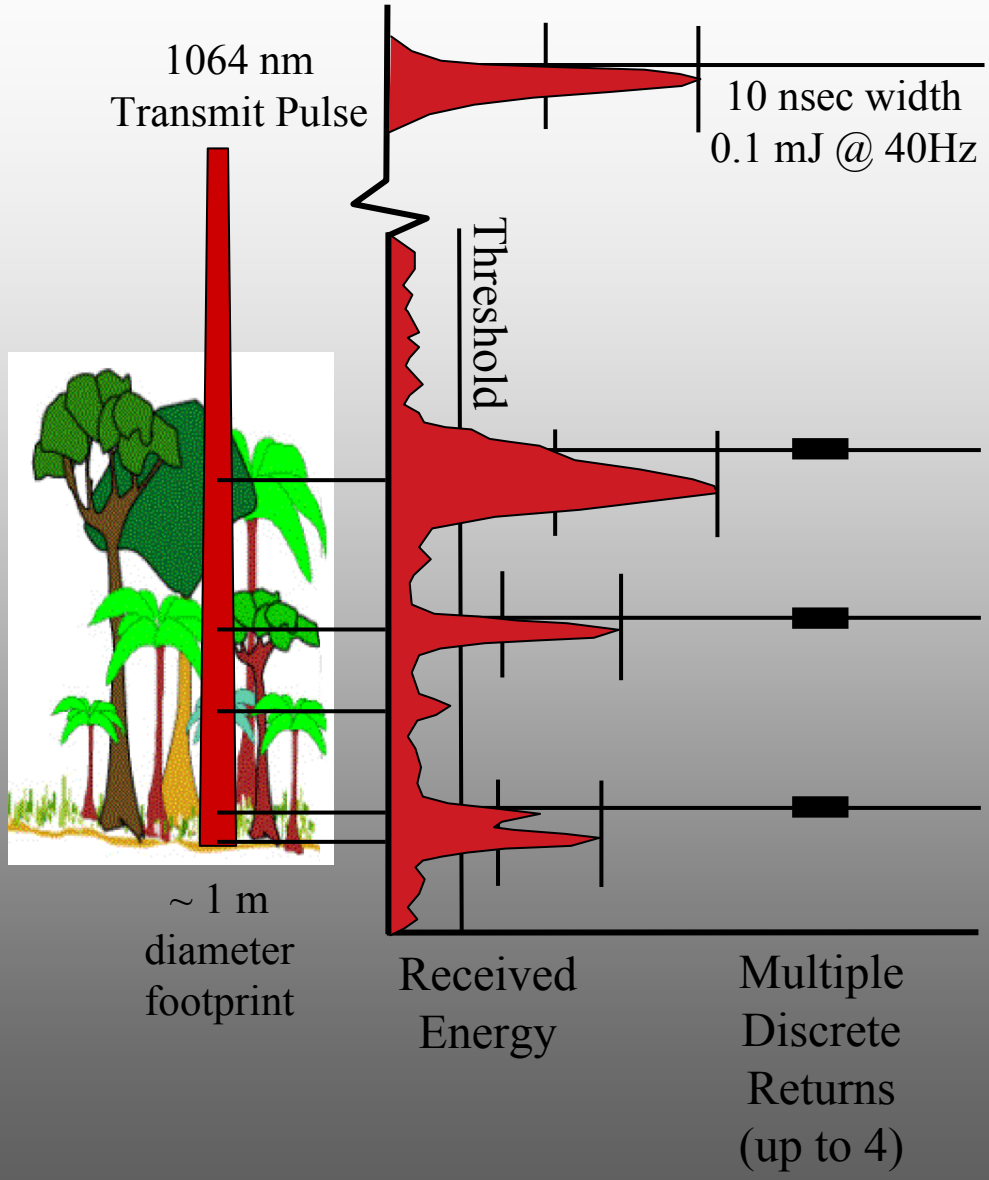
- **Airborne lidar swath mapping**
- **http://www.pugetsoundlidar.org**
- **http://core2.gsfc.nasa.gov/lidar/terrapoint**

- **Federal-local multi-agency collaboration**
  - **Local counties and municipalities**
  - **Regional transportation council**
  - **USGS & NASA**
- **Contract with TerraPoint, LLC**
  - **Competitively selected commercial vendor**
  - **2000-05 Jan-March leaf-off data acquisition**
  - **~15,000 sq km of Puget Lowland mapped**
  - **1 pulse per sq m = 15 billion laser pulses**
  - **Up to 4 discrete returns per laser pulse**
  - **Return intensity for more recent mapping**
  - **Deliverables:**

classified point cloud (ground, canopy, buildings)

highest surface and bald Earth DEMs (1.8 m grid)

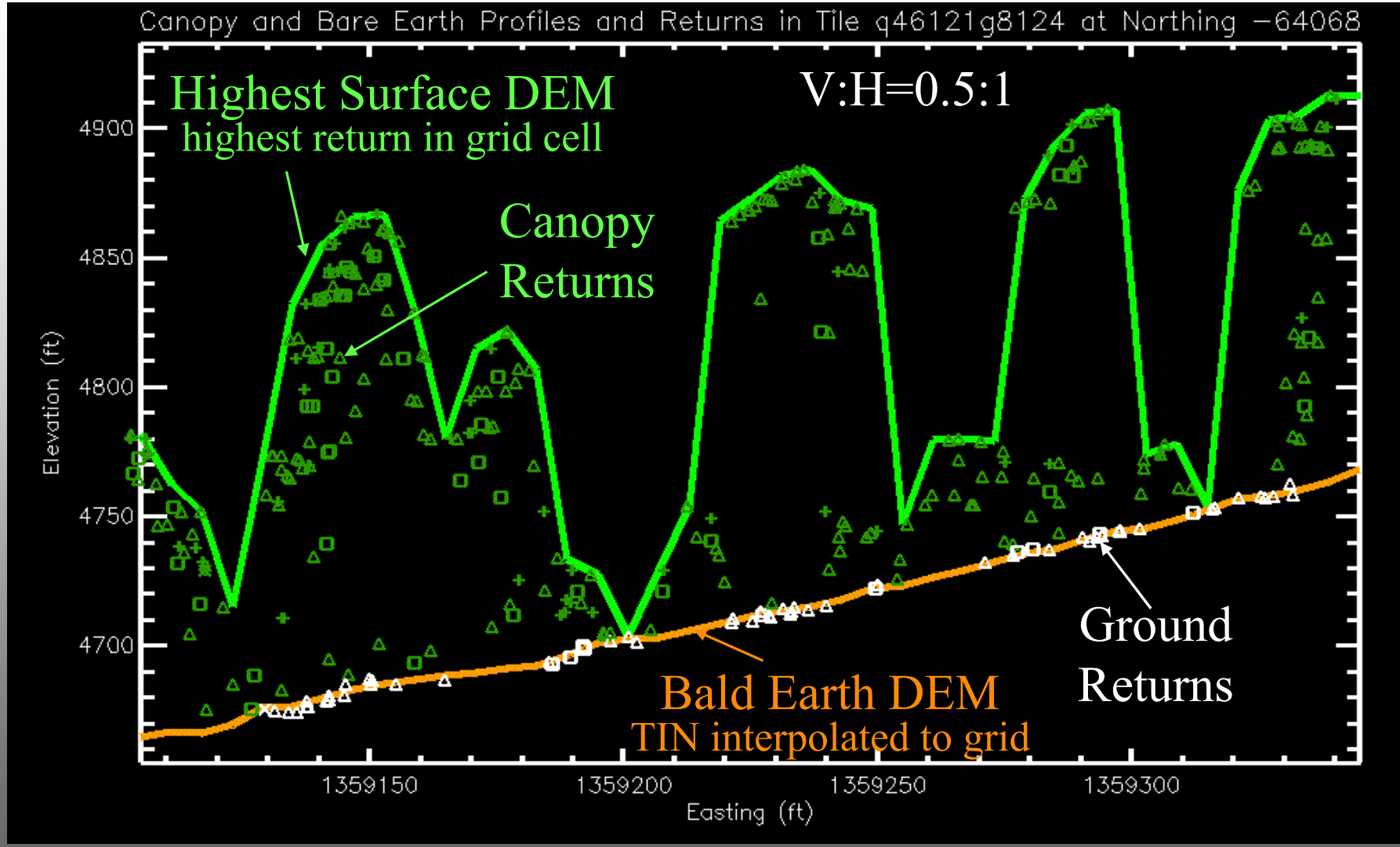
TerraPoint Discrete Return Laser Ranging



Measurement Approach

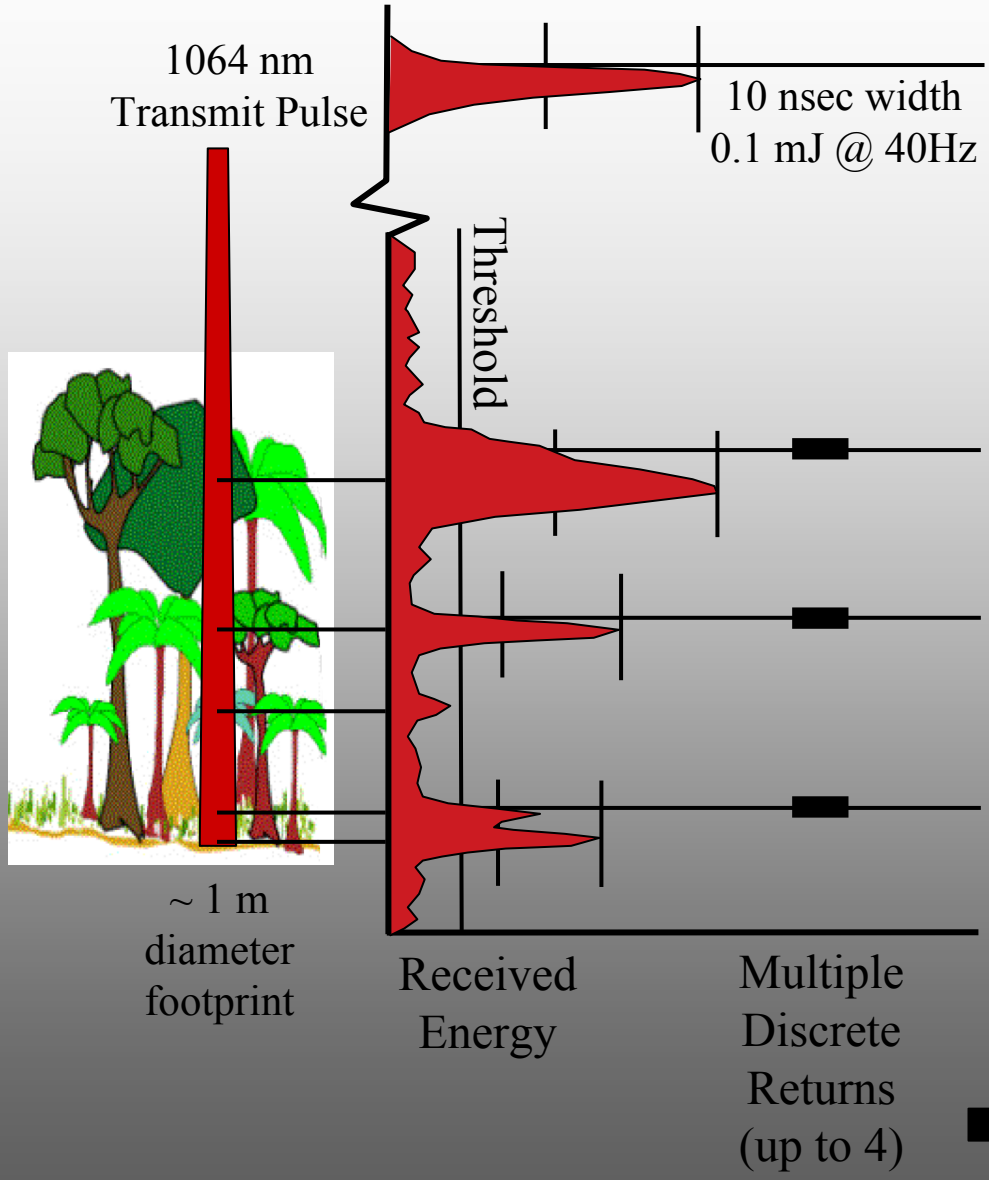
- Short duration, small diameter, near-infrared laser pulse
- Reflected photons collected by telescope
- Si:APD detectors converts photons to output voltage
- Up to four discrete return where received energy exceeds a threshold level
- Travel time determined by leading-edge constant-fraction discriminator, to minimize range walk
- Variable gain amplifier to accommodate changing signal strength as a function of changing ranging distance due to topographic relief (for later surveys)
- Received energy recorded for each return (for later surveys)

Highest Surface and Bald Earth DEMs From Classified Point Cloud



First returns =Δ; second returns =□; third returns = +; fourth returns are very rare.

Discrete Return Laser Ranging



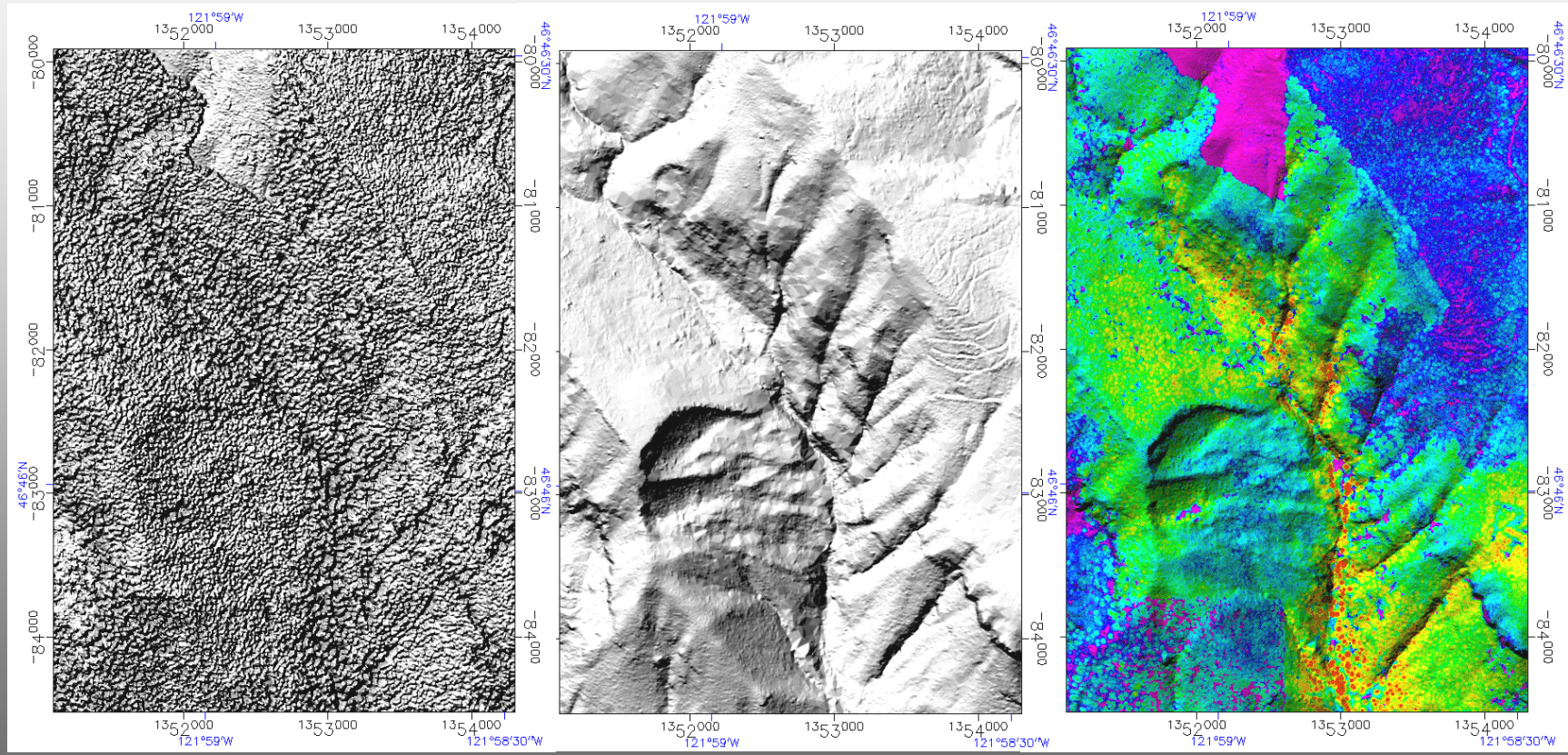
All Lidar Surveys are not Equal

- Surveys with low sampling density (e.g., 5 x 5 m posting) will under-sample tree crowns and ground relief beneath canopy
- Systems with lower signal-to-noise or a too-high threshold will be less sensitive to weak returns (from sparse canopy and/or ground mostly covered by canopy)
- Systems with constant threshold and gain will be less sensitive where ranging distance is greater (e.g. valley bottoms)
- Detection of ground beneath short-stature vegetation (e.g., grass, ferns, shrubs) difficult for all leading-edge, discrete return systems but especially so for those with larger pulse widths and/or detector bandwidths

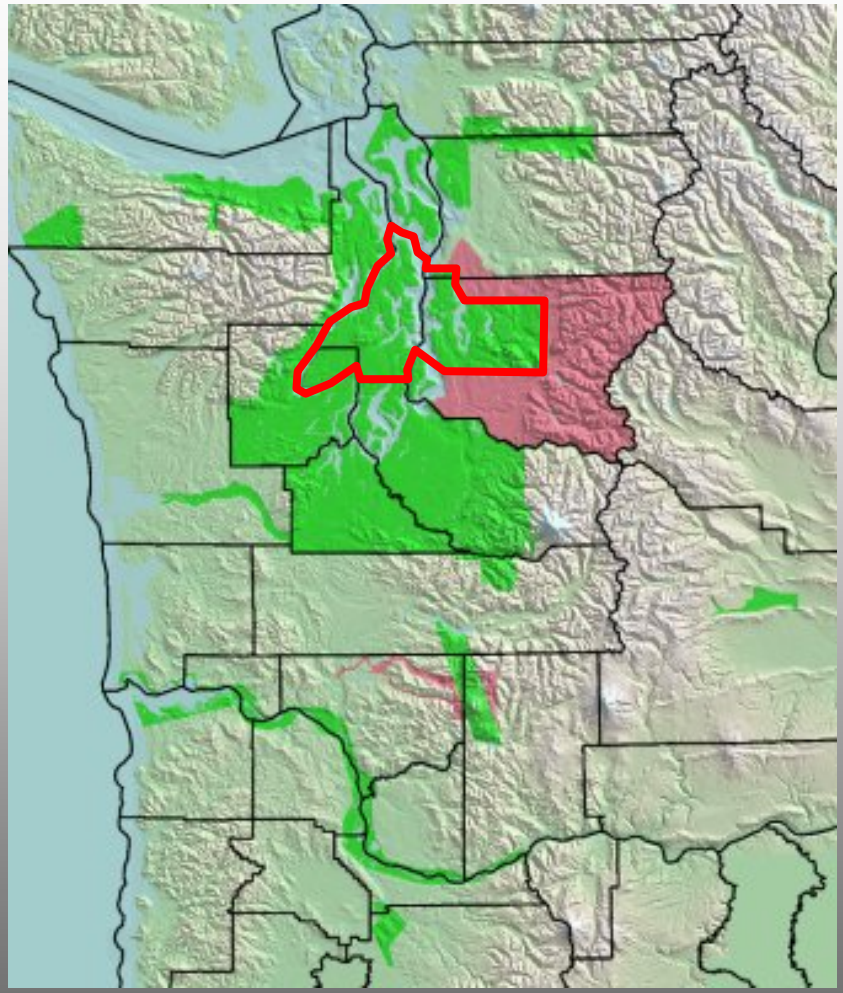
➡ **underestimate of canopy height**

Highest Surface and Bald Earth DEMs

Highest Surface | Bald Earth | Highest Surface - Bald Earth



Improving PSLC Data Through Time



Puget Sound Lidar Consortium

Other public surveys (limited canopy data)

Initial 2000 Survey:

Kitsap, King, and NE Thurston Counties

"Highest" Surface DEM

- Distance-weighted average of all 1st returns

Bald Earth vegetation & building removal

- Virtual Deforestation (Haugerud & Harding, 2002)

Pointing Calibration

- No overlapping swath adjustment = cross-track tilts

Subsequent Surveys:

Highest Surface DEM

- Highest 1st return within 6 foot pixel
- No data value for pixels lacking returns (e.g. water)

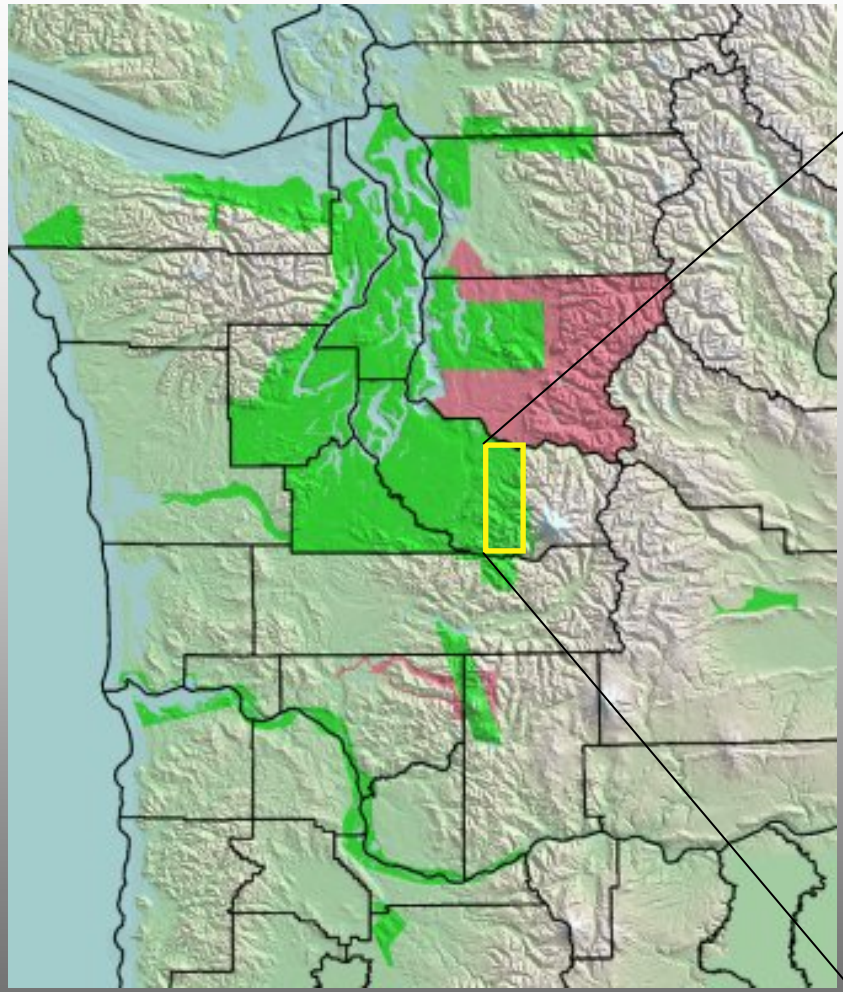
Bald Earth vegetation & building removal

- TerraScan commercial software

Pointing Calibration

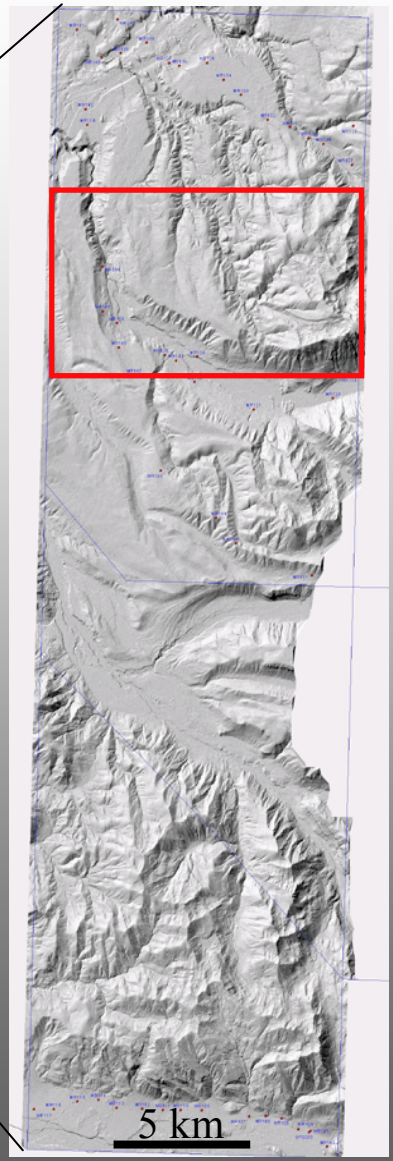
- Overlapping swath adjustment minimizes tilts

Western Mount Rainier Airborne Lidar Survey



Puget Sound Lidar Consortium

Other public surveys (limited canopy data)



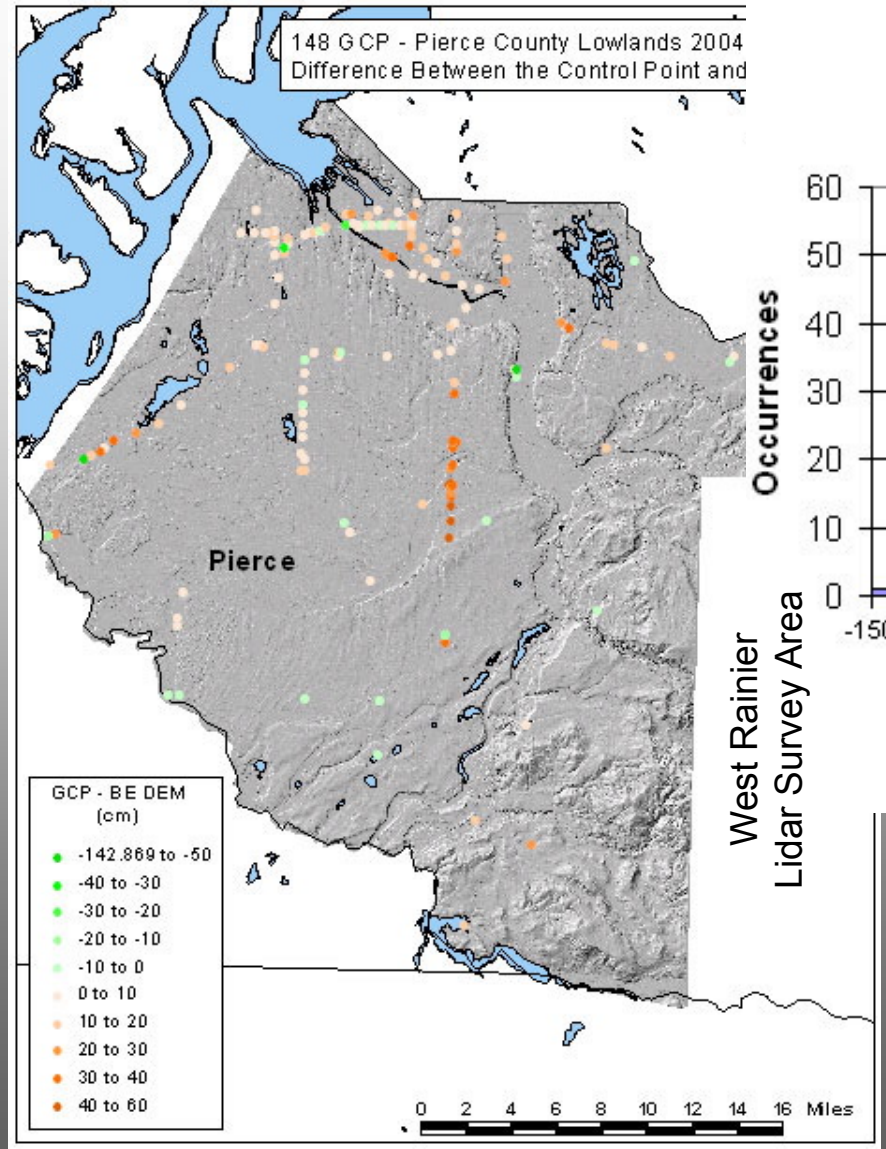
Acquired:
Nov-Dec, 2002
Snow-free
Deciduous leaf-off
2 laser pulses per m^2

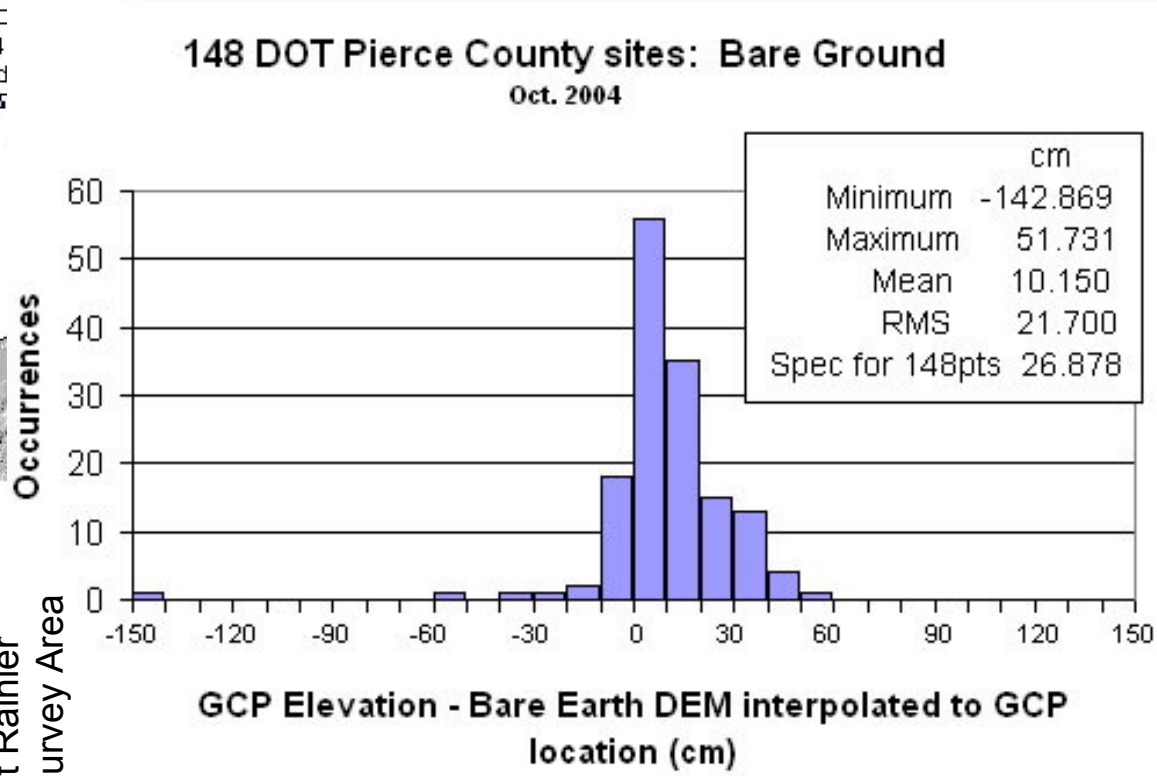
DEMs:
Highest surface
Bald Earth

DEM grid resolution:
1.8 m (6 survey feet)

Projection: State Plane
Zone: Washington North
Horizontal Units: US Survey Ft
(integer postings divisible by 6)
Vertical Units: International Ft
(signed floating point)
Spheroid: GRS80
Datums:
Horizontal: NAD83, 1991 Adj.
Vertical: NAVD88
(using NGS GEOID-99)

Western Pierce County Bald Earth DEM Validation Using 148 WA DOT Survey Points





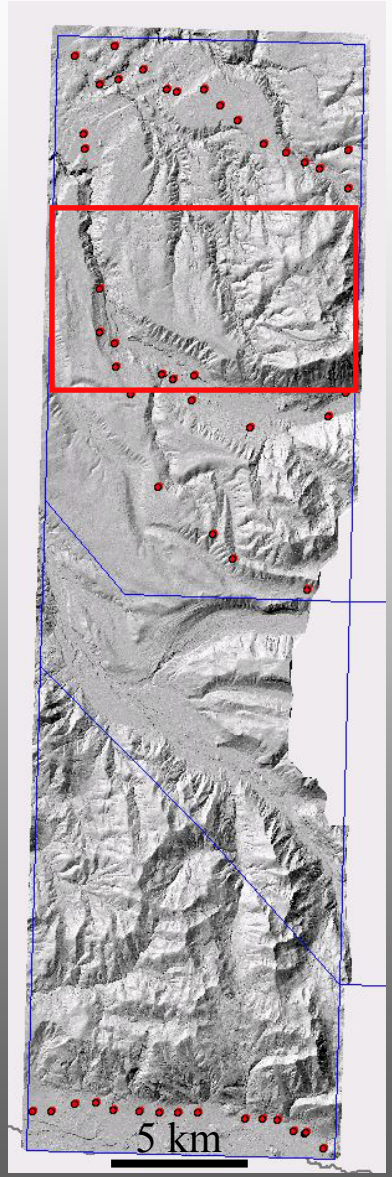
Flat, Non-vegetated Areas

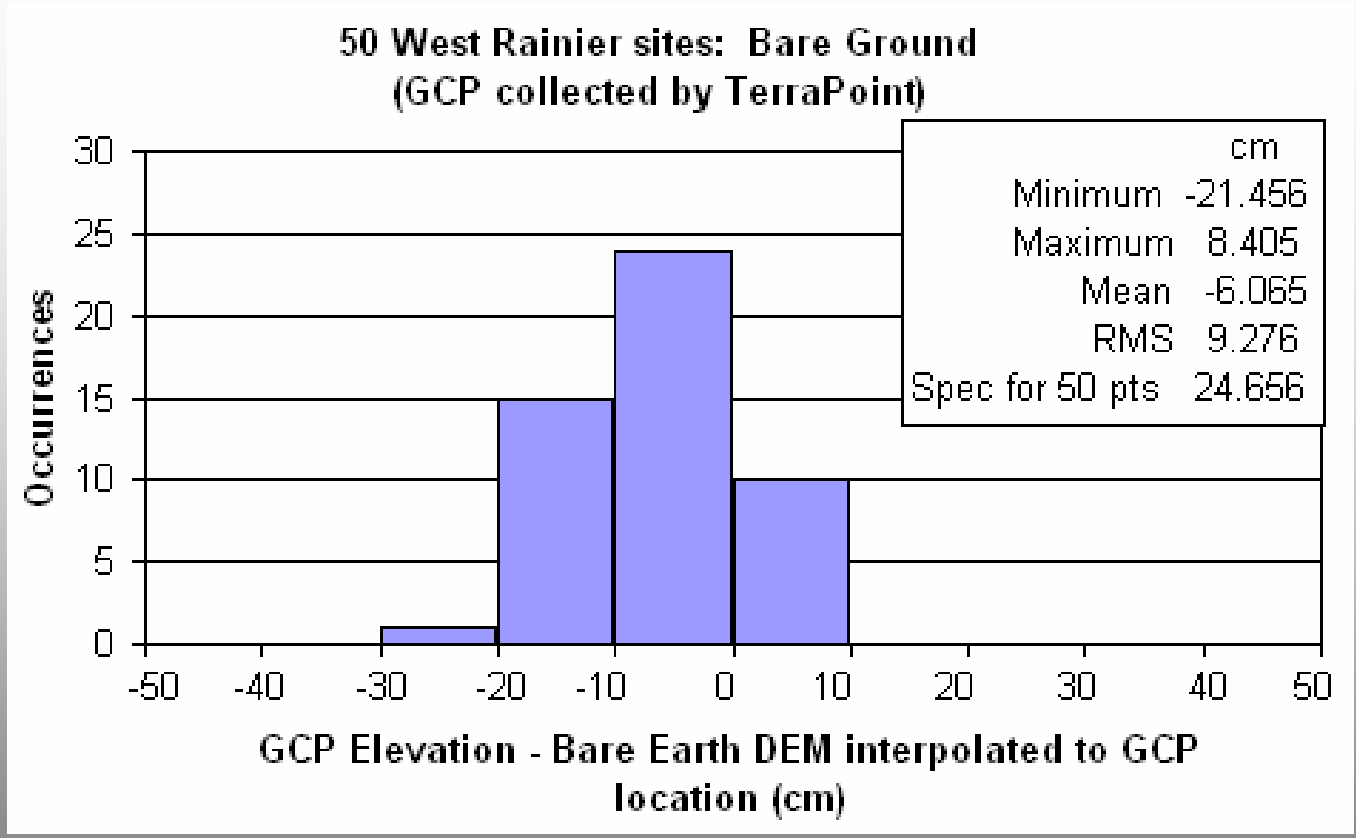
Mean elevation difference = 10 cm

RMSE = 22 cm

(from D. Martinez, PSRC)

West Rainier Bald Earth DEM Validation Using 50 TerraPoint Rapid Static D-GPS Points





Flat, Non-vegetated Areas

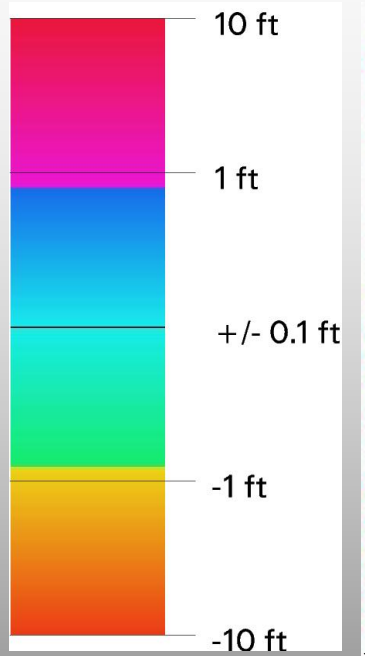
Mean elevation difference = -6 cm

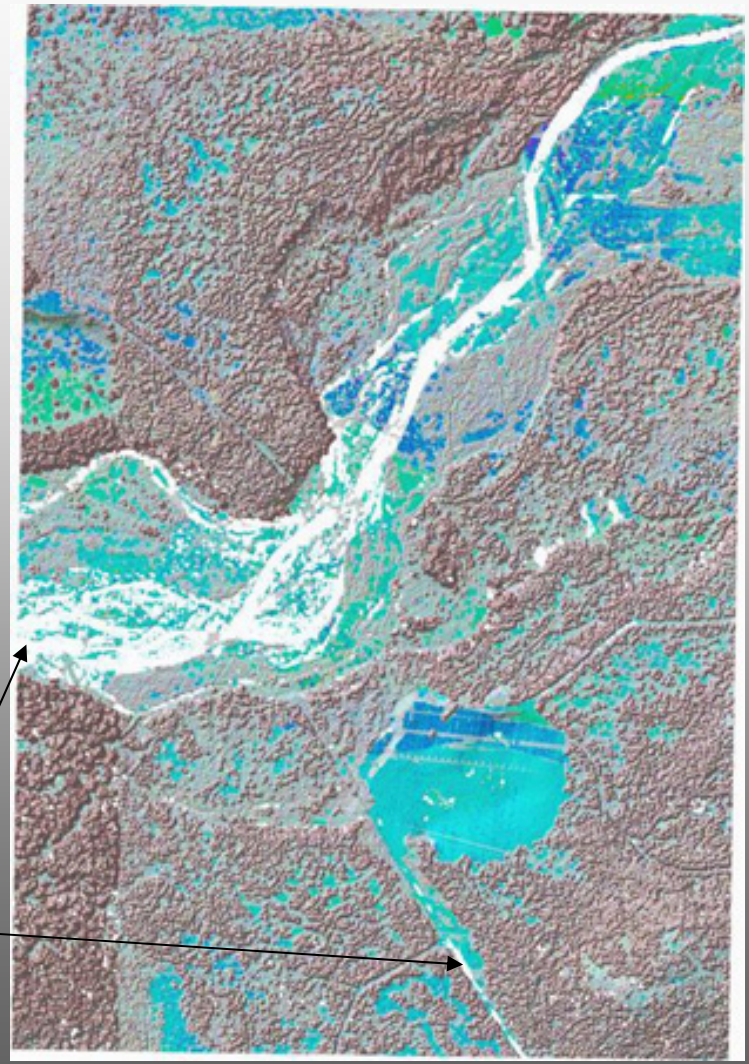
RMSE = 9 cm

(from D. Martinez, PSRC)

Elevation Comparison of Overlapping Swaths

Point cloud tile: 1/100th of USGS 78.5” quadrangle





Data Voids:

specular water

low-reflectance fresh asphalt

Reproducibility

Elevation differences between two highest surface DEMs created from overlapping swaths:

Per tile RMSE ~ 20 to 40 cm for all slopes where non-vegetated

≥ 50% swath side-lap enables test anywhere (typically ~1/5 of tiles tested)

(from R. Haugerud, USGS)

PSLC Data Availability and Manipulations

- Delivered as ESRI Arc e00 export files in USGS 7.5” quarter-quads
  - survey feet horizontal units referenced to pixel center; international foot vertical units
  - available online at http://www.pugetsoundlidar.org
- Converted to binary floating-point grid using Arc gridfloat
- ENVI header file manually created from gridfloat header file
  - referenced to pixel corner, inadvertently introducing 3 foot easting and northing shift
- Quarter-quads mosaiced in ENVI
- Exported as floating point survey feet geotiffs
  - West Rainier, Darrington-Devils Mtn., Mount St. Helens and northern San Andreas only
  - available at http://core2.gsfc.nasa.gov/lidar/terrapoint with extensive documentation
  - will be available through EarthScope Data Portal with FGDC-compliant meta-data
- Classified point cloud data not available on-line
  - compressed ASCII files distributed by request on DVD or portable hard-drive
  - each return: gps_week, gps_sec, easting, northing, elevation, # of returns, return #, angle, intensity, class
  - intensity parameter collected starting fall, 2002 (but is invalid for much of Rainier)
- USGS EDC Seamless Server data is a derivative subset
  - conversion to 1/9” (3.3 m) lat/long introduces small errors (see EDC metadata)
  - bald Earth only; no highest surface; early PSLC data; not up-to-date; no point cloud

SRTM Registration and Resampling to Lidar

- Used 4 research grade 1° x 1° cells distributed by USGS EDC
- Used ENVI SRTM DEM ingest and mosaiced 2 x 2 cell array
- Converted to Lidar projection using ENVI built-in transform with up-sampling to 6 foot grid using nearest neighbor resampling
  - How accurate is ENVI transform from WGS-84 lat/long to NAD83 state plane?
  - Must account for survey foot vs. international foot

    ENVI does not have survey foot unit; must enter it as a user defined unit

    Survey foot = 1200/3937 meters ~ 0.30480061 meters; international foot = 0.3048 m

    Rainier near easting, northing origin for Washington north so potential error < 1 m

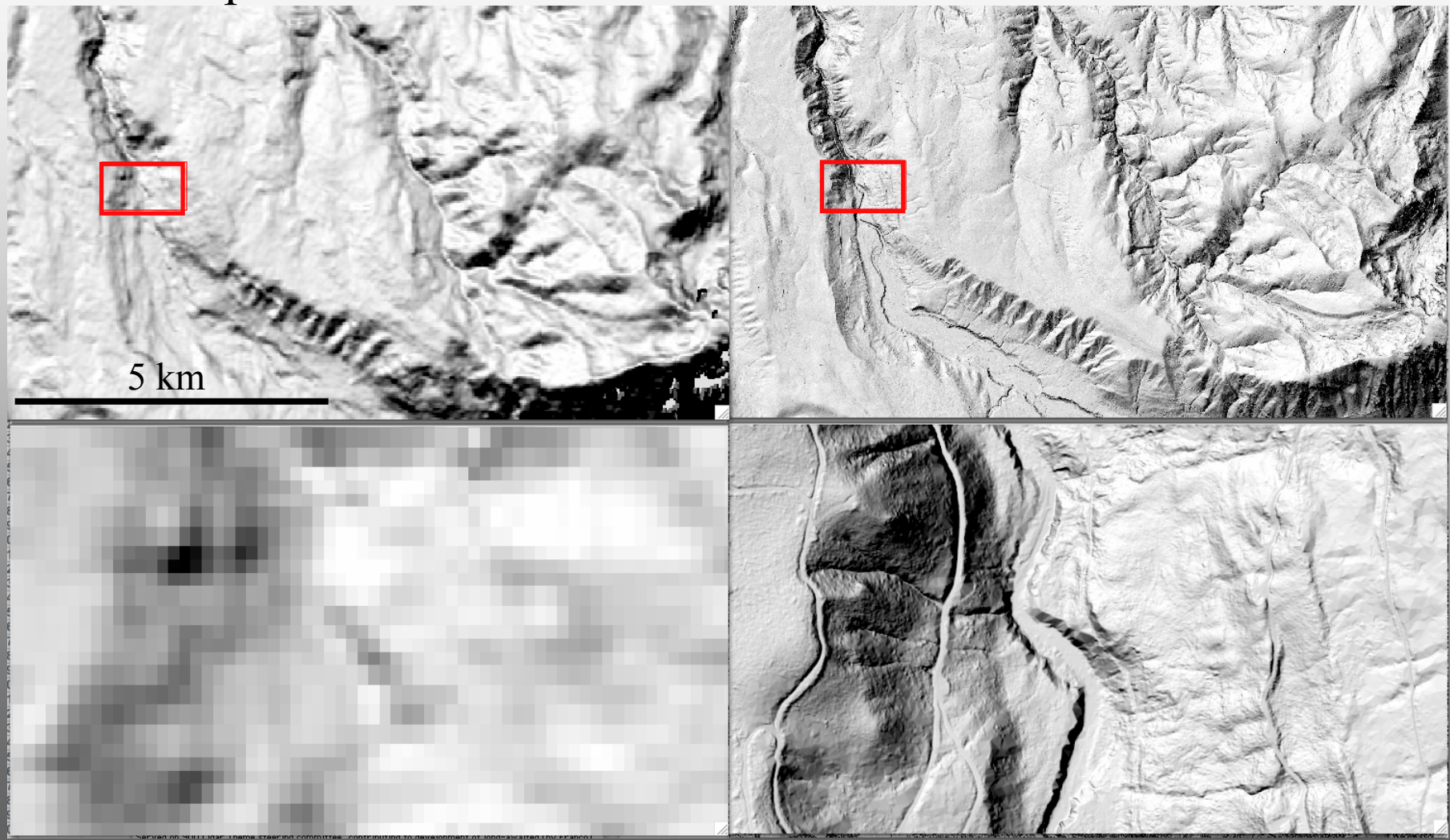
    (for areas far from easting, northing origin the horizontal error can be ~ 10 m)
- Is EDC SRTM referenced to pixel center or pixel corner?
  - Potential horizontal error of 1/2 pixel in x and y (~15 m)
  - Examination of header indicates ENVI assumes referencing to pixel corner
- No spatially varying horizontal displacements applied

Shaded Relief DEM Representations

SRTM 30 m DEM
C-band phase center

6270 x 3586 arrays
~ 22 x10^6 pixels

Lidar 1.8 m DEM
Bald Earth

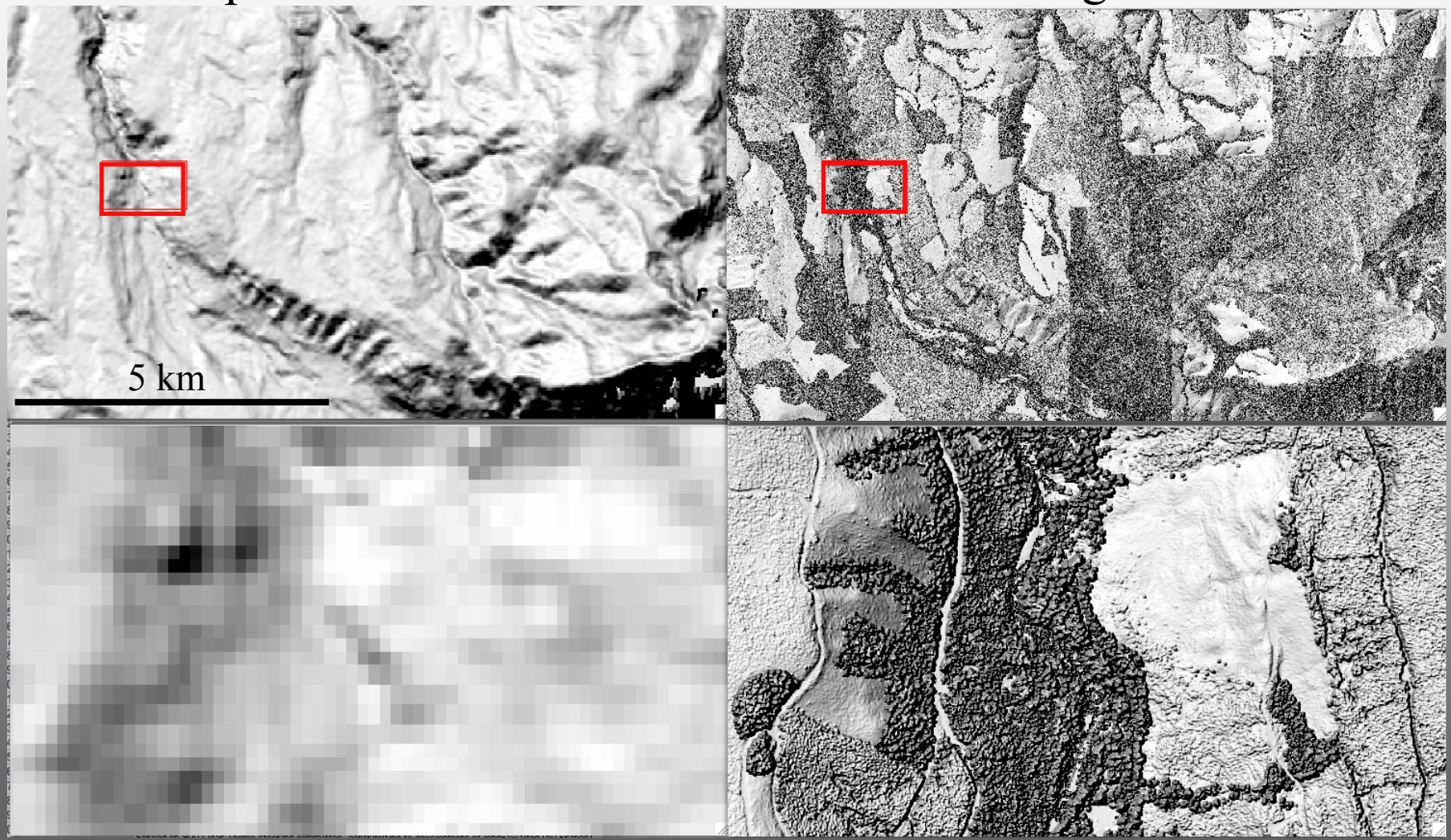


Shaded Relief DEM Representations

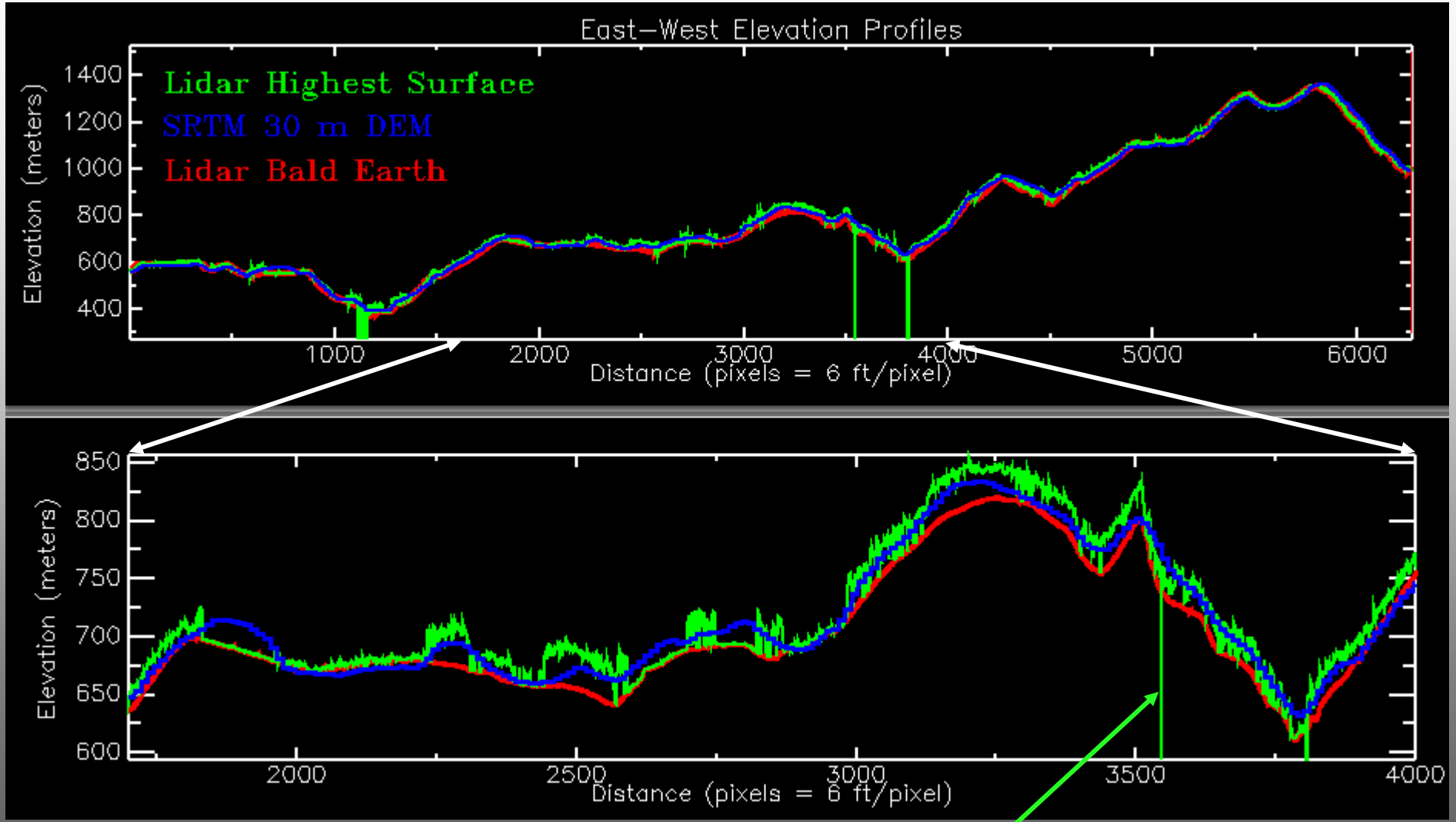
SRTM 30 m DEM
C-band phase center

6270 x 3586 arrays
~ 22 x10^6 pixels

Lidar 1.8 m DEM
Highest Surface

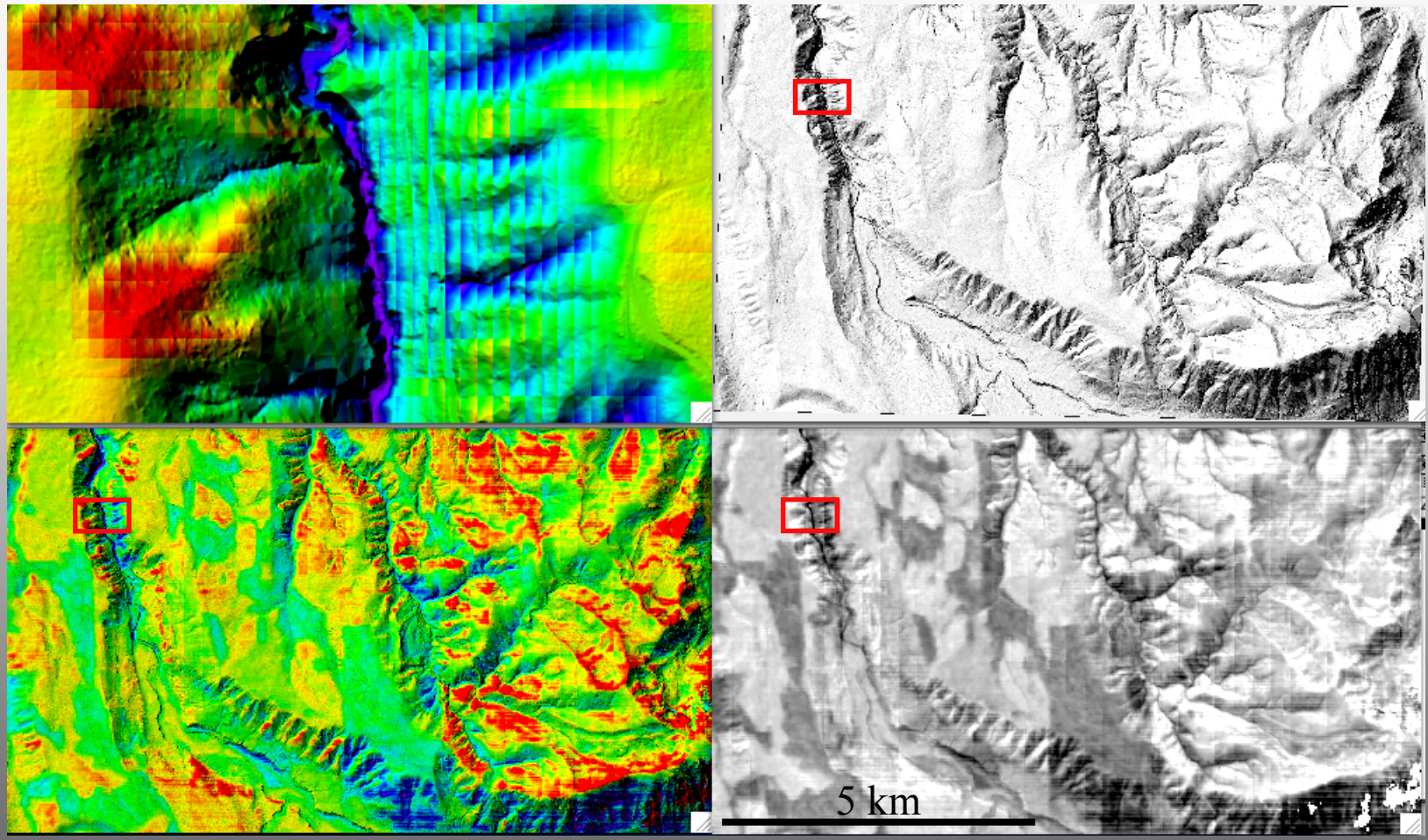


Representative Elevation Profiles



Lidar Bald Earth – SRTM Elevation Difference

Lidar Bald Earth Shaded Relief



Shaded Relief Colored by Difference Lidar – SRTM Elevation Difference

Yellow to red: + difference, Green to blue: – difference

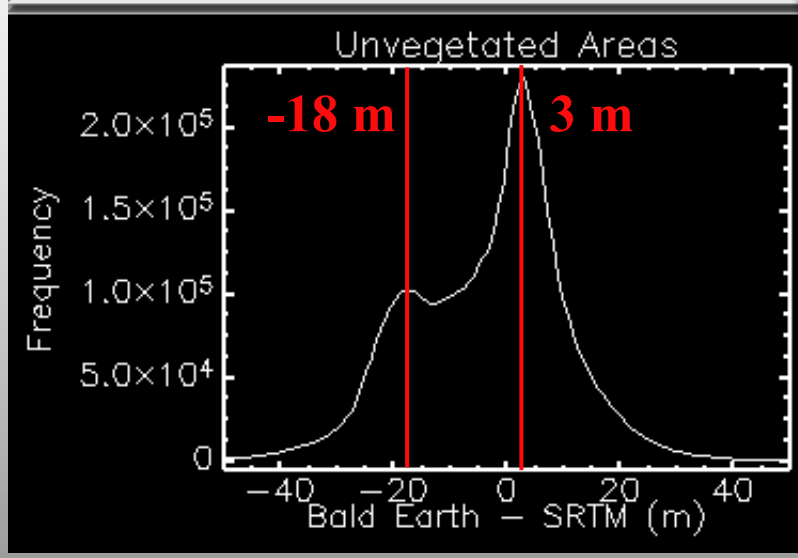
Lidar Bald Earth – SRTM Elevation Difference

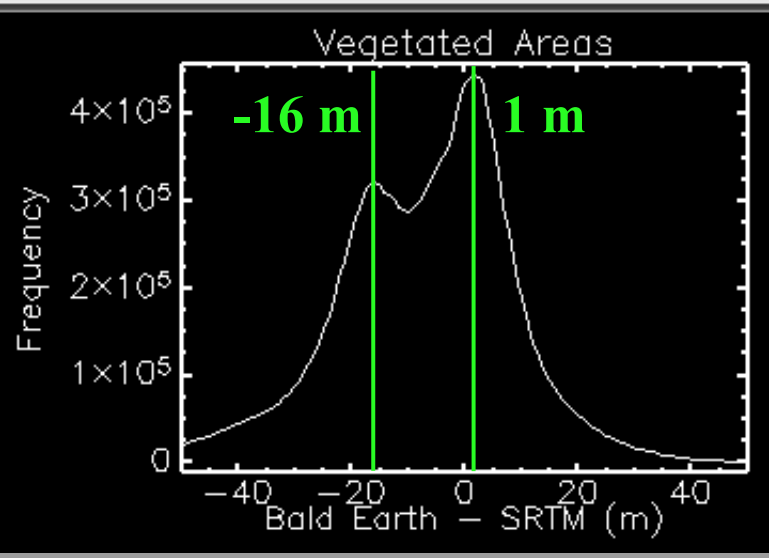
Dims: Full Band (6257397 points)

Band	Min	Max	Mean	Stdev
1	-100.160645	120.620972	-2.970541	13.651753

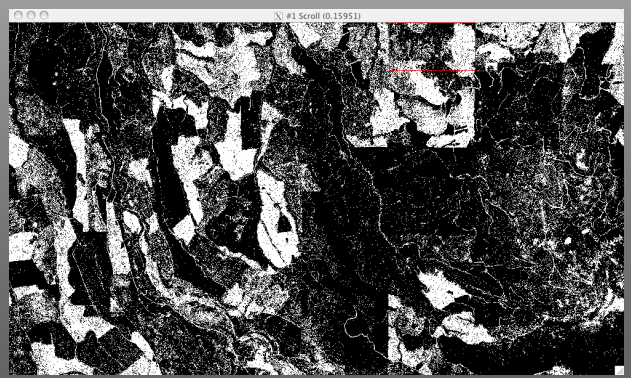
Dims: Full Band (22484220 points)

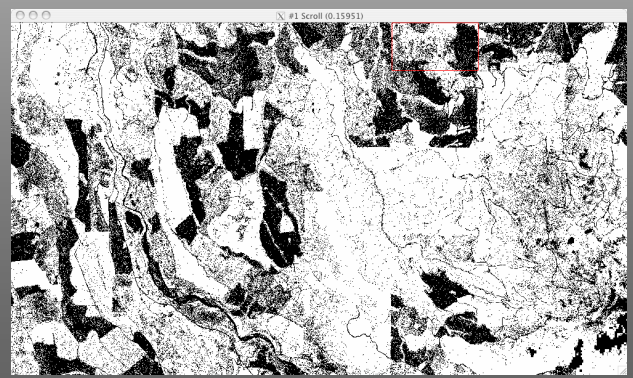
Band	Min	Max	Mean	Stdev
1	-99.026855	125.860840	-6.735726	16.004823





Non-vegetated Areas H.S. DEM < 1 m above B.E. DEM

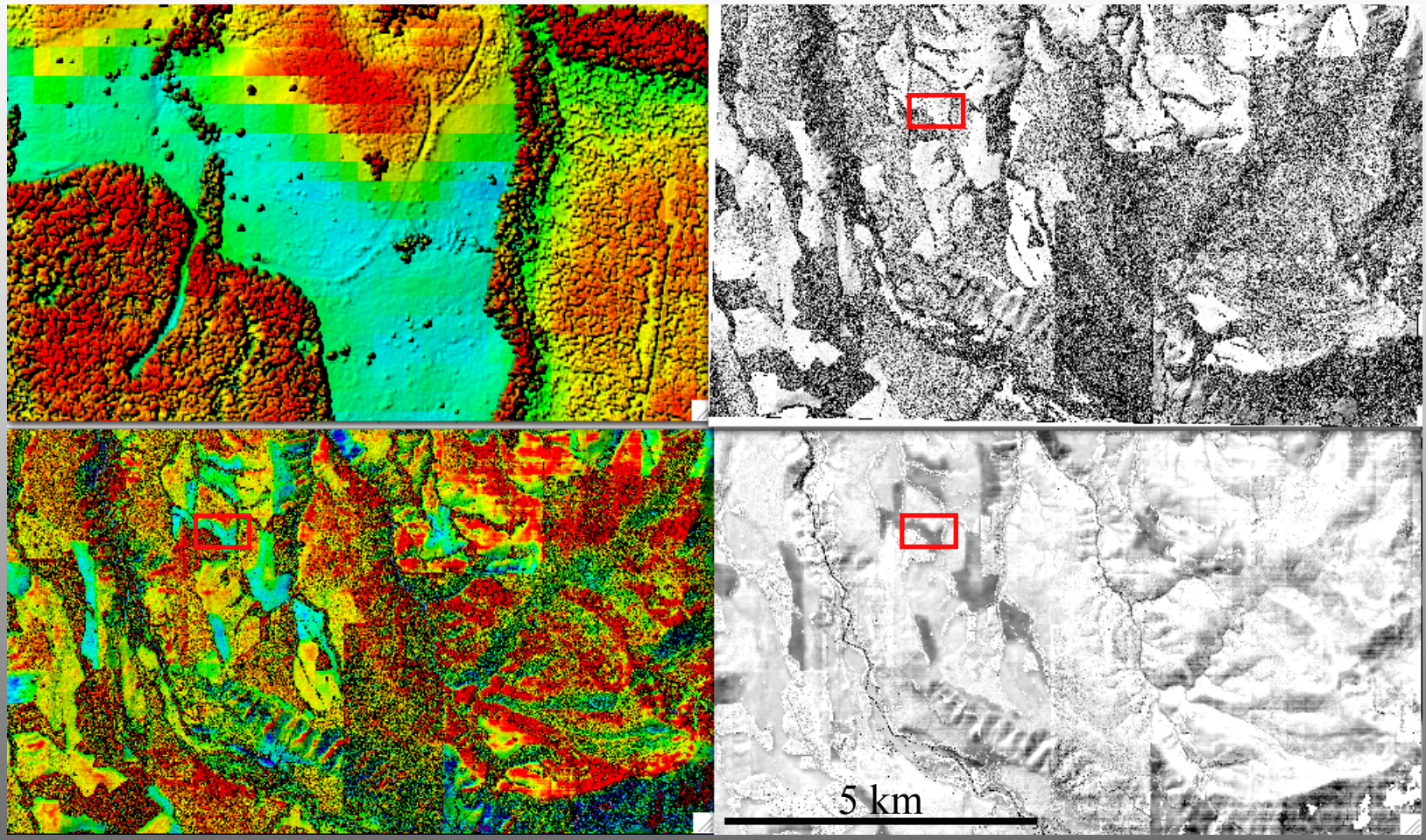




Vegetated Areas H.S. DEM > 1 m above B.E. DEM

Highest Surface – SRTM Elevation Difference

Lidar Highest Surface Shaded Relief



Shaded Relief Colored by Difference Lidar – SRTM Elevation Difference

Yellow to red: + difference, Green to blue: – difference

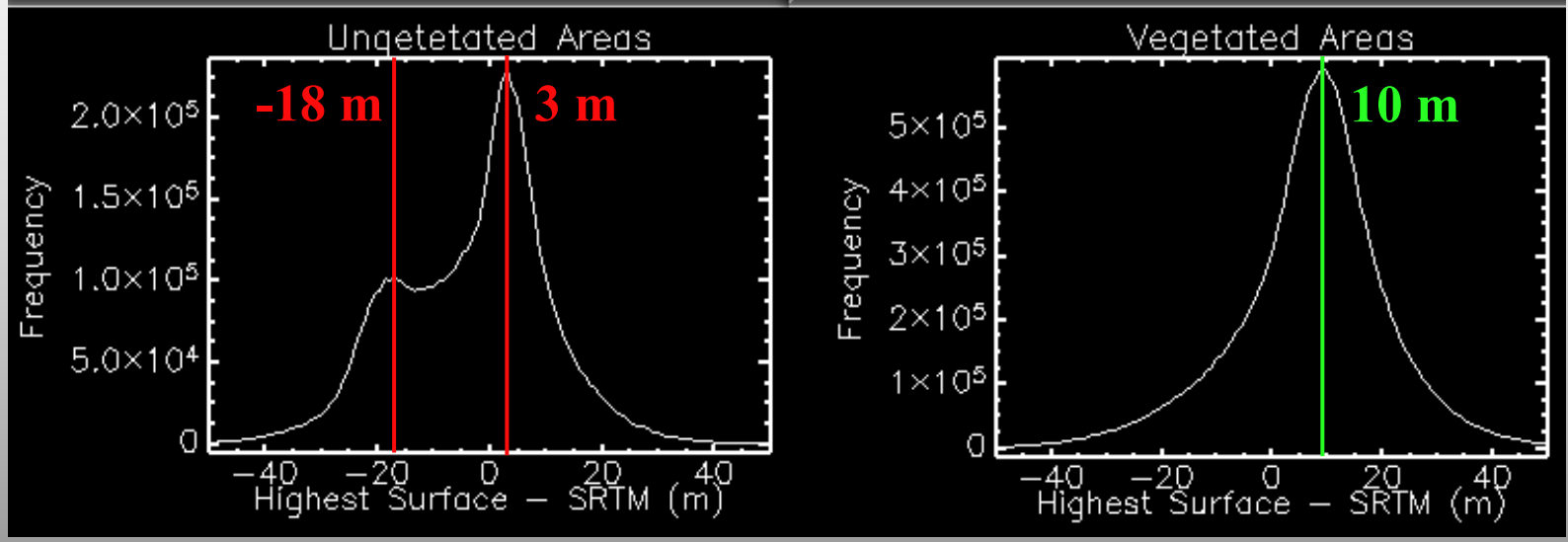
Highest Surface – SRTM Elevation Difference

Dims: Full Band (6257397 points)

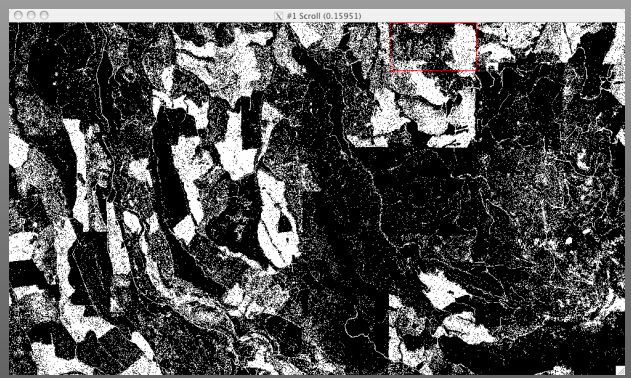
Band	Min	Max	Mean	Stdev
1	-99.212524	121.506958	-2.615235	13.675095

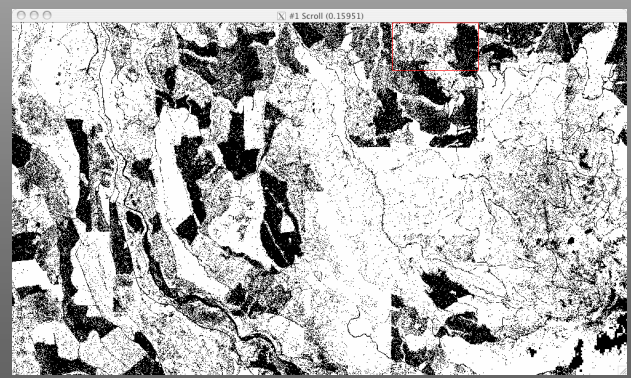
Dims: Full Band (22484220 points)

Band	Min	Max	Mean	Stdev
1	-96.202637	140.067261	7.623817	14.264310



Non-vegetated Areas H.S. DEM < 1 m above B.E. DEM



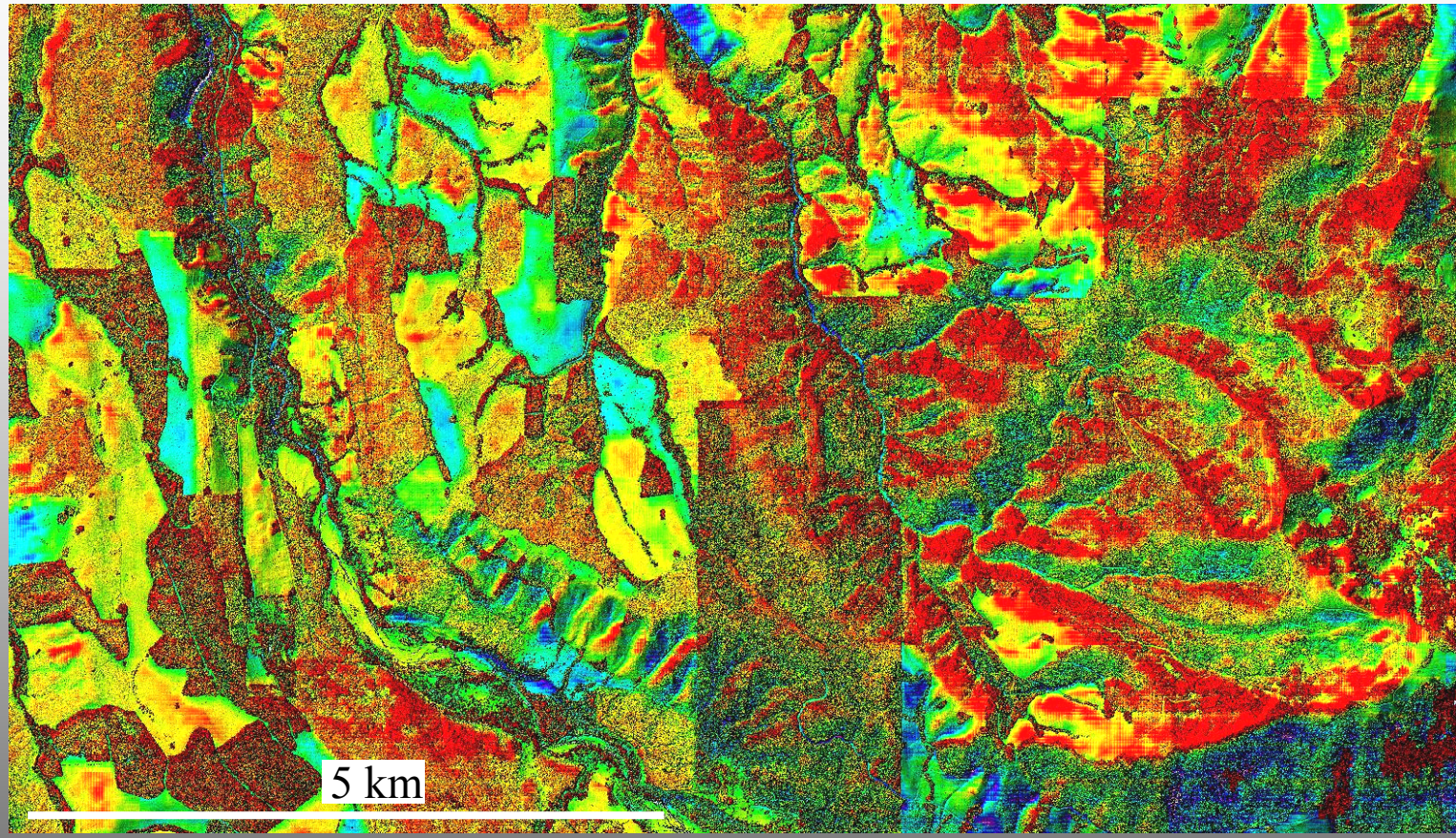


Vegetated Areas H.S. DEM > 1 m above B.E. DEM

Highest Surface – SRTM Elevation Difference

Smooth Areas: Non-vegetated

Textured Areas: Vegetated



Highest Surface Shaded Relief Colored by Difference

Yellow to red: + difference, Green to blue: – difference

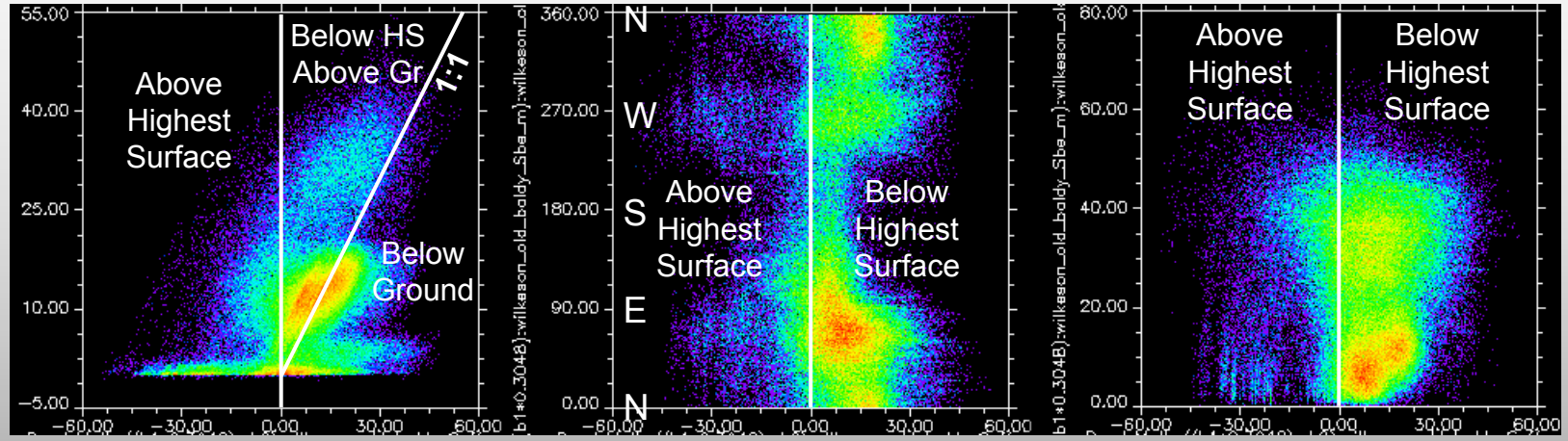
Elevation Differences vs. Canopy Height, and Topography Azimuth and Slope

Y Axis

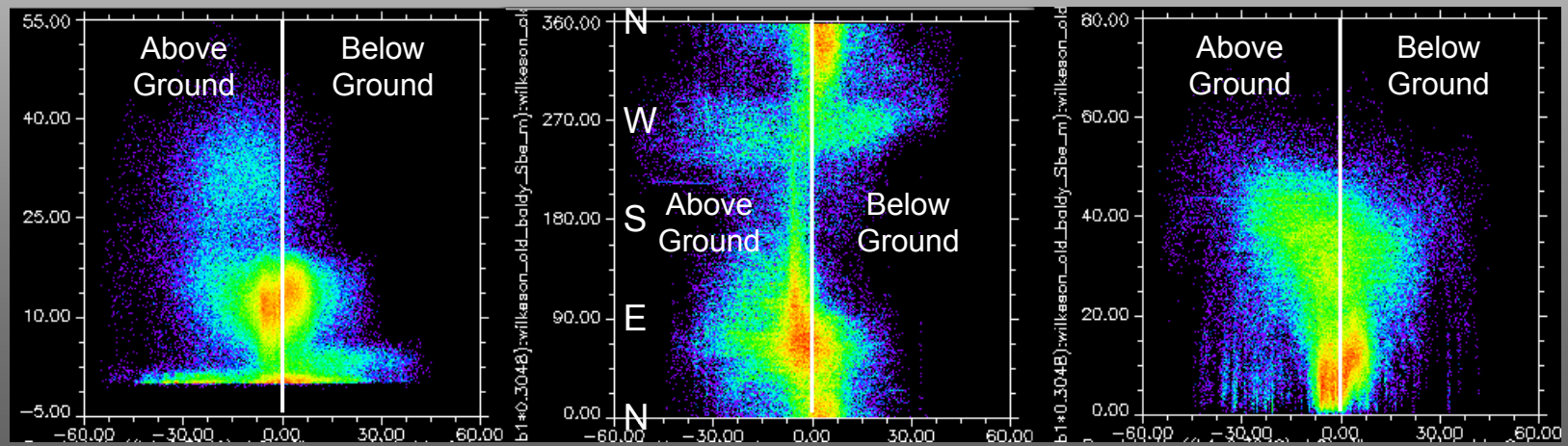
Highest Surface – Bald Earth
-5 to 55 m

Bald Earth Azimuth
0 to 360°

Bald Earth Slope
0 to 80°



Highest Surface – SRTM (-60 to 60 m)

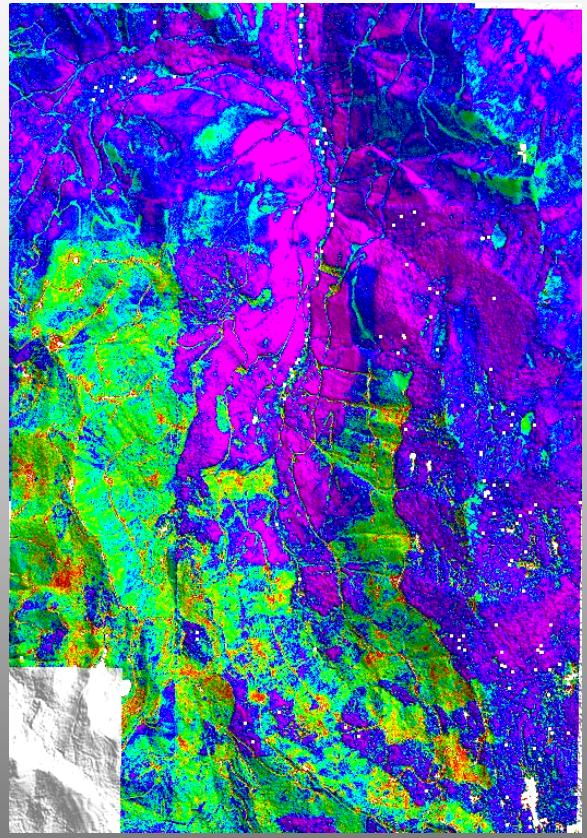


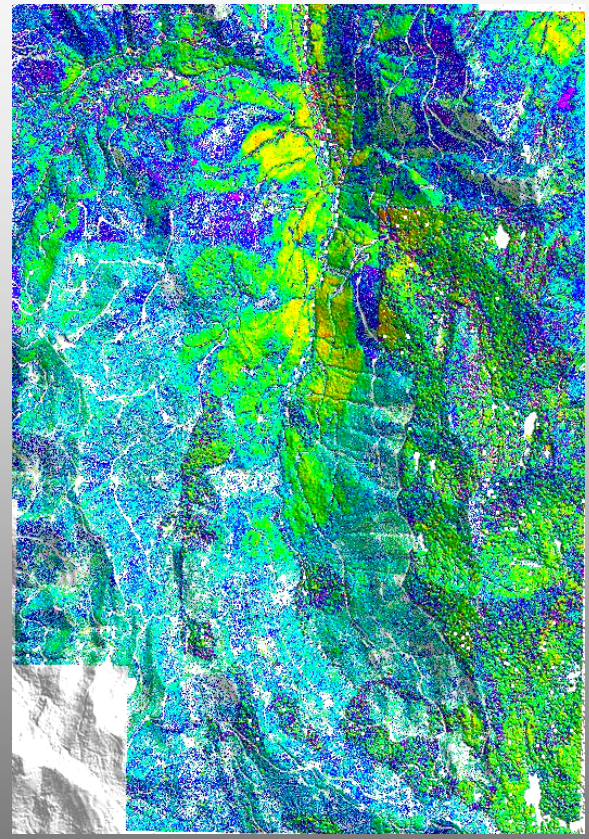
Bald Earth – SRTM (-60 to 60 m)

Next Step: Relate C-band penetration to Canopy Point Cloud Properties

Openness
Fraction of 1st returns on ground

0%
20%
40%
60%
80%
97%





Roughness

$\frac{75^{th} - 25^{th} \text{ \% height}}{90^{th} \text{ \% height}}$

>=0.75
0.60
0.45
0.30
0.15
0.02

2 km

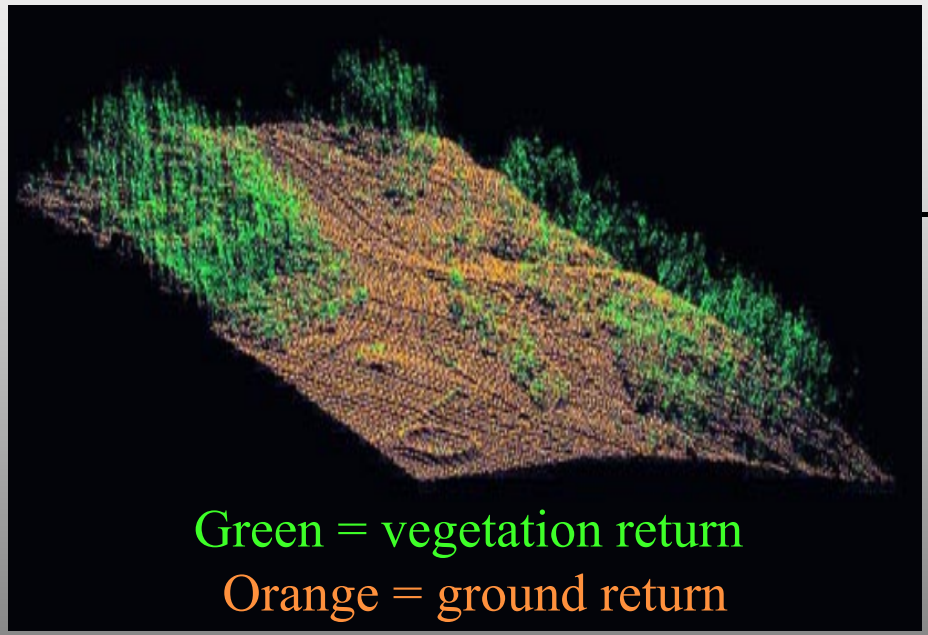
(from R. Haugerud, USGS)

SRTM vs. High-Res Lidar DEM Summary

- SRTM C-band 30 m DEM vs. lidar swath mapping 1.8 m DEM
  - In vegetated areas the distance the C-band phase center is located below the lidar canopy top is 7.6 ± 14.3 m (modal peak = 10 m) and is correlated with vegetation height, but the correlation has considerable variance (related to slope azimuth & magnitude, and likely to canopy openness & roughness)
  - In tall stands (> 20 m) the phase center is between the canopy top & ground
  - In intermediate stature stands (5 to 20 m) the SRTM phase center varies from above the canopy top to below the ground
  - In non-vegetated areas, the SRTM phase center to ground elevation difference is bimodal; the peaks of the two distributions are 3 m below the ground and 18 m above the ground - the latter possibly due to clearings within forests where SRTM senses the adjacent stands
  - The mean and variance of the SRTM phase center to ground elevation difference is correlated with the lidar ground azimuth; the phase center is biased high for S-facing slopes and low for N-facing slopes (SRTM view azimuth or horizontal registration effect) and the variance is a maximum for E and W facing slopes
  - For areas of steeper lidar ground slope (above 20°), the SRTM phase center is increasingly biased above the ground surface with increasing slope

Backup Slides

Classification of Ground and Vegetation Returns



Detection of ground returns depends on:

Surface properties

- vegetation height and density
- spatial and angular distribution of gaps
- reflectivity of the ground

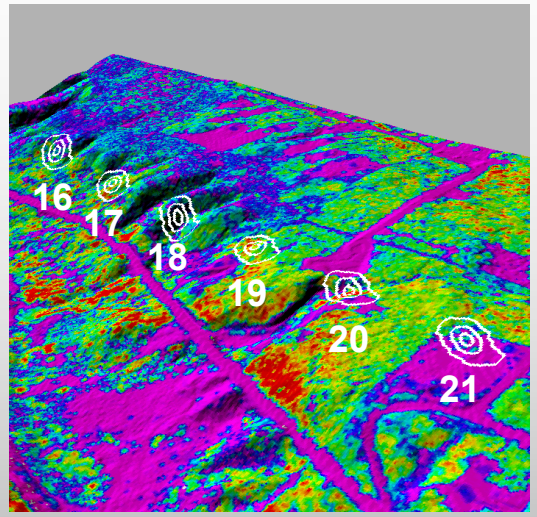
Altimeter properties

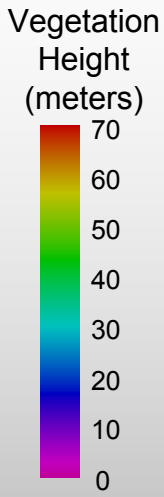
- off-nadir beam pointing
- density of laser footprints
- size of laser footprints
- laser pulse width
- detector bandwidth
- signal-to-noise performance
- threshold level
- ranging electronics detection method

Data processing

- filtering to identify ground returns

Comparison to ICESat Received Echo Waveforms





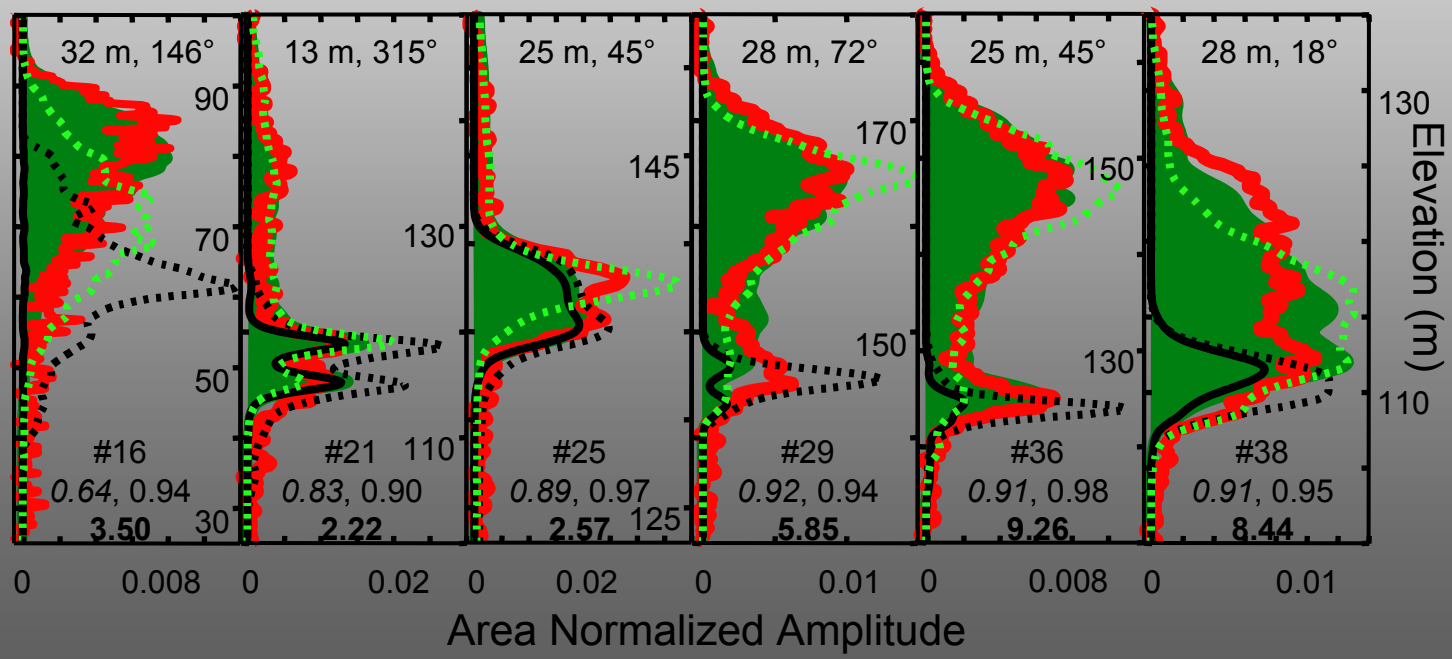
GLAS instrument model applied to TerraPoint airborne swath-mapping laser altimeter data.

Harding and Carabajal, GRL, 2005

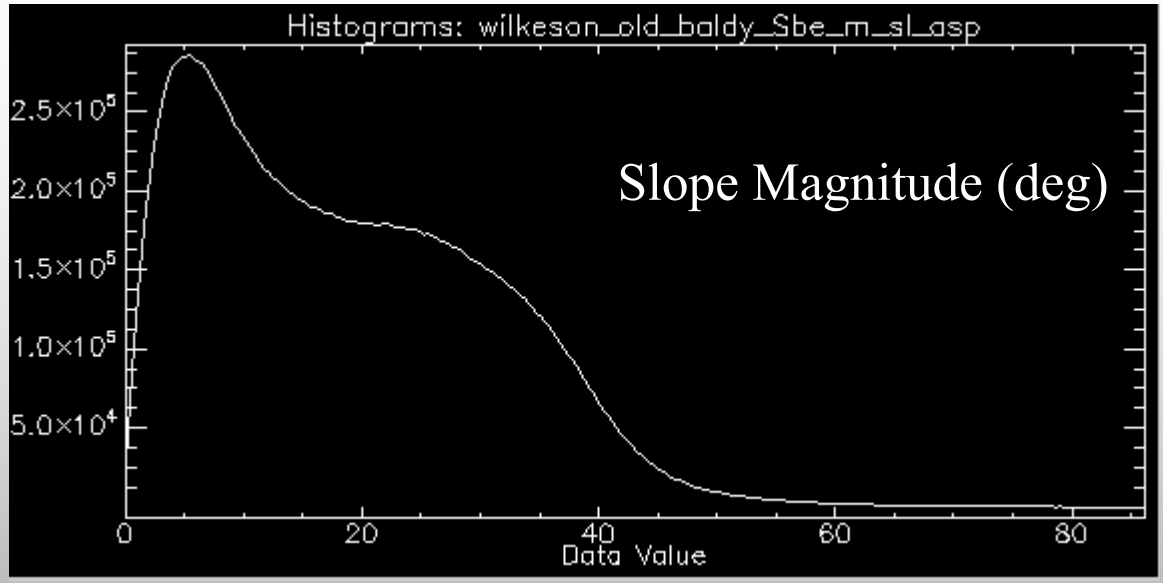
Received echo

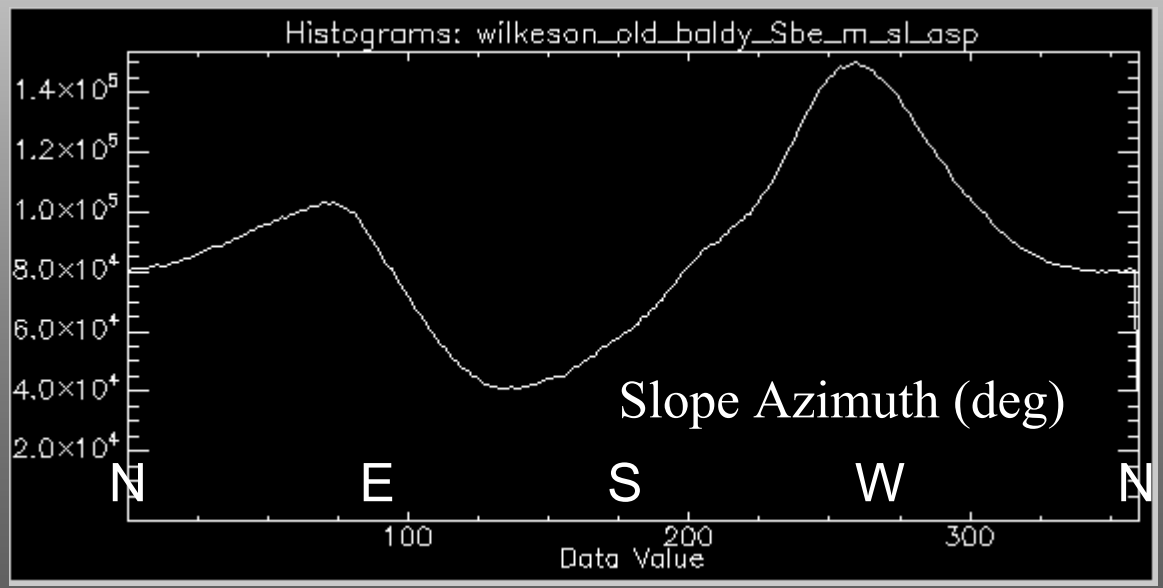
Model at location of best match

Ground contribution



West Rainier Validation Area
Ground Slope Magnitude and Azimuth





Computed in ENVI from bald Earth DEM array using 3 x 3 pixel array (5.4 x 5.4 m).

In slope computations, ENVI converts horizontal units to meters auto-matically so user must convert vertical units from feet to meters.