Delineating the Taiga-Tundra Ecotone with Landsat, LiDAR and Spaceborne Sub-meter Imagery

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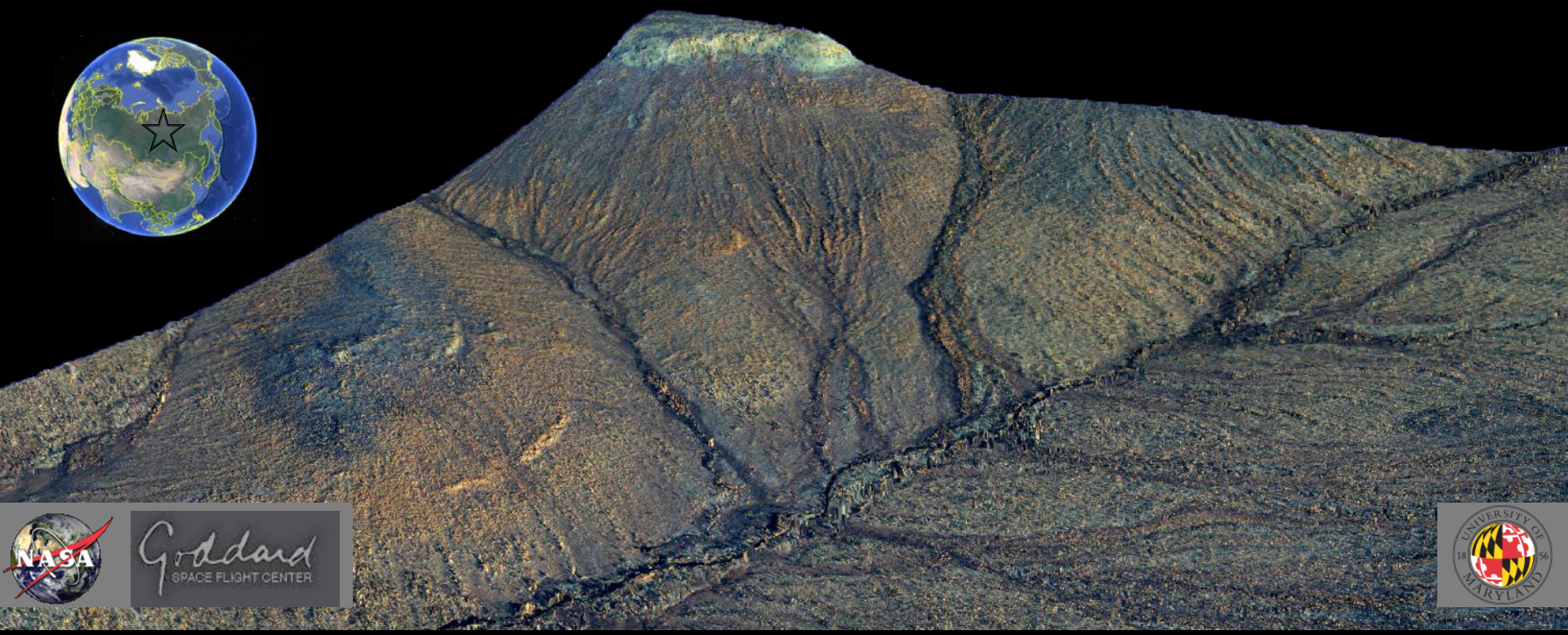


WorldView -1 DSM and WorldView-2 pan sharpened 0.5 m in true color Sept 9 2011, shown in 3D near the Kotuy River Siberia ©DigitalGlobe NextView 2011

Project Objectives

- Use recently available Landsat based percent tree canopy cover maps, circa 2000, 2005 & 2010, with estimates of uncertainty to improve our prior circumpolar arctic-boreal transition assessment.

- Use high-resolution data in intensive study sites along the forest-tundra transition zone and characterize the spatial patterns of the tree-tundra mosaic across the boundaries. These data include commercial sub-meter panchromatic and stereo imagery from WorldView-1,2,3 and Quickbird-2.

- Estimate forest cover and biomass change in intensive study site transects using high-resolution stereo satellite data, field observations, and allometric models.

In this talk:

1. **Prior work that has lead to our current state of the art for estimating ecotone**
2. **Recent results**

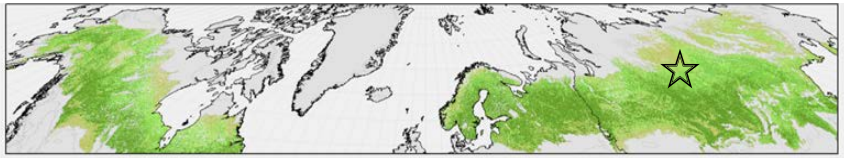
   Montesano et al. 2016, Neigh et al. 2016, Sexton et al. 2016

Scientific Significance

Climate change is expected to alter tree line.
A validated moderate resolution baseline is required to monitor change.

Strategic objective for NASA Earth science is to advance knowledge of the Earth as a system to meet the challenges of environmental change
(NASA Science Plan 2014)
•*Detect and predict changes in Earth's ecosystems and biogeochemical cycles, including land cover, biodiversity, and the global carbon cycle.*

Fig. 1 Landsat 30m Vegetation Continuous Fields (VCF) - forests canopy cover
Circa 2000, 2005, 2010 (Sexton et al. 2013)



Why is this work critical?

The Boreal forest is one of the largest biomes on Earth (~30% of global forest area), contains 38 ±3.1 Pg of above ground carbon (Neigh *et al.* 2013) and is experiencing > 1.5°C of warming. Small scale studies have found changes in TTE structure due to warming but currently large scale studies with moderate resolution data are challenging due to variations in vegetation structure, topography, edaphic conditions, and other factors (Ranson et al. 2011).

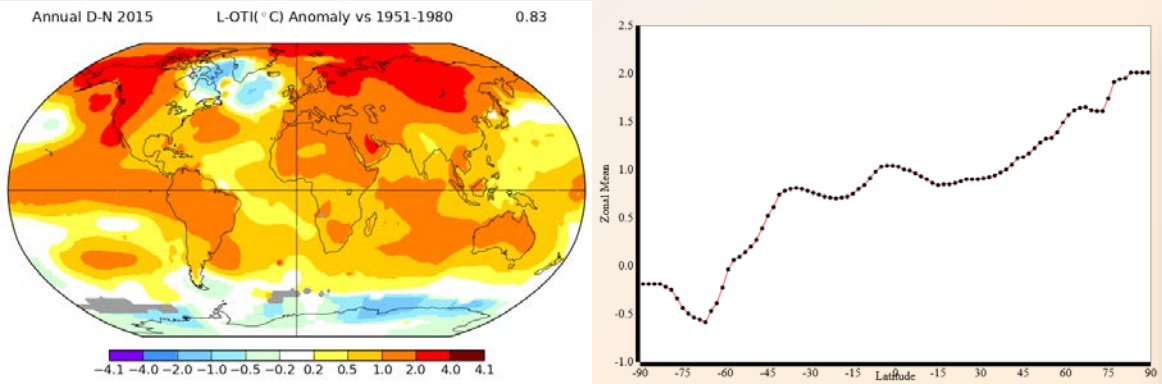


Fig 2. http://data.giss.nasa.gov/gistemp/maps/

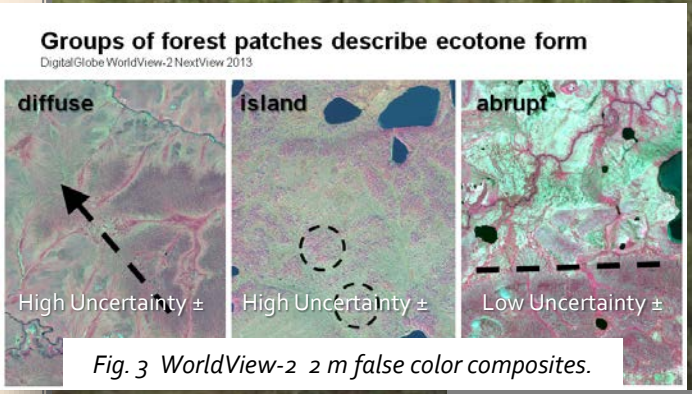


Fig. 3 WorldView-2 2 m false color composites.

Landsat Estimates of Tree Canopy Cover

Climate change is expected to alter tree line.
A validated moderate resolution baseline is required to monitor change.

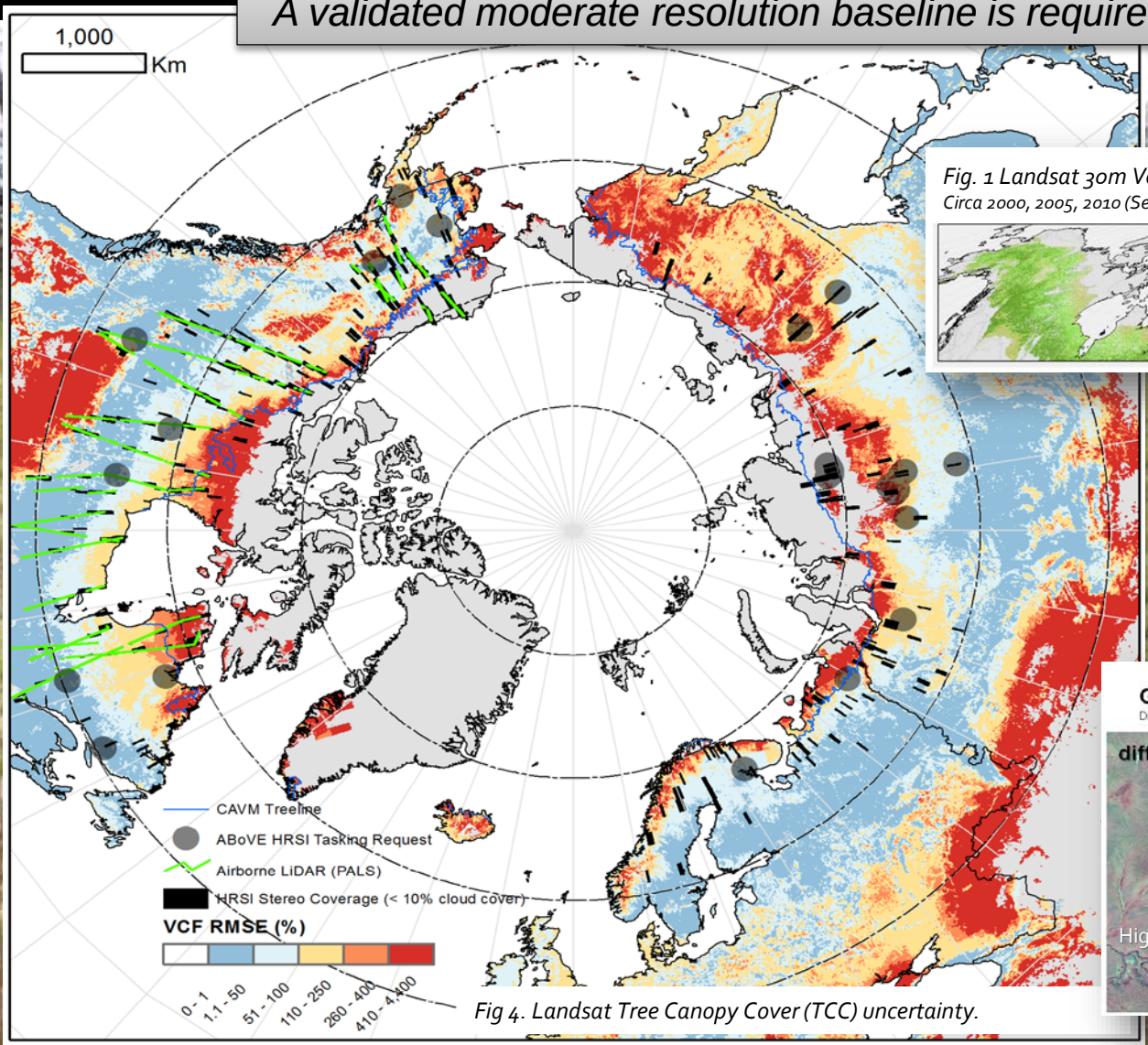
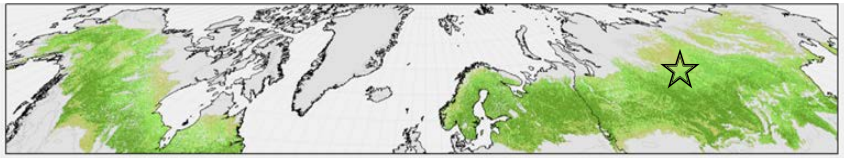


Fig 4. Landsat Tree Canopy Cover (TCC) uncertainty.

Fig. 1 Landsat 30m Vegetation Continuous Fields (VCF) - tree canopy cover
Circa 2000, 2005, 2010 (Sexton et al. 2013)



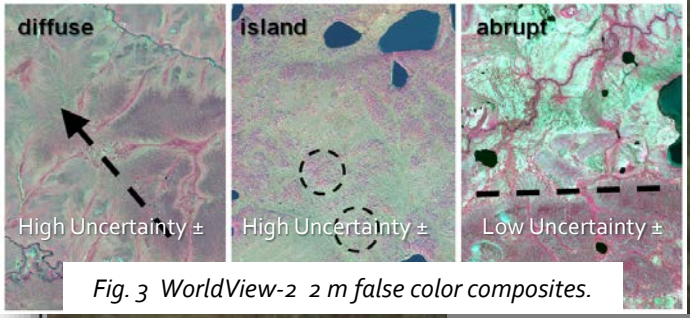
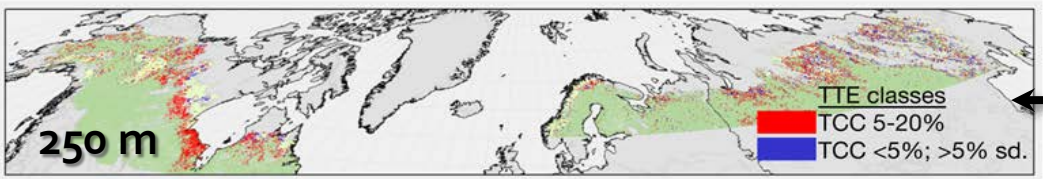


Fig. 3 WorldView-2 2 m false color composites.

Previous Work

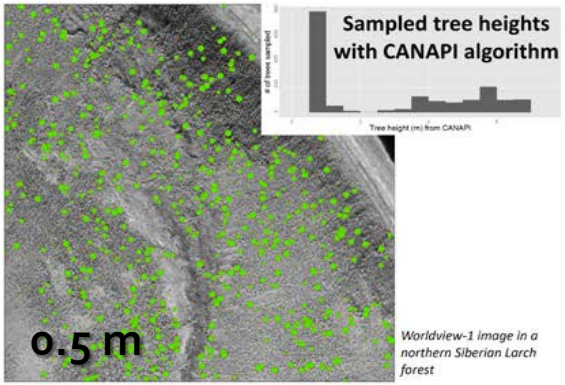
MODIS VCF Validation (Montesano et al. 2009)

Circumpolar MODIS-derived TTE (Ranson et al. 2011)

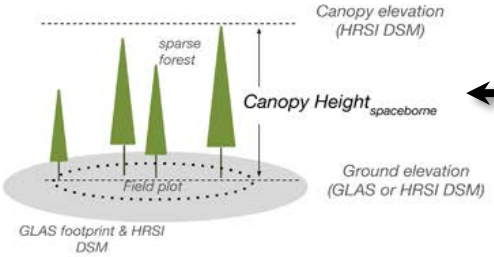


Global Landsat VCF(Sexton et al. 2013)

HRSI Canopy Height (Chopping et al. 2011; Montesano et al. 2014)



Worldview-1 image in a northern Siberian Larch forest



We have progressively increased the resolution of our TTE observations to the forest patch scale.

Quickbird imagery in 425 sites.

MODIS derived estimate of TTE

Current Work

Landsat derived estimate of TTE

Increased discrimination of small forest patches

Landsat derived estimate of TCC optimized with sub meter stereo WV-1,2,3 and PALS

What is a Forest?

Sexton *et al.* 2016 *Nature Climate Change*

Global agreement of presence and absence of forest cover circa 2000 between 8 land cover datasets.

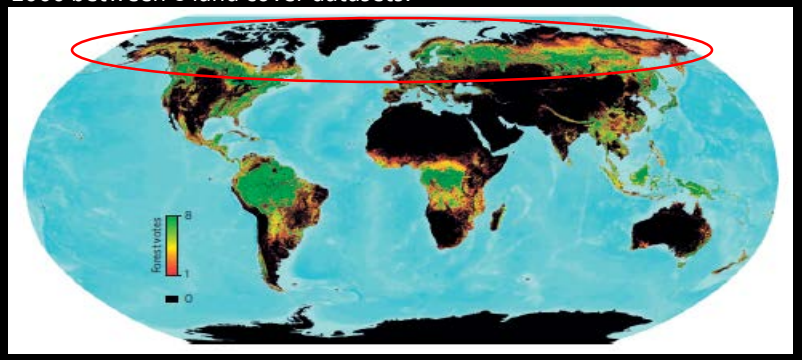


Table 1 | Global forest area by biome[21].

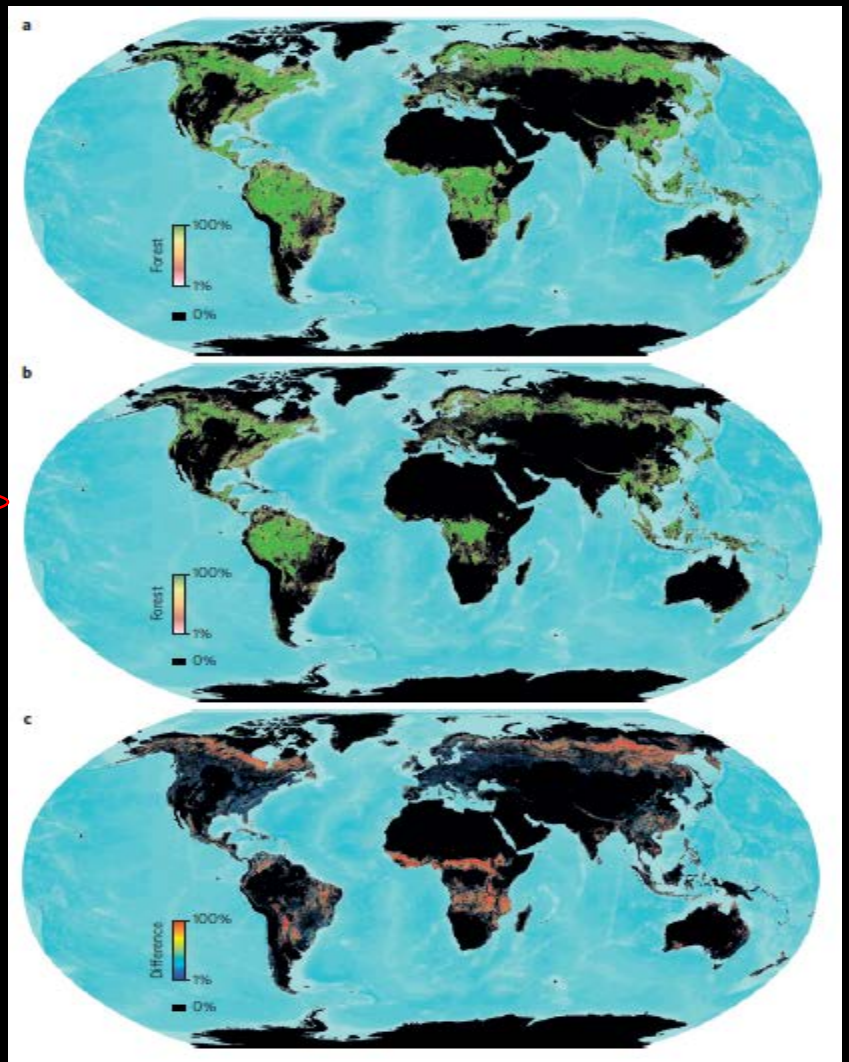
Biome	Area		Forest (>10% tree)		Forest (>30% tree)		Difference	
	km²	%	km²	%	km²	%	km²
Boreal forests/taiga	14,224,916	76.90	10,938,418	45.10	6,415,061	31.80	4,523,357
Deserts and xeric shrublands	27,752,829	2.34	650,180	0.46	126,774	1.89	523,406
Flooded grasslands and savannahs	1,036,966	45.21	468,838	10.60	109,913	34.61	358,925
Mangroves	293,404	80.23	235,402	57.19	167,793	23.04	67,609
Mediterranean forests	3,180,903	23.48	746,793	11.22	357,037	12.25	389,757
Montane grasslands and shrublands	5,120,243	9.91	507,643	4.43	226,628	5.49	281,016
Temperate broadleaf and mixed forests	12,466,617	59.80	7,455,587	40.73	5,077,288	19.08	2,378,300
Temperate conifer forests	4,010,340	69.88	2,802,276	53.26	2,135,870	16.62	666,406
Temperate grasslands	9,904,686	9.17	907,986	4.21	416,923	4.96	491,063
Tropical and subtropical coniferous forests	707,026	75.95	536,967	39.64	280,249	36.31	256,718
Tropical and subtropical dry broadleaf forests	2,969,433	47.59	1,413,112	23.96	711,398	23.63	701,714
Tropical and subtropical grasslands	20,089,822	34.52	6,934,566	10.68	2,146,591	23.83	4,787,975
Tropical and subtropical moist broadleaf forests	19,513,086	86.13	16,806,448	69.55	13,570,480	16.58	3,235,968
Tundra	7,449,513	12.76	950,209	4.39	326,854	8.37	623,355

Inland water, rock and ice, and deserts and xeric shrublands (each with <2.5% tree cover) are excluded.

Despite technological advances using satellite-based estimates of global forest area they still range from 32.1 x10^6 to 41.4 x 10^6km².

Ambiguity in the forest term >10->30% tree cover is the major reason why.

Maps of forest cover defined by UNFCC: a) 10%, b) 30%, c) Difference



Methods: What tools can we use to reduce uncertainty?

Gao, J. Towards accurate determination of surface height using modern geoinformattic methods: possibilities and limitations. *Prog. Phys. Geog.* 2007, *31*, 591-605.

Table 1 Vertical accuracies achieved with various stereo images using the photogrammetric method

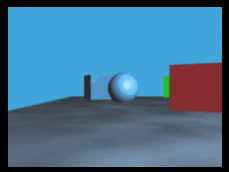
Imagery	Ground resolution	Swath width	Accuracy	Affecting factors*	Pros	Cons
Aerial photography	Varying with camera focal length	Varying with flying height	3 cm–14.3 m	Flying height, image resolution Accuracy of ground control	Highly accurate; DSM possible	Slow; expensive; available for small areas
TK-350 space photograph	10 m	200 km by 300 km	17 m (27–39 m for DEM of 40 m cell)	Surface cover; DEM cell size; ground control	wide area coverage	Low accuracy; images not widely available
ASTER	15 m	60 km	10–39 m	Surface relief	Inexpensive; data available globally	Not so accurate, mostly for DEM; long repeat cycle (16 days)
SPOT-1–4 SPOT-5	0–20 m Up to 4 m	60 km	5–10 m 5 (5.2–6.8) m 2.38 (2.60–2.89) m	Geometric model adopted; GCP quality	More accurate than ASTER images A large ground area is covered	Expensive; Across-track 3D only; time lapse between stereopair
Ikonos	1 m (PAN) 4 m (XSL)	11.3 km	0.2–0.7 m (DEM accuracy: 1–4 m at 68% LE)	Sensor orientation; ground cover; Extra ground control	Images available at short return period; large B/H ratio; along-track and across-track 3D possible	Expensive, limited ground cover
QuickBird Geo Stereo	2.4 m	16.5 km	0.2–1.38 m (DEM accuracy: 10 m)	3D model used, ground control quality; external DEMs	DSM possible; stereo images obtained at the same time	Expensive, sophisticated software needed

*All photogrammetric methods are subject to base-to-height (B/H) ratio

Hi-res stereo data are no direct cost with NGA NextView licensed access (Neigh et al. 2013). DigitalGlobe has a large archive and many no cost software options are now available.

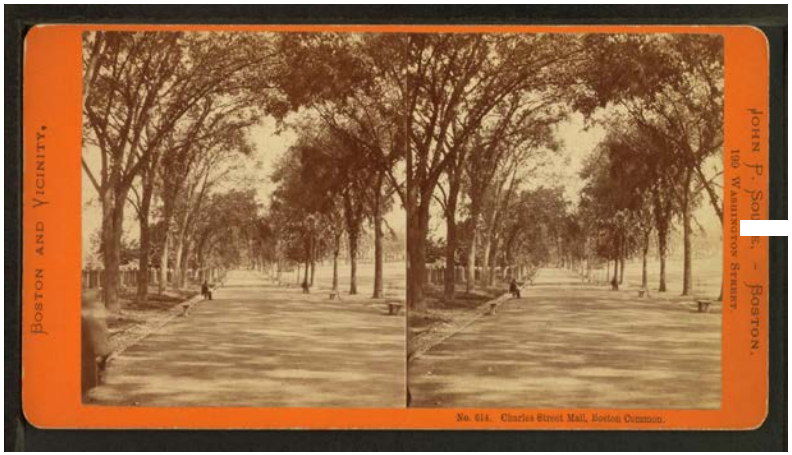
Sub Meter Spaceborne Photogrammetry

Parallax is a displacement or difference in the apparent position of an object viewed along two different lines of sight, and is measured by the angle or semi-angle of inclination between those two lines



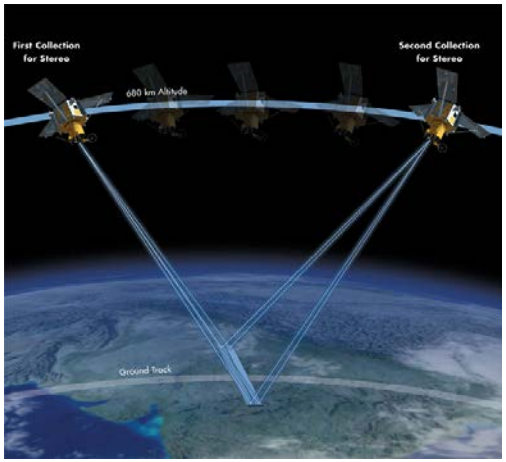
This animation is an example of parallax. As the viewpoint moves side to side, the objects in the distance appear to move slower than the objects close to the camera.
http://en.wikipedia.org/wiki/Parallax

Boston Commons 1890



Most stereoscopic methods present two offset images separately to the left and right eye of the viewer.
http://en.wikipedia.org/wiki/Stereoscopy

Hi-res stereo from satellites 2000+



DigitalGlobe has a constellation of satellites that collect within track stereo imagery. Currently hundreds of thousands of images exist that could be used to estimate forest canopy height.

Height disparity through parallax is one of the oldest tools in photogrammetry but modeling forest canopy height with very hi-res satellite stereo imagery has not been widely used.

US Forest Canopy Heights Validated
IKONOS vs. G-LiHT

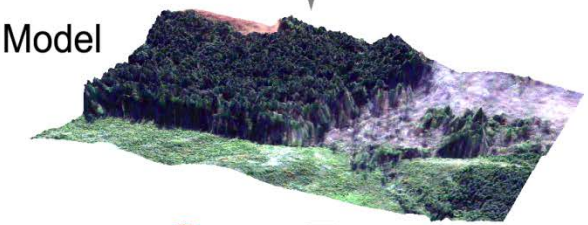
Neigh *et al.* 2014 *remote sensing*
Neigh et al. 2016 *Remote Sensing of Environment*

Stereo IKONOS

DigitalGlobe NextView 2014

Digital Surface Model

DSM



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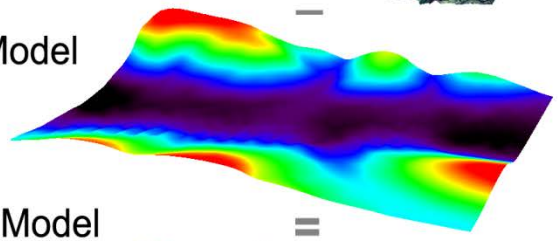
Digital Terrain Model

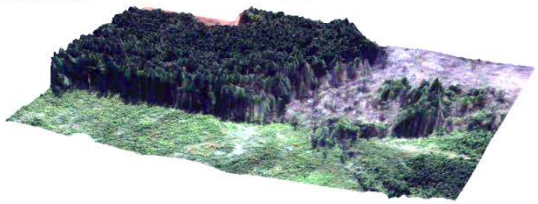
DTM



IKONOS
Canopy Height Model

=

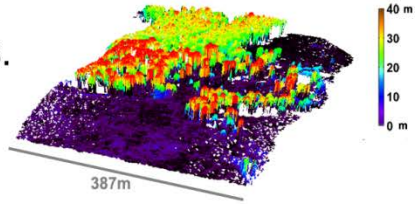
CHM

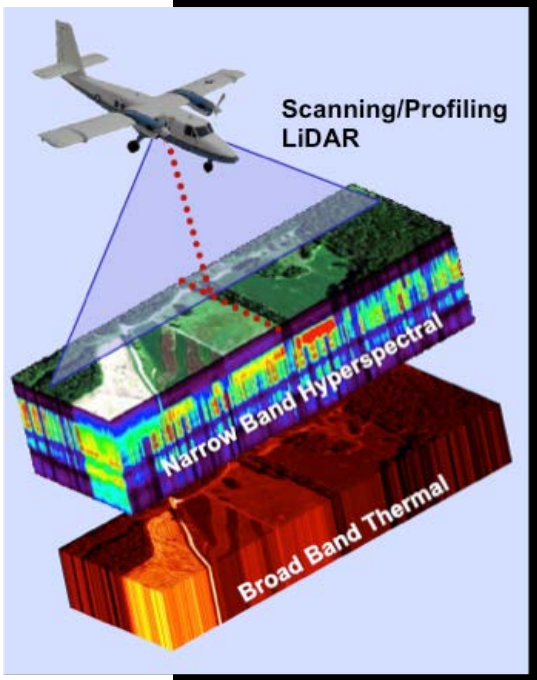


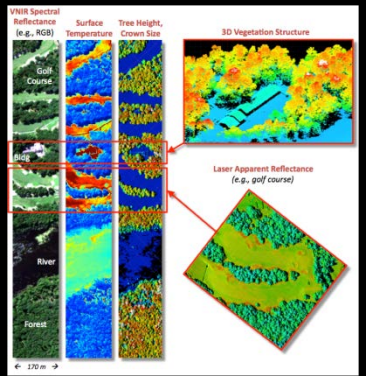
~2 m RMSE

vs.

G-LiHT
Canopy Height Model







Technology and Data Policy Advances

1

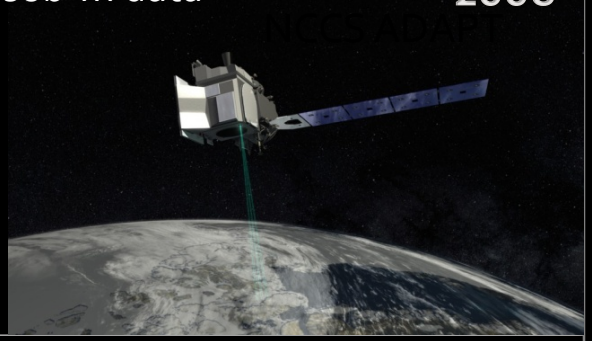
Open US Gov. access to DG sub-m data ~2008

Neigh et al. 2013 . EOS trans.

USGS opens Landsat archive

2011 - NASA GSFC begins acquiring data

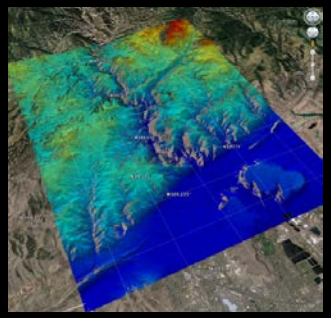
http://cad4nasa.gsfc.nasa.gov



2

AMES stereo pipeline ~2012

Originally developed for 1997 Mars Pathfinder mission used for intelligent robotics navigation



Open-source released for DG data

http://irg.arc.nasa.gov/ngt

Shean *et al.* 2016 *ISPRS J. Photogrammetry and Remote Sensing*

3

GSFC ADAPT Cluster ~2013

Originally developed for Discover supercomputer for climate simulation.

No cost access granted to NASA funded scientists

http://nccs.nasa.gov

Advanced Data Analytics Platform (ADAPT)

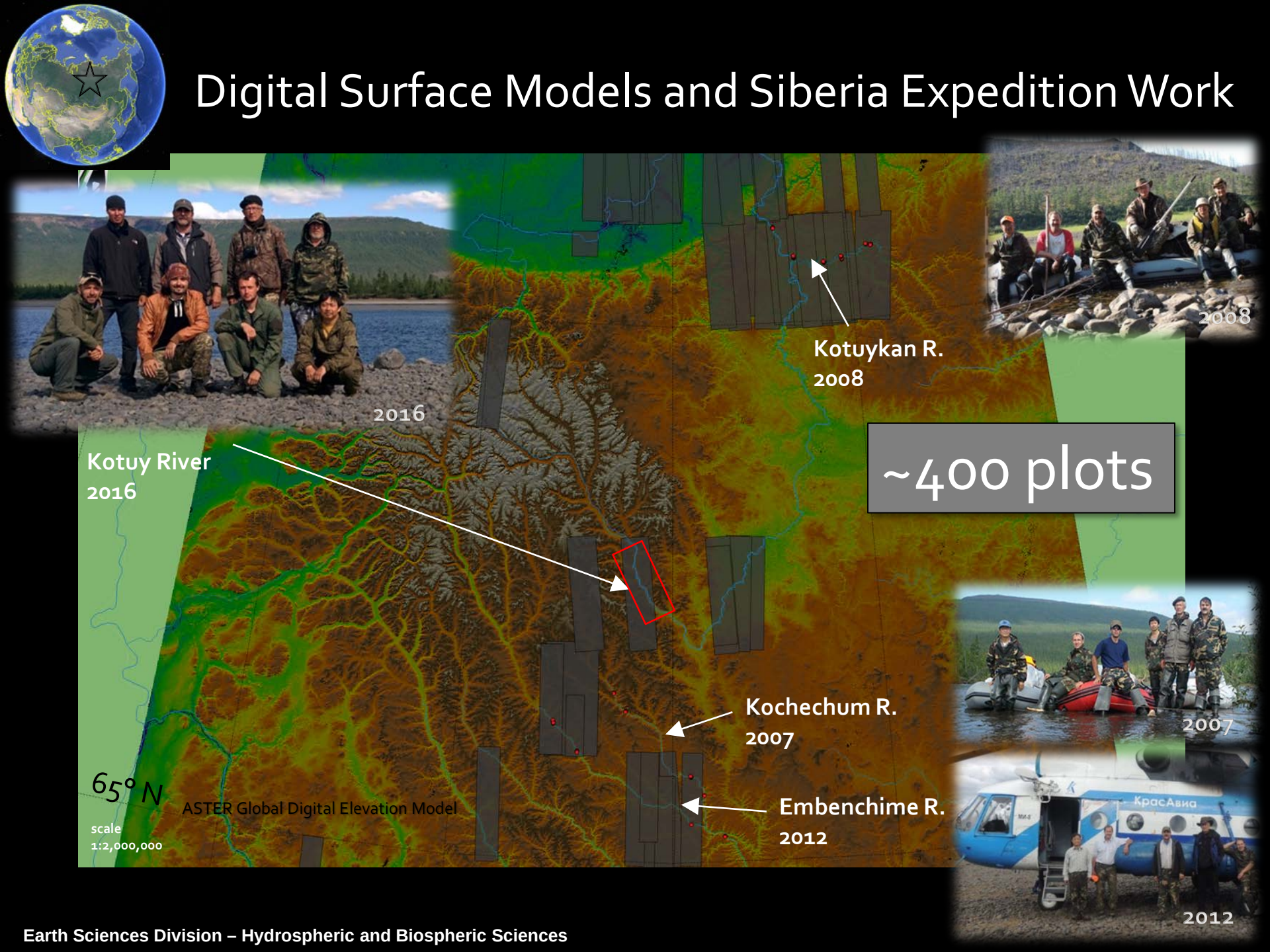
Forest Structure and Growth

Combine Landsat forest products with available commercial stereo and next gen. spaceborne LiDAR to close the knowledge gap in the spatial distribution of terrestrial C stocks.

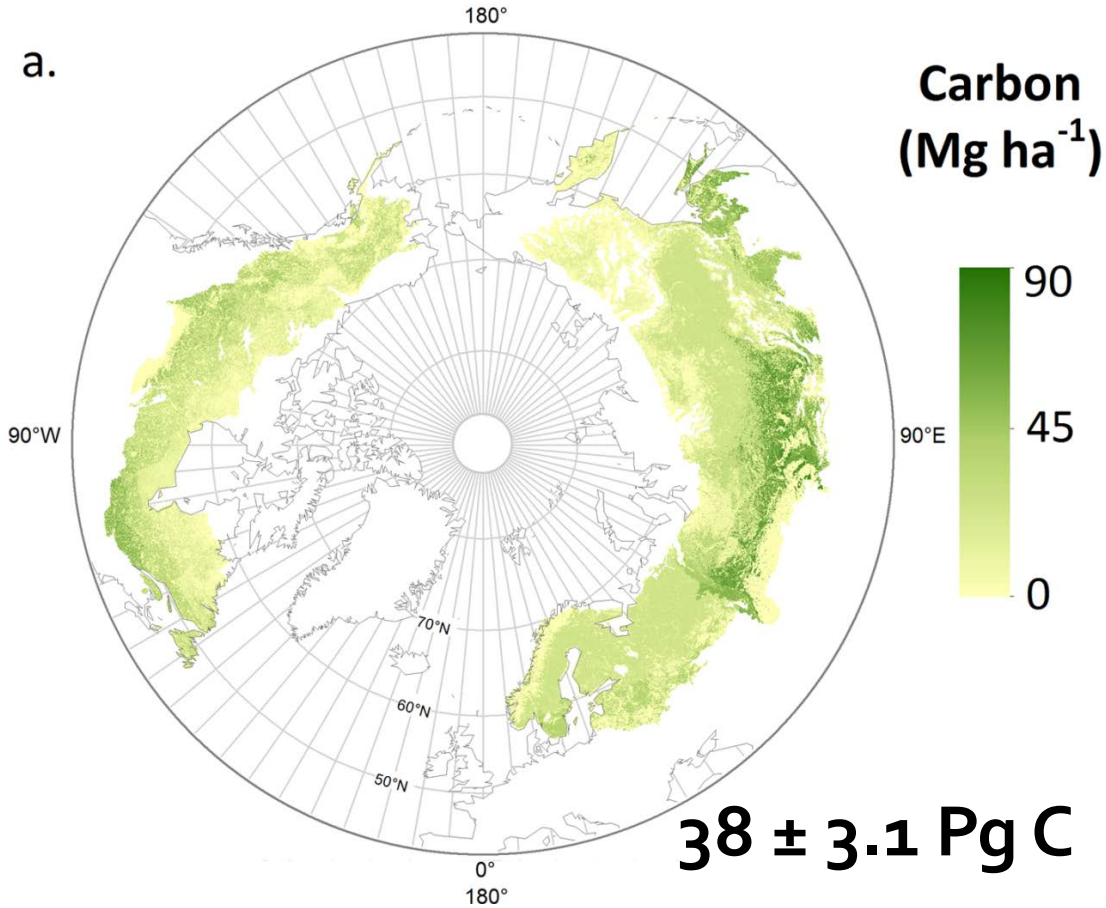
Combining these advances we have processed >2,000 WV stereo pairs on the ADAPT compute cluster

1. 720 cpus, 2.5Tb ram <24 hrs to process > 10 image pairs
2. Large volumes of data exist to be processed.

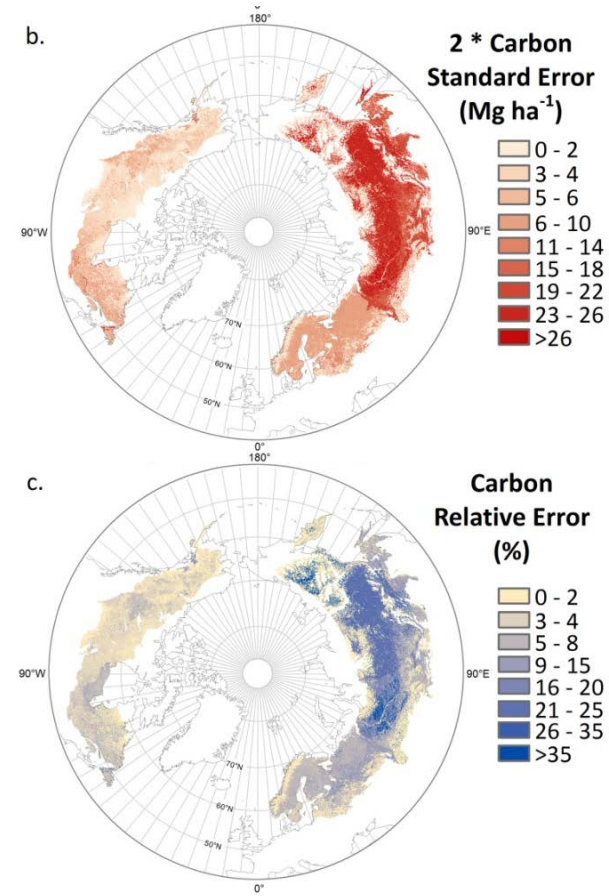
Digital Surface Models and Siberia Expedition Work



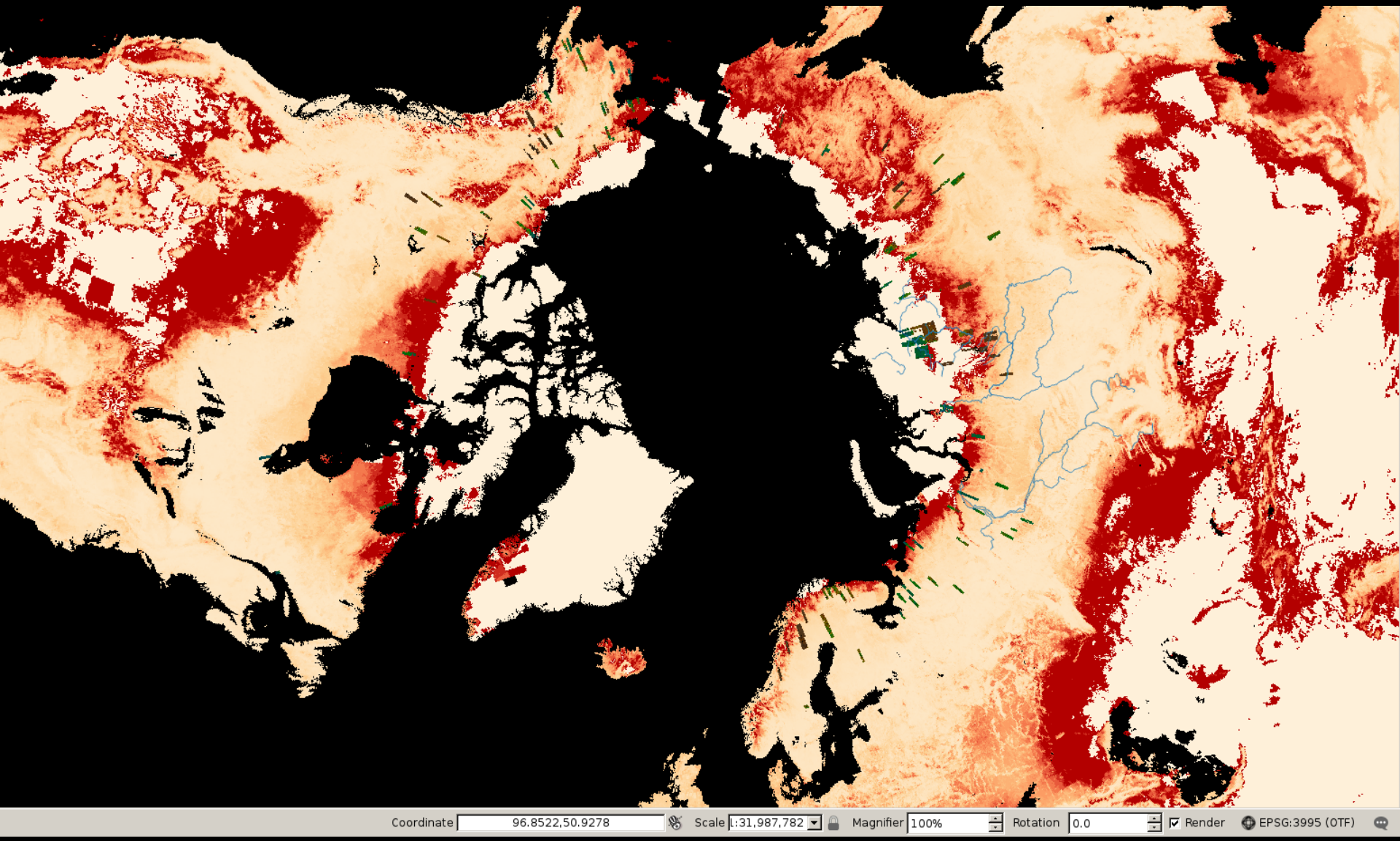
Expeditions in Siberia?



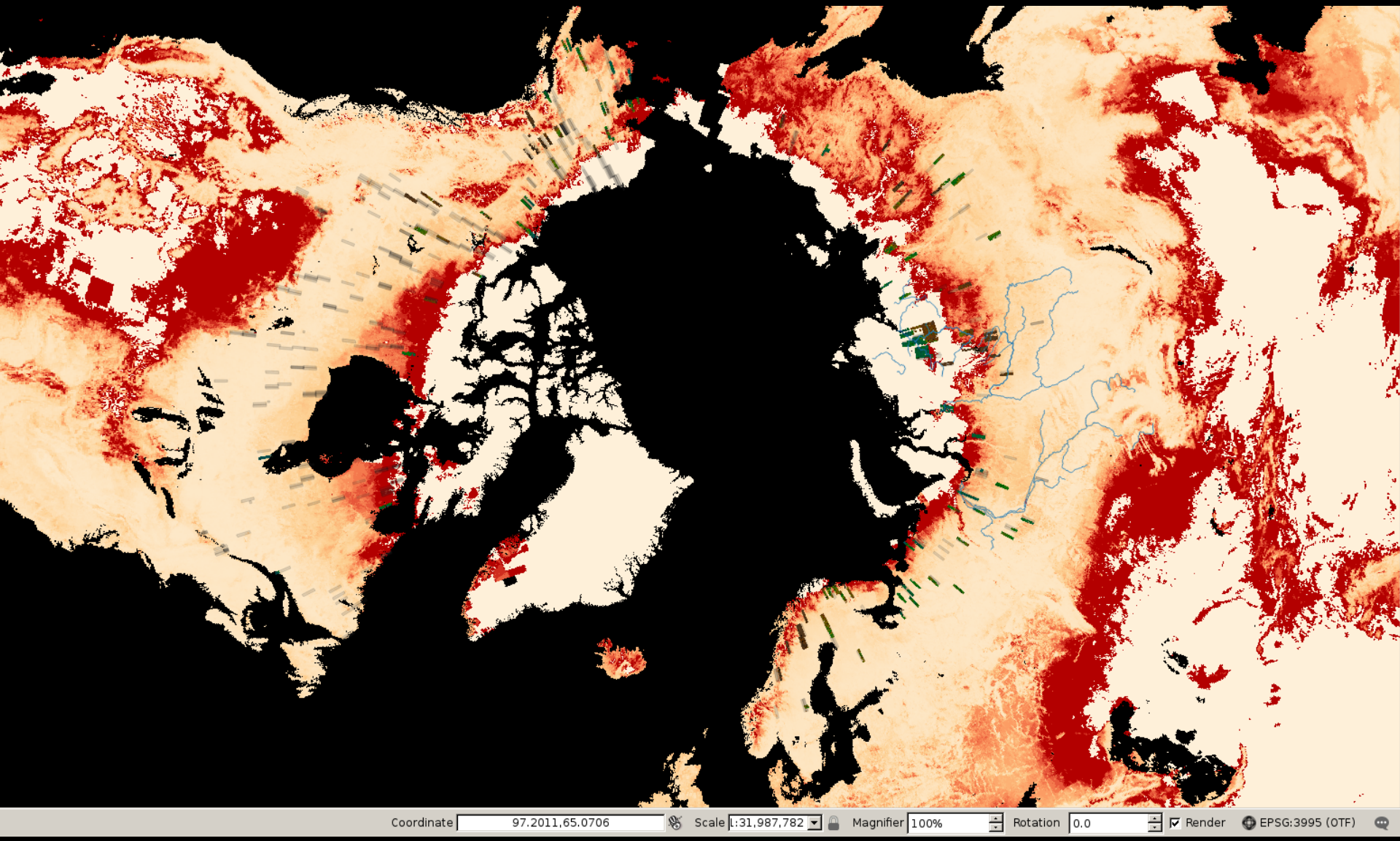
38 ± 3.1 Pg C



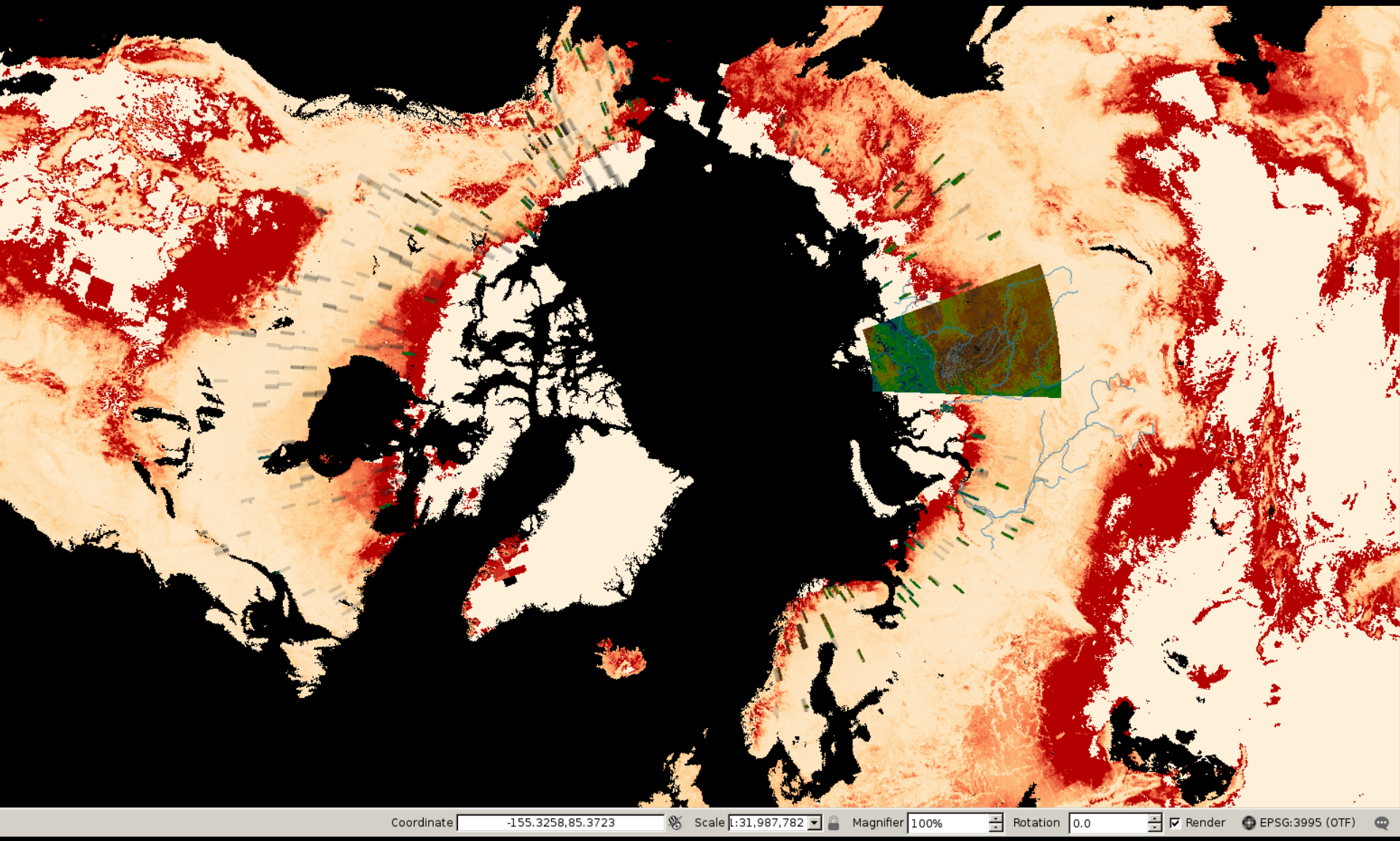
Neigh et al. 2013 RSE fig 2



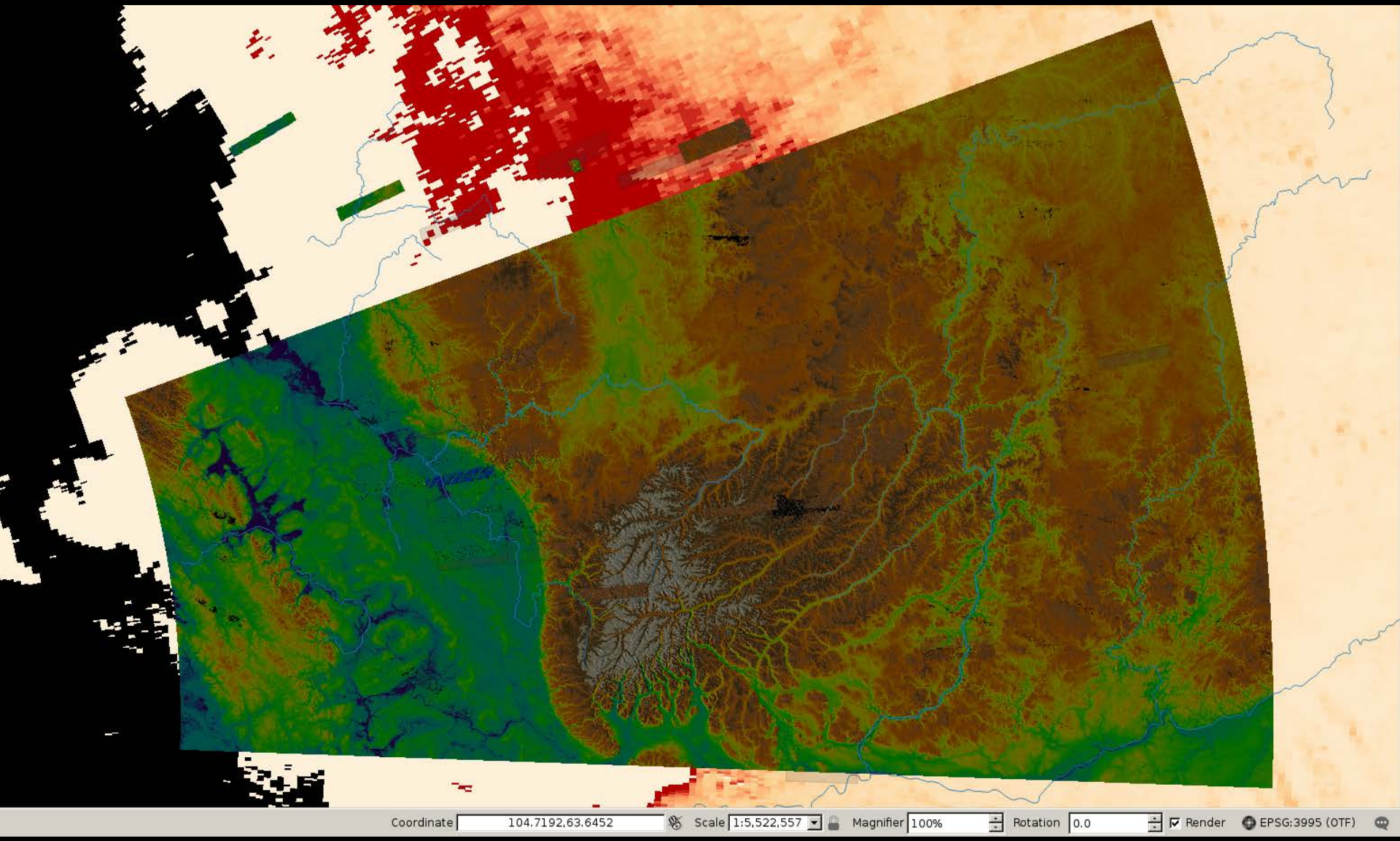
Processed 1 m resolution 17 x 120 km WorldView digital surface models



Processed 1 m resolution 17 x 120 km WorldView digital surface models
+ stereo strips that we plan to process within the next 6 months.



ASTER GDEM overlaid with WV-1,2 stereo strips

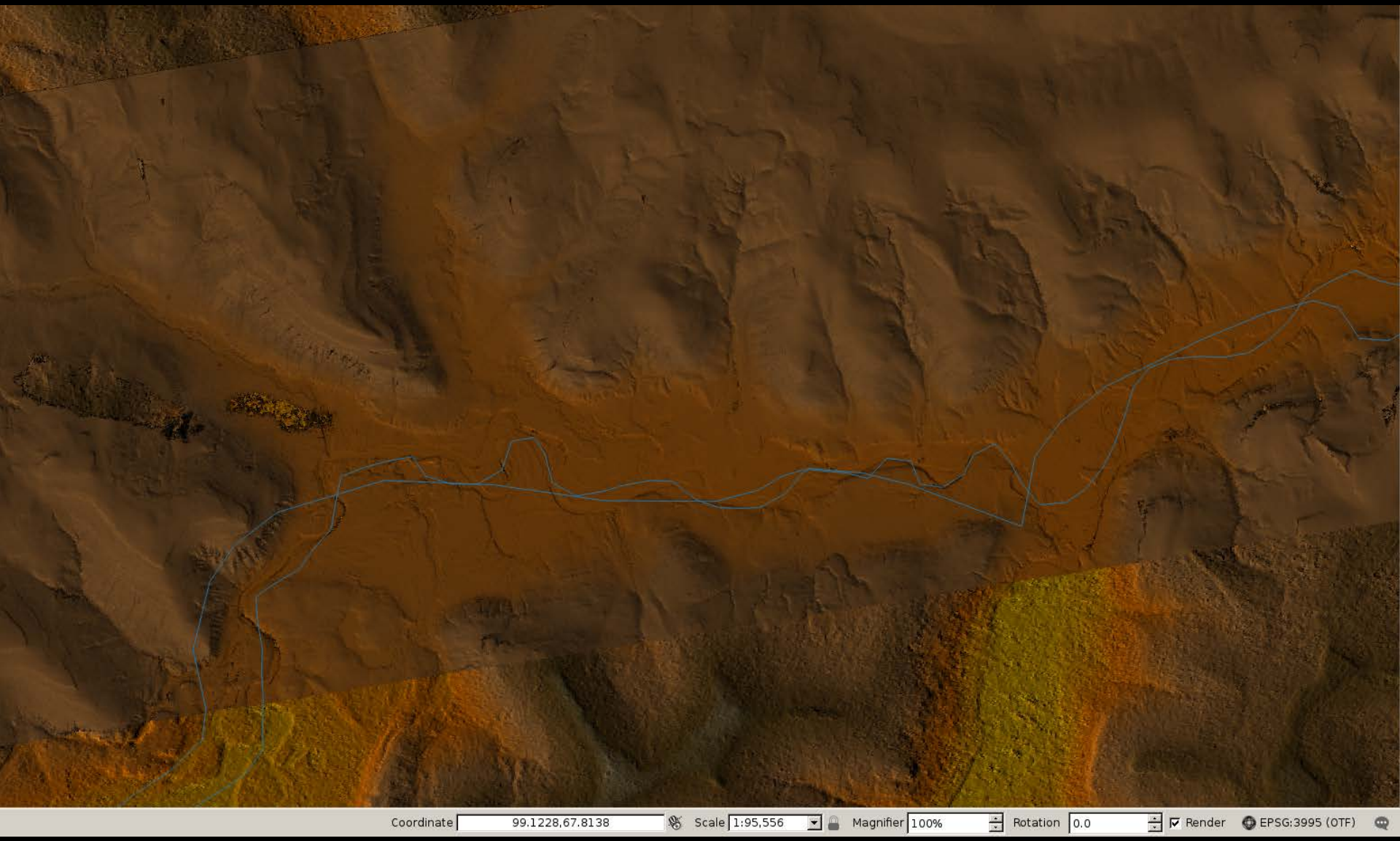


ASTER GDEM overlaid with WV-1,2 stereo strips

ASTER GDEM overlaid with WV-1,2 stereo strips
Our 2016 Kotuy river expedition

https://goo.gl/photos/Kh2ogTDtQtLqVgij6

ASTER GDEM overlaid with WV-1,2 stereo strips
2016 Kotuy river expedition

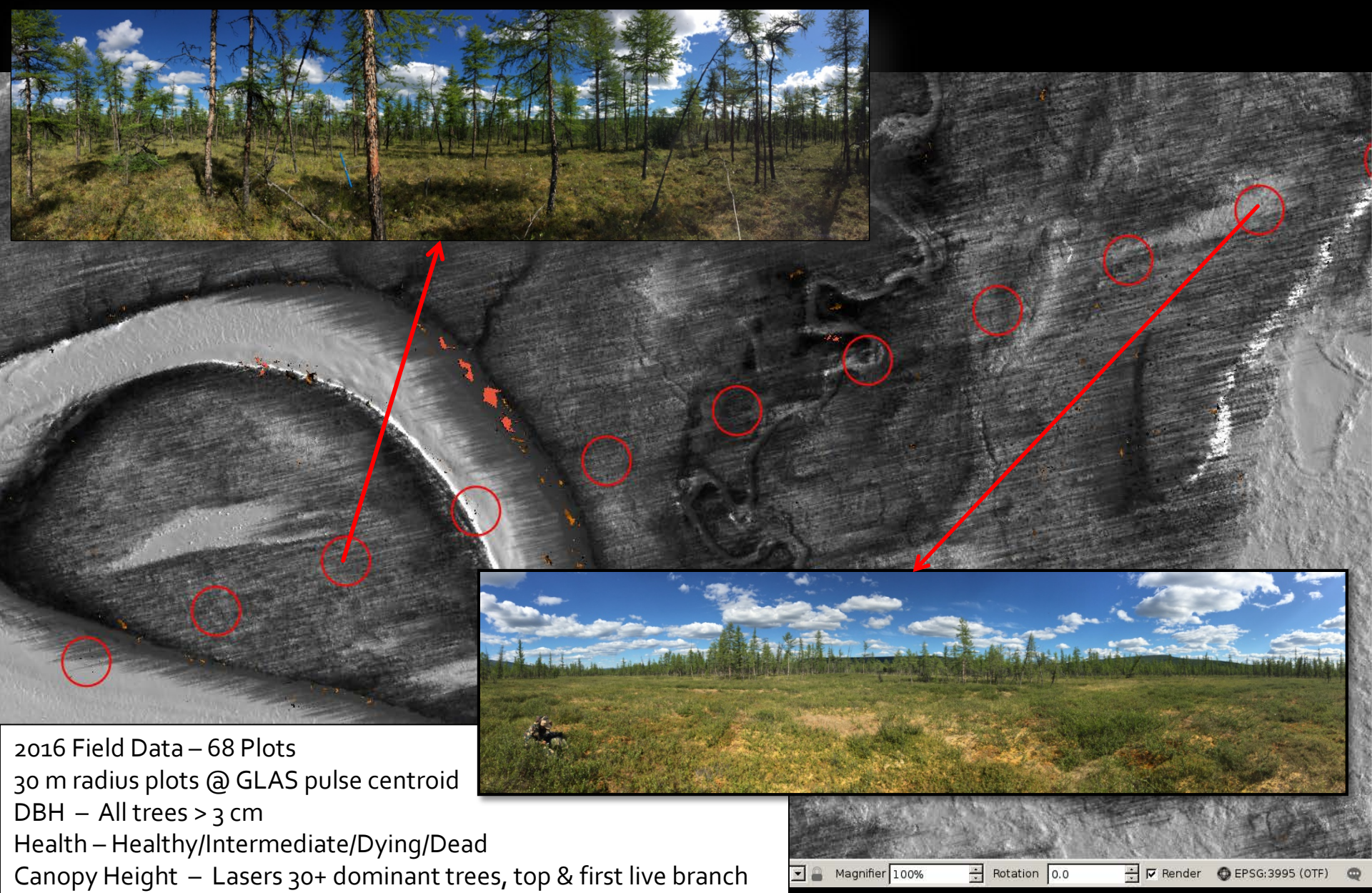


ASTER GDEM overlaid with WV-1,2 stereo strips
2016 Kotuy river expedition

WV1 Digital Surface Model 1 m resolution, Winter 2013
2016 Kotuy river expedition

WV-1, 0.5 m resolution, Winter 2013 , ©DigitalGlobe 2013 NextView License
2016 Kotuy river expedition

WV-1, 0.5 m resolution, Winter 2013 , ©DigitalGlobe Nextview License
GLAS shots shown in red, 2016 Kotuy river expedition



2016 Field Data – 68 Plots
30 m radius plots @ GLAS pulse centroid
DBH – All trees > 3 cm
Health – Healthy/Intermediate/Dying/Dead
Canopy Height – Lasers 30+ dominant trees, top & first live branch
Canopy – Size m
Dendro – Cores of 5 dominant trees, burn history
Permafrost depth – cm 5+ samples
GPS Photo – 360° Panoramic

©DigitalGlobe NextView License
2016 Kotuy river expedition

©DigitalGlobe NextView
9/8/2016 WV-3
True color 1.24 m

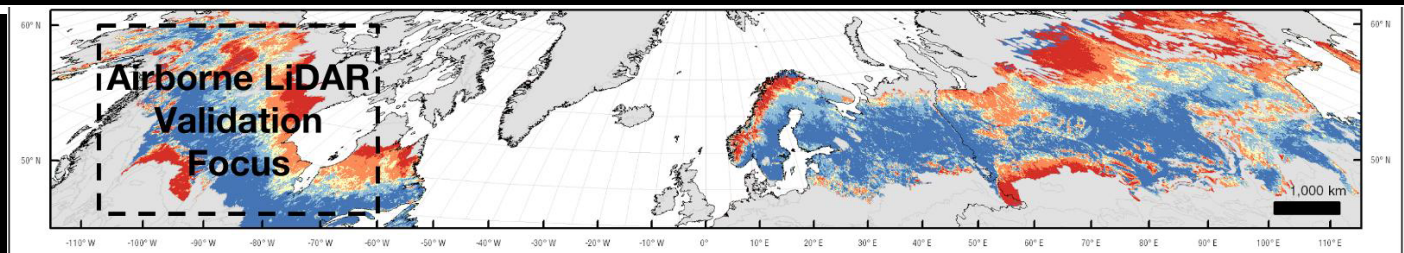
Recent Results 1

Landsat VCF calibration and validation with Airborne LiDAR

Poster & published - Montesano *et al.* 2016 *remote sensing*

Results:

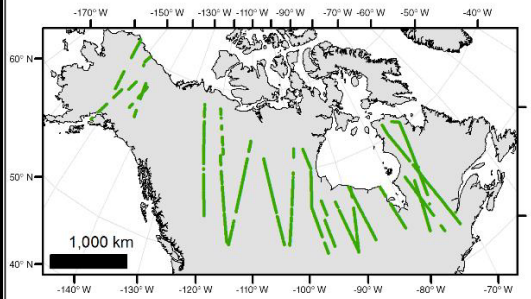
1. Landsat VCF in the TTE more closely relates to canopy closure of trees >2 m in height R^2 0.5 vs. >5 m in height R^2 0.42
2. Validation improved tree canopy cover uncertainty estimates in sparse TTE forests for three temporal epochs (2000, 2005, and 2010) by reducing systematic errors
3. Average pixel-level uncertainties in tree canopy cover were 29.0%, 27.1% and 31.1% for the 2000, 2005 and 2010 epochs respectively



Error estimates derived directly from the Landsat VCF (c. 2000) drive the approach to validate tree canopy cover in areas of sparse tree cover and high tree cover uncertainty.

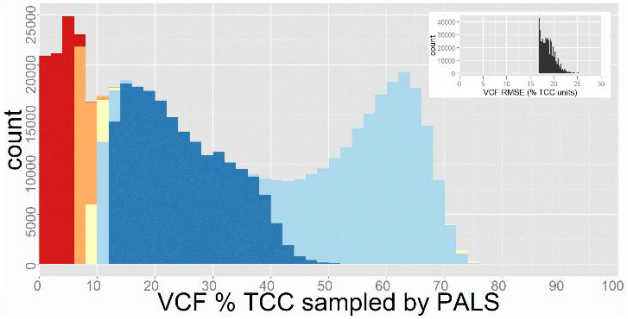
VCF RMSE % Relative Error Category: Low Relative Error; (0-50); Moderate Relative Error; (50-75]; High Relative Error; (75-100]; Error > Magnitude of TCC Value; >100; Error > 2 x Magnitude of TCC Value; >200

Airborne LiDAR Sampling (PALS) of VCF Tree Canopy Cover and its Errors



(Left) Spatial distribution of LiDAR sampling across Canada and Alaska

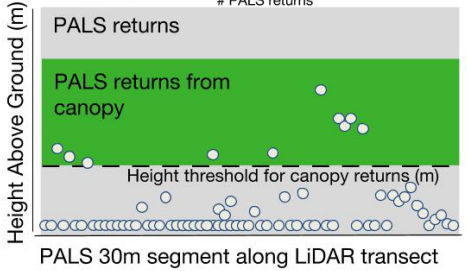
(Right) The distribution of VCF % TCC sampled by airborne LiDAR broken down by relative error category

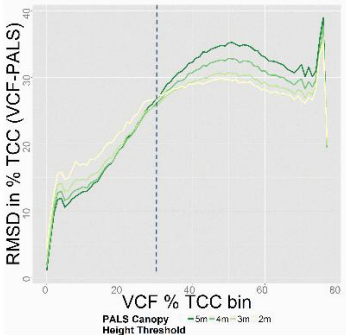


PALS Derivation of Canopy Closure: Canopy Height

- Original PALS returns were aggregated across 30m segments to estimate canopy closure, a variable
- similar to tree canopy cover. For each segment, canopy closure was estimated using 4 different canopy height thresholds. Each estimate was compared with that of its corresponding VCF pixel.

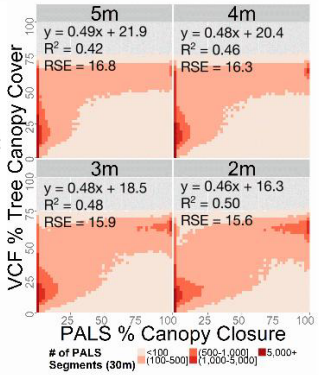
$$\text{PALS 30m canopy closure} = 100 * \frac{\text{(\# PALS returns from canopy)}}{\text{\# PALS returns}}$$





(Left) Root mean square difference (RMSD) of tree canopy cover from VCF & PALS. Binned at 1% TCC intervals.

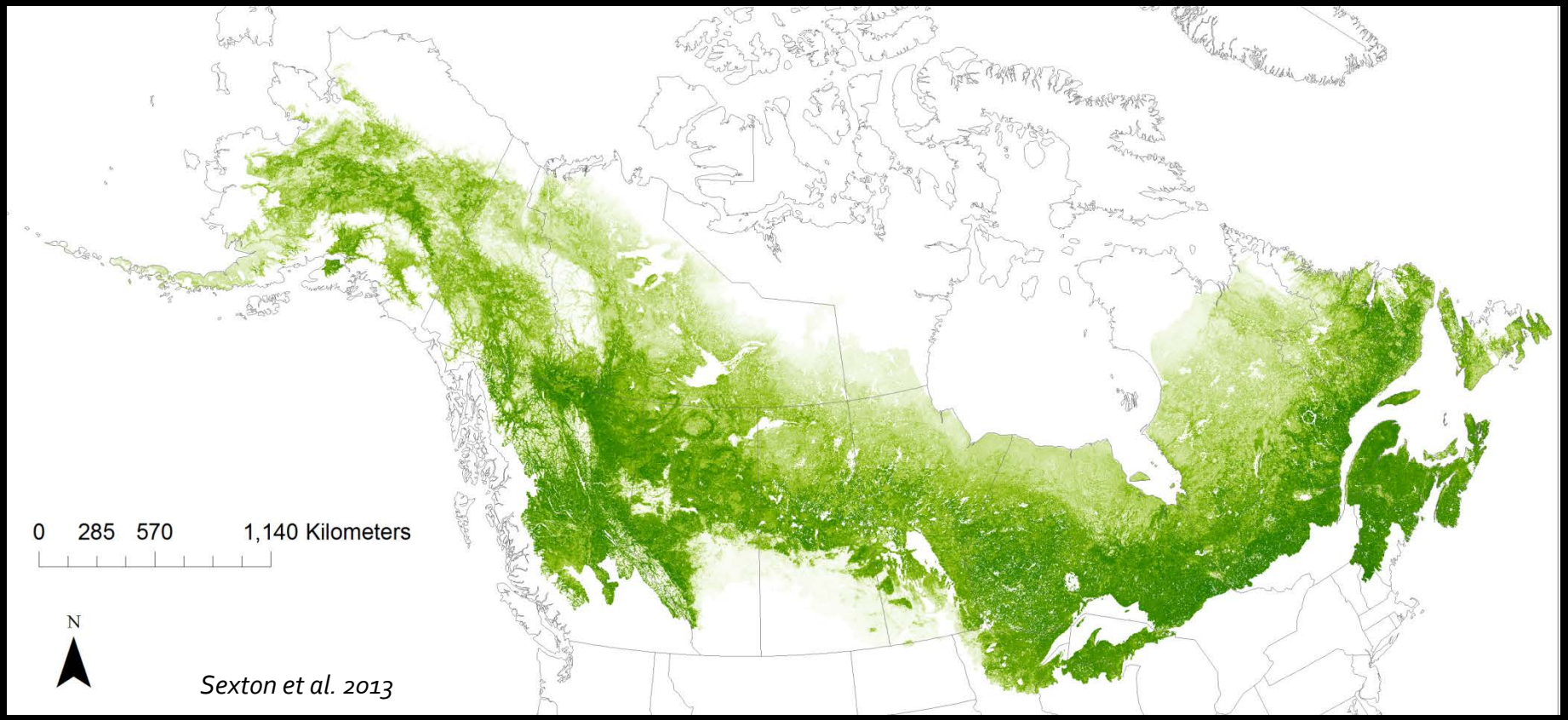
(Right) Tree Cover: VCF vs PALS. Binned scatter at various canopy height thresholds.



Recent Results 1

Landsat TCC calibrated for North America and cal/val with Airborne LiDAR

Original 2010 Landsat Boreal Tree Canopy Cover



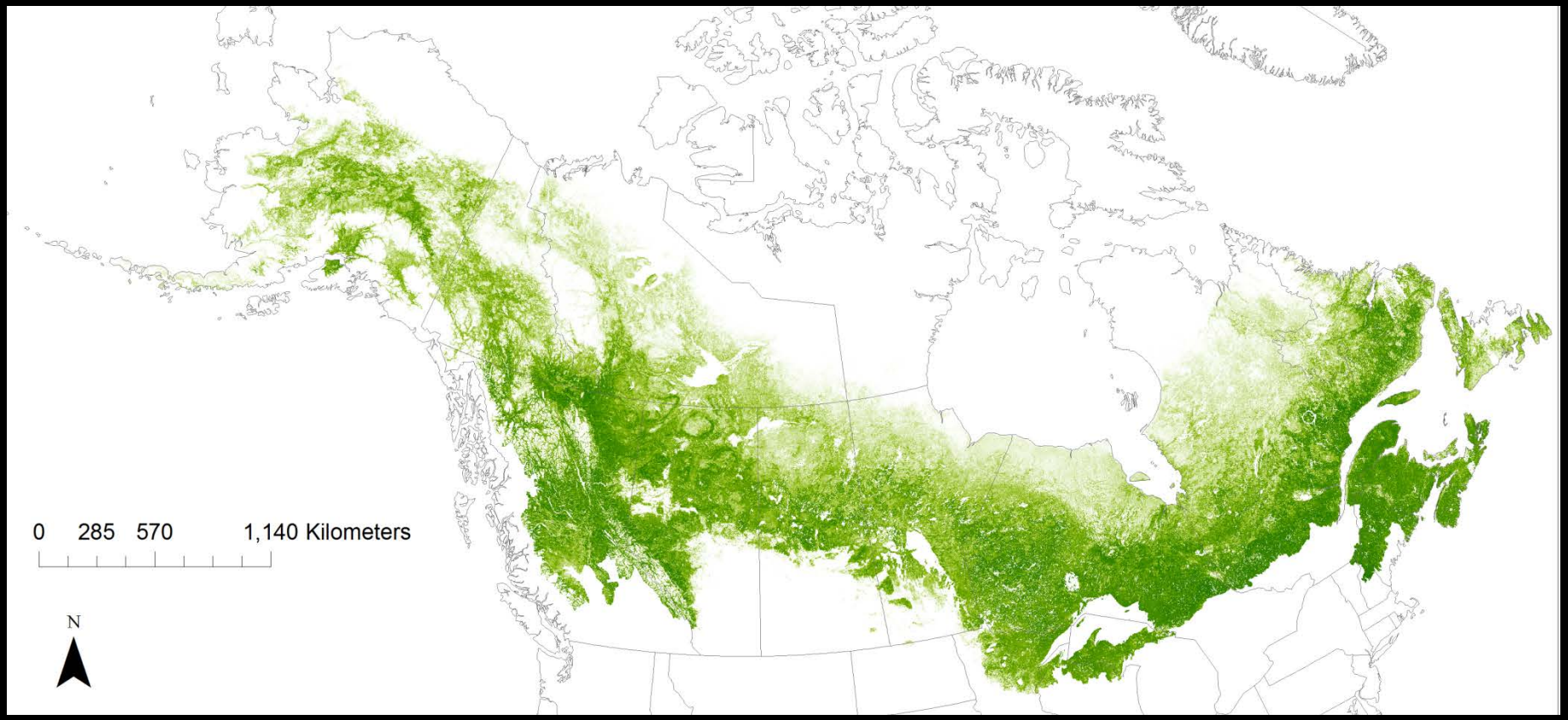
Presented @ 500 m resolution, processed @ 30 m

Recent Results 1

Landsat TCC calibrated for North America and cal/val with Airborne LiDAR

Publication in prep.

2 m Calibrated 2010 Landsat Boreal Tree Canopy Cover



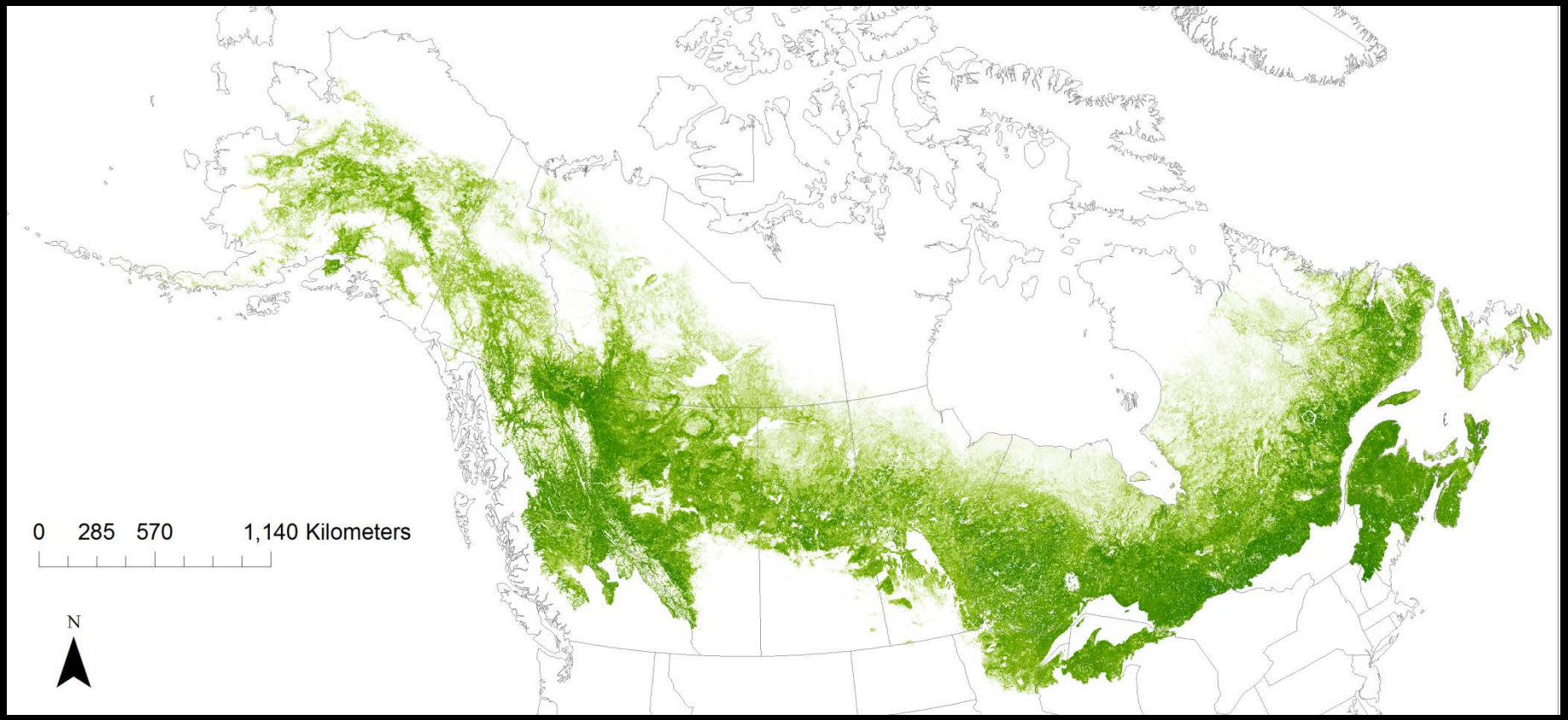
Presented @ 500 m resolution, processed @ 30 m

Recent Results 1

Landsat TCC calibrated for North America and cal/val with Airborne LiDAR

Publication in prep.

5 m Calibrated 2010 Landsat Boreal Tree Canopy Cover



Presented @ 500 m resolution, processed @ 30 m

Recent Results 2

WV-1,2 digital surface model comparison with GliHT in the Tanana Valley, AK

Validating the Results of Using WorldView Satellite Data to Map Canopy Height in the Tanana Valley Region of Alaska

William Wagner[1] Christopher S. R. Neigh[2] Paul M. Montesano[2,3] Laura I. Duncanson[2]
1. University of Maryland 2. Biospheric Sciences Laboratory Code 618 NASA GSFC 3. Science Systems Applications Inc.

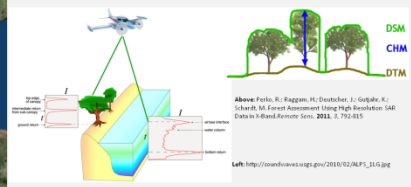
Abstract

The Arctic-Boreal region is an important area to study due to its large forests, its role in the global carbon cycle, and its susceptibility to climate change. The regions remote location and size makes it difficult to study these areas using airborne and field approaches.

This study evaluates an approach for estimating canopy height using high resolution stereo Digital Surface Models from WorldView datasets. The stereo data in the Tanana Valley region were processed using NASA's Ames Stereo Pipeline and used to derive a canopy height model (CHM). Airborne light detection and ranging (LiDAR) data were collected using Goddard's Hyper-spectral and Thermal Imager (G-LiHT).

A pixel based comparison between canopy heights derived from stereo DSMs and G-LiHT was conducted at varying spatial resolutions: 3m, 5m, 10m, and 30m to assess the accuracy of stereo datasets as a function of spatial scale.

Background

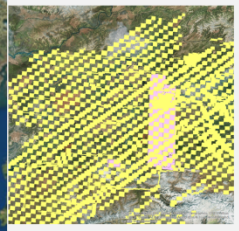


Above: Perko, R.; Raggam, H.; Deutscher, J.; Gutjahr, K.; Schardt, M. Forest Assessment Using High Resolution SAR Data in X-Band.*Remote Sens.* **2011**, *3*, 792-815

Left: http://soundwaves.usgs.gov/2010/02/ALPS_1LG.jpg

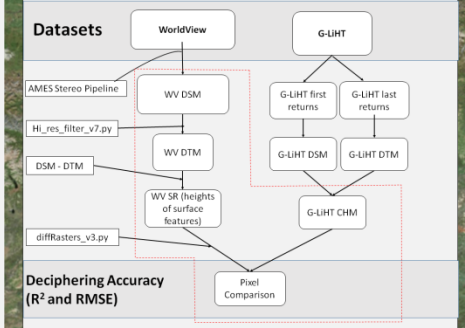
Top Left: Introduction to how LiDAR works. Light reflected from surfaces gives us information about surface features based on time(t) and intensity(I) of the reflected light.

Top Right: Demonstrates how this LiDAR data can be used to derive canopy height. Heights of surface features can be found by comparing first and last returns of the reflected light.



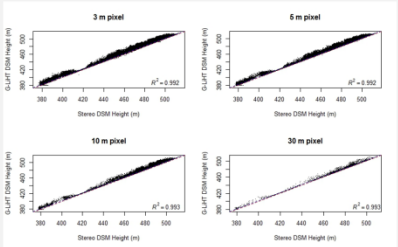
Left: Image demonstrating how the program ArcMap was used to identify key areas of overlap between the G-LiHT flight paths (yellow tiles) and the available World-View datasets (pink tiles)

Methods:



Above: Figure demonstrating the methods used in the study. The starting datasets are listed at the top, with the middle section showing what data was processed and ultimately used in the final pixel comparison. The dotted red line represents the data worked with specifically in this study.

Results: AK_20140721_pm_l1s671



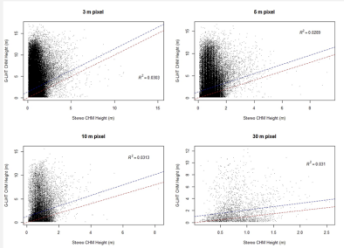
The above plot represents an area of study using different G-LiHT paths overlapping WV data within the Tanana Valley region.

The area was filtered for slope and areas with inclines greater than 10° of slope were not included in the comparison.

This figure shows the relationship between the WV DSM produced through the ASP compared to a DSM created using the G-LIHT data.

Results continued:

AK_20140721_pm_l1s671



This graph is a comparison between the CHM values obtained by G-LiHT and a CHM model derived from the WV DSM by subtracting the DTM.

Discussion:

The plots produced in this specific study area shows that while the WV DSM produced fairly accurate results, the DSM did not have that same level of accuracy in producing a CHM.

The plot showed very little correlation between the two CHMs and showed a tendency for the WV CHM to underestimate the true canopy height.

Possible sources of errors for these results include problems in viewing angles for stereo image pairs in ASP.

Acknowledgements:
Additional Insight and Support was provided by Bruce Cook and Stephanie Miller.

References:

Neigh, C.S.R.; Masek, J.G.; Bourget, P.; Cook, B.; Huang, C.; Rishmawi, K.; Zhao, F. Deciphering the Precision of Stereo IKONOS Canopy Height Models for US Forests with G-LiHT Airborne LiDAR. *Remote Sens.* **2014**, *6*, 1762-1782.

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Perko, R.; Raggam, H.; Deutscher, J.; Gutjahr, K.; Schardt, M. Forest Assessment Using High Resolution SAR Data in X-Band.*Remote Sens.* **2011**, *3*, 792-815.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Recent Results 2

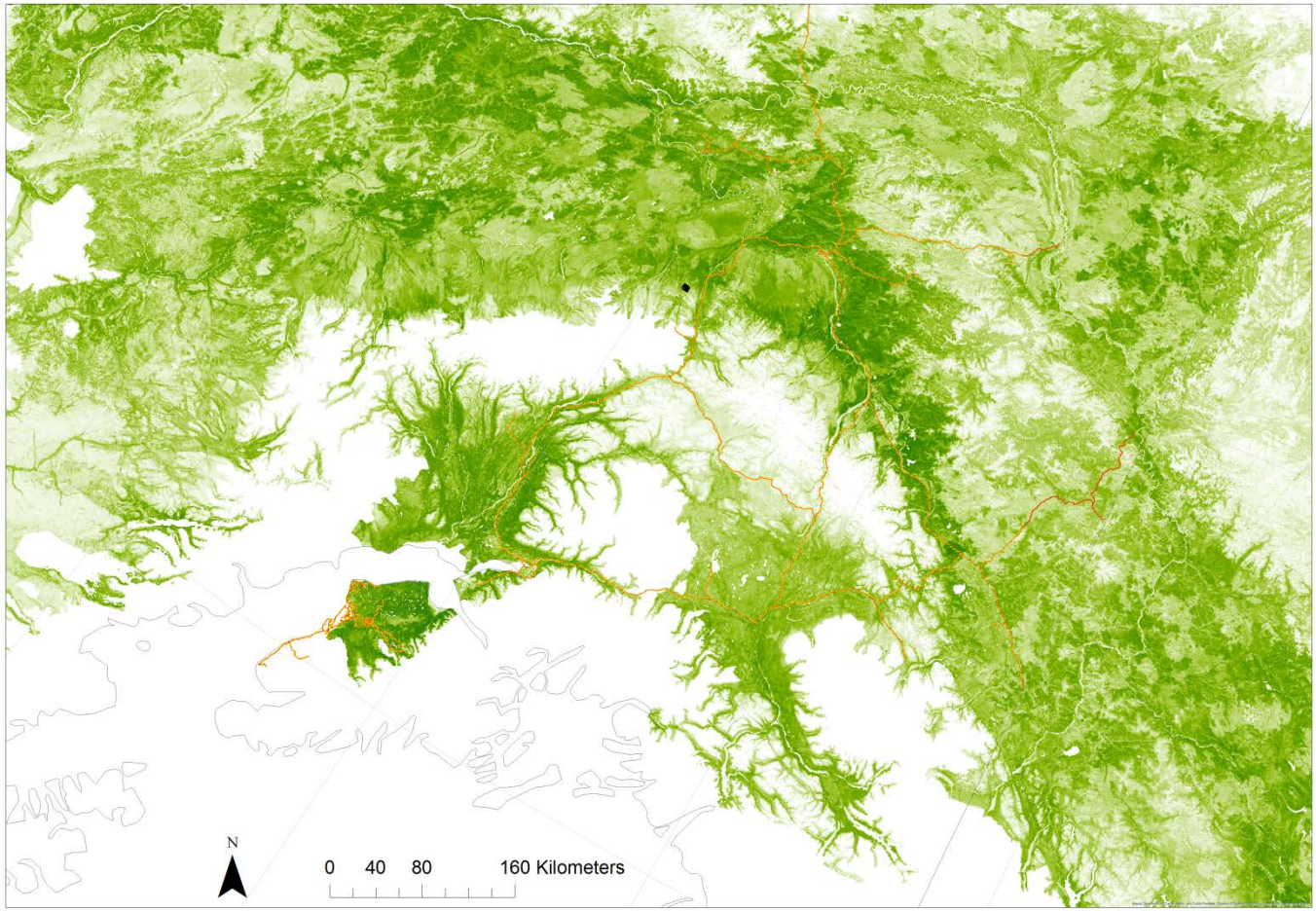
WV-1,2 Digital surface model comparison with GliHT in the Tanana Valley, AK

Results:

1. WV Canopy Height Models (CHMs) from winter months are poorly correlated to GliHT airborne LiDAR derived CHMs (R2 < 0.3) at multiple resolutions within 1-2 yrs of data acquisition.

2. WV CHMs within growing season are correlated to GliHT CHMs (R2 > 0.7) at multiple resolutions.

3. Seasonality and viewing geometry must be considered when trying to map vegetation height & cover with WV stereo data.



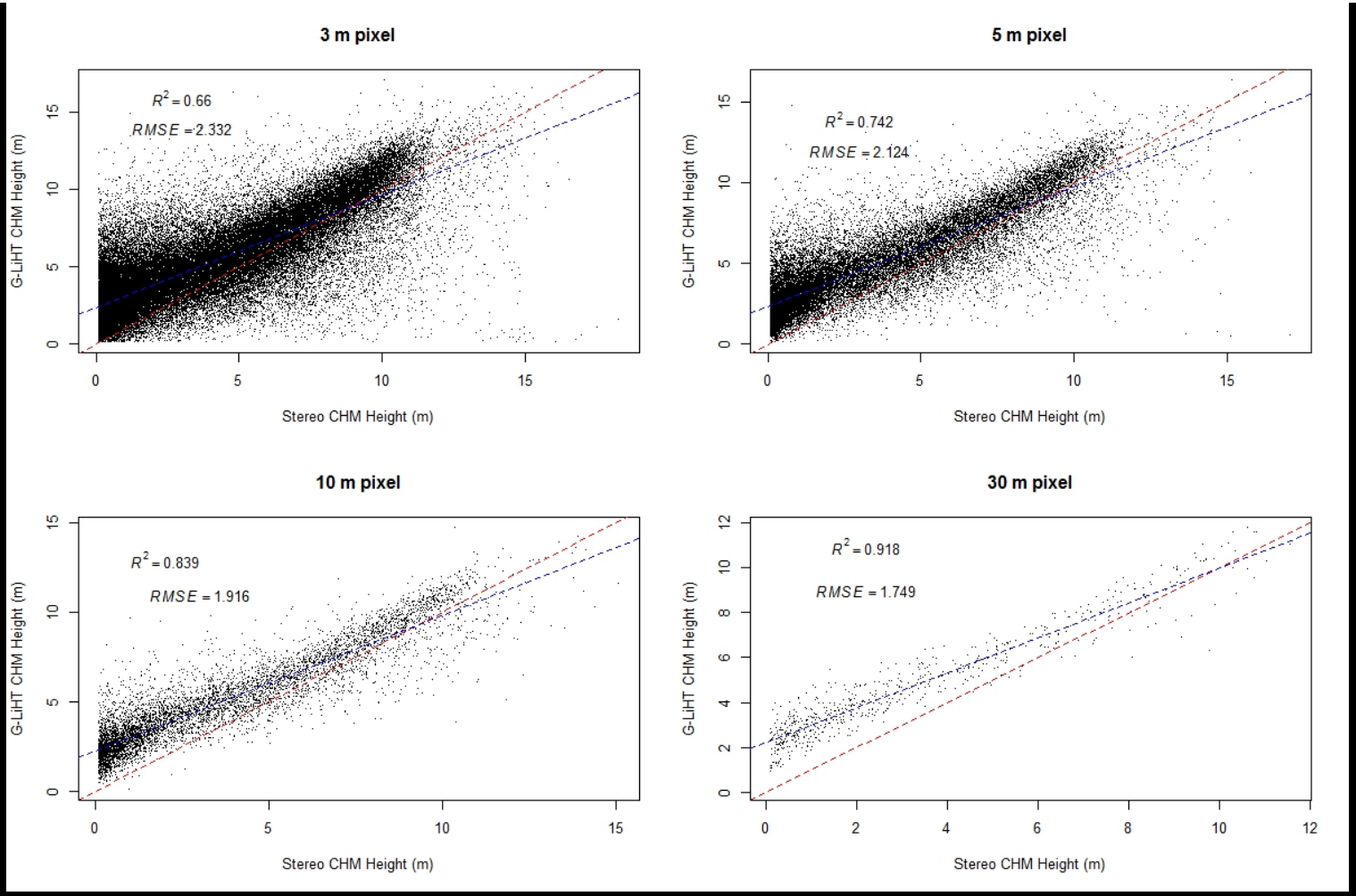
Landsat TCC 2 m calibrated, Black point is inter-comparison location

Recent Results 2

WV-1,2 Digital surface model comparison with GliHT in the Tanana Valley, AK

Publication in prep.

July 30
2013
WV1



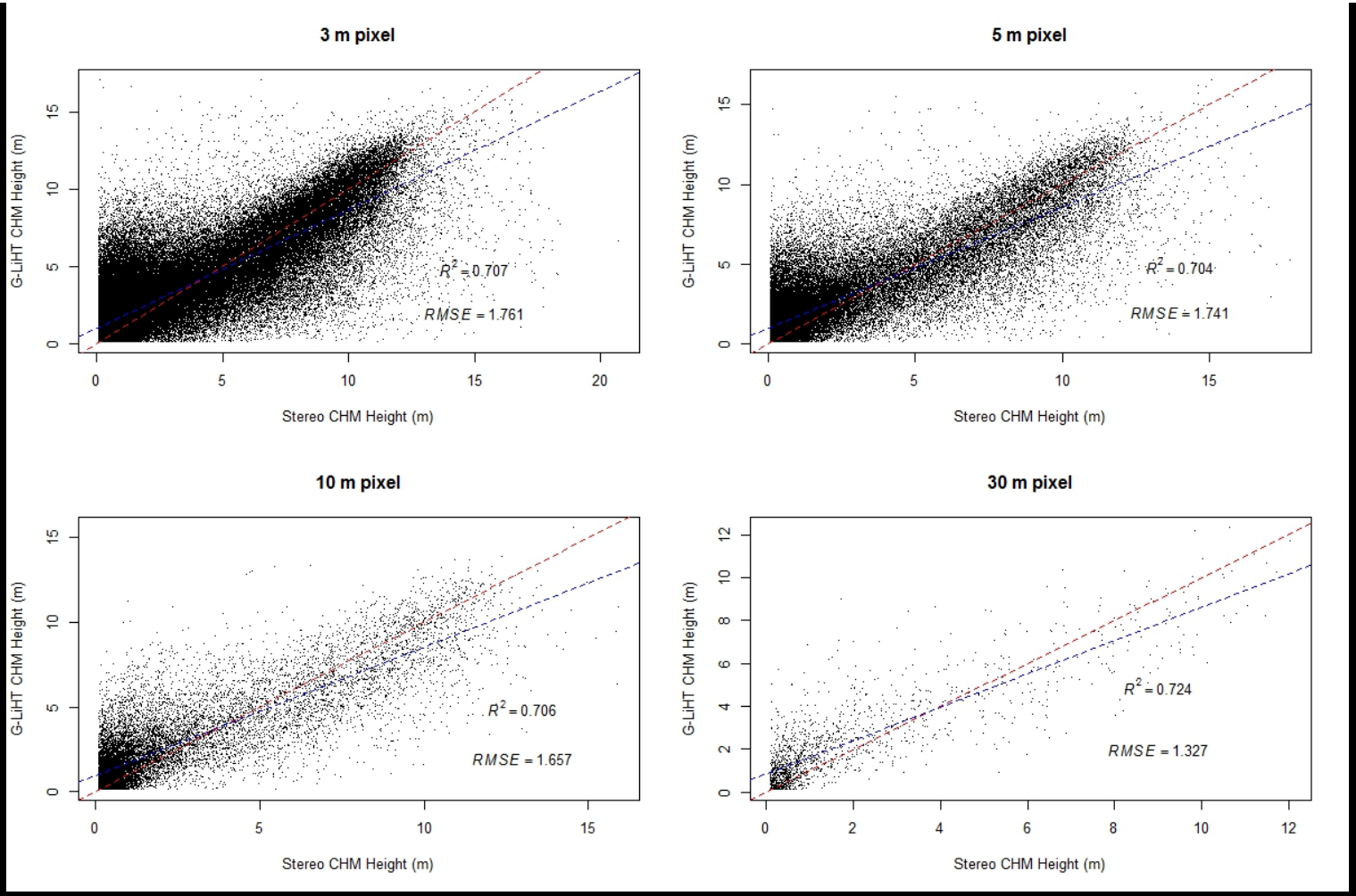
Raster maps from point clouds between the 2013 WV CHM and the 2014 G-LIHT CHM for the different G-LIHT tiles at the different resolutions (3, 5, 10, 30) were compared.

Recent Results 2

WV-1,2 Digital surface model comparison with GliHT in the Tanana Valley, AK

Publication in prep.

July 31
2013
WV1



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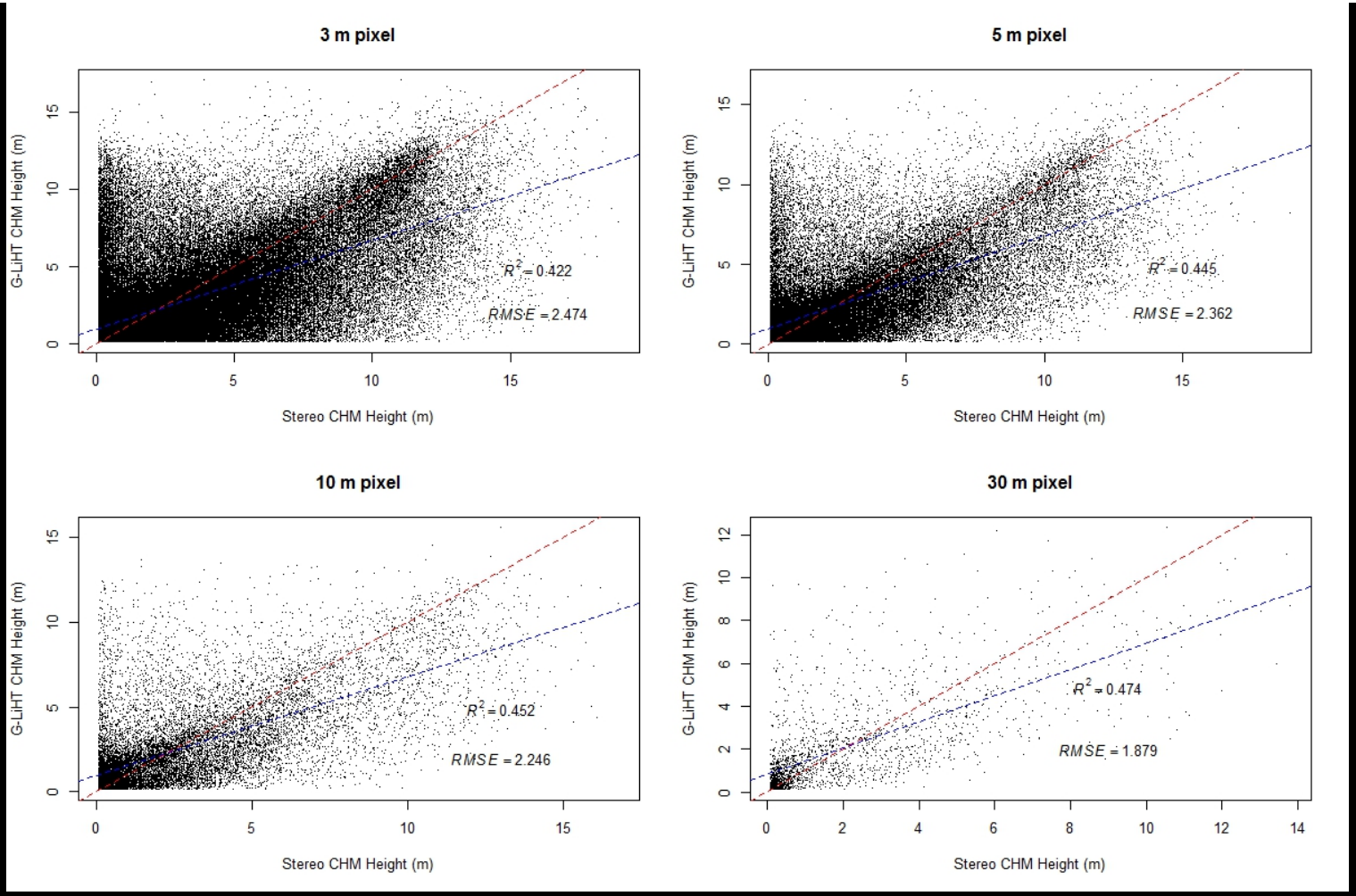
Recent Results 2

WV-1,2 Digital surface model comparison with GliHT in the Tanana Valley, AK

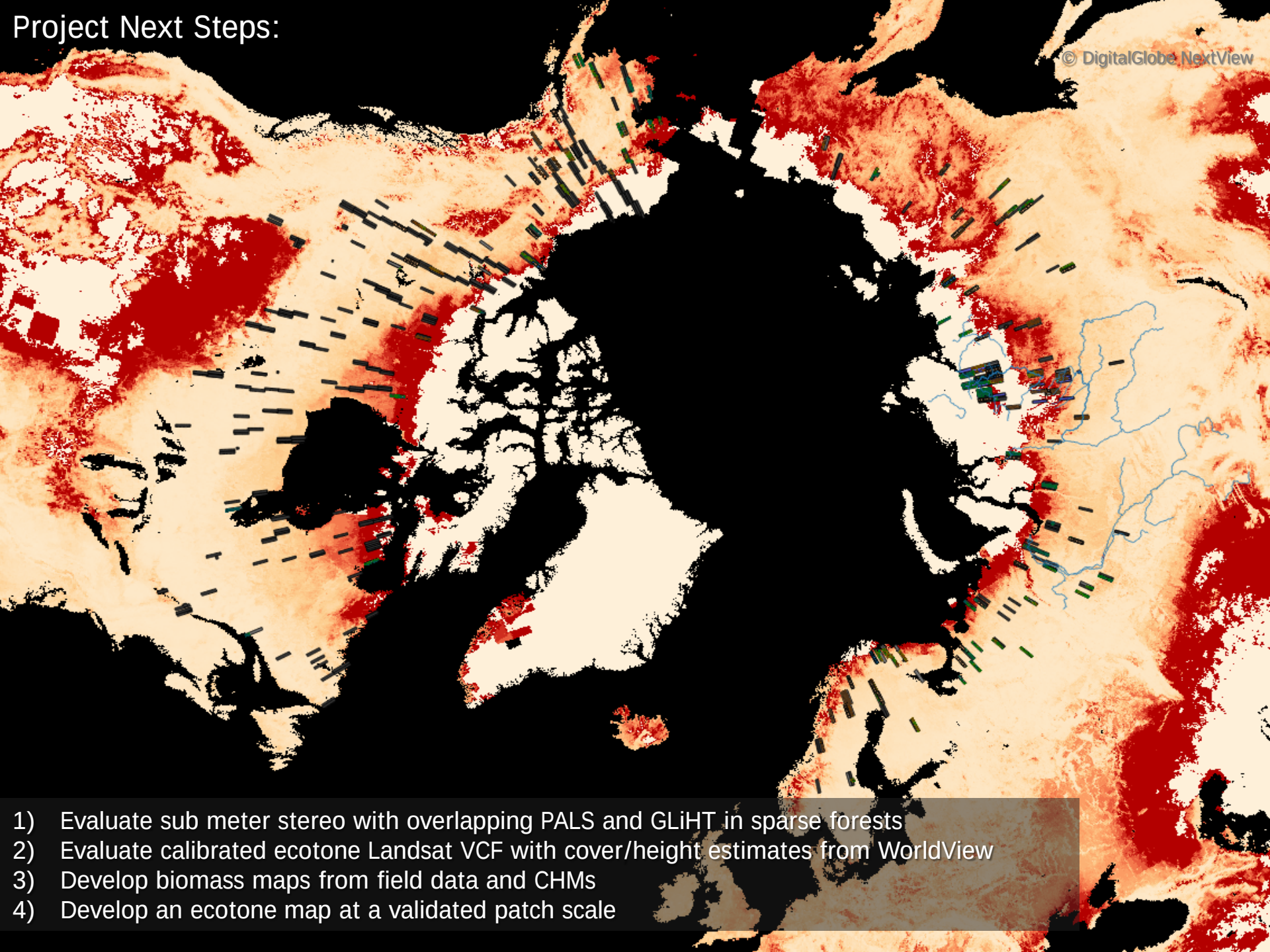
Publication in prep.

Nov 6
2013
WV2



Raster maps from point clouds between the 2013 WV CHM and the 2014 G-LIHT CHM for the different G-LIHT tiles at the different resolutions (3, 5, 10, 30) were compared.

Project Next Steps:

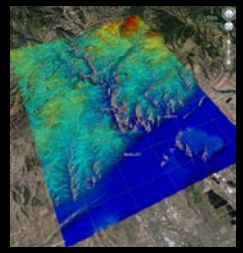


1) Evaluate sub meter stereo with overlapping PALS and GLiHT in sparse forests
2) Evaluate calibrated ecotone Landsat VCF with cover/height estimates from WorldView
3) Develop biomass maps from field data and CHMs
4) Develop an ecotone map at a validated patch scale

Future steps toward advancing ecotone research

1
~1-2 yrs

Broad use of compute with US Gov. access to global archives of WorldView stereo data

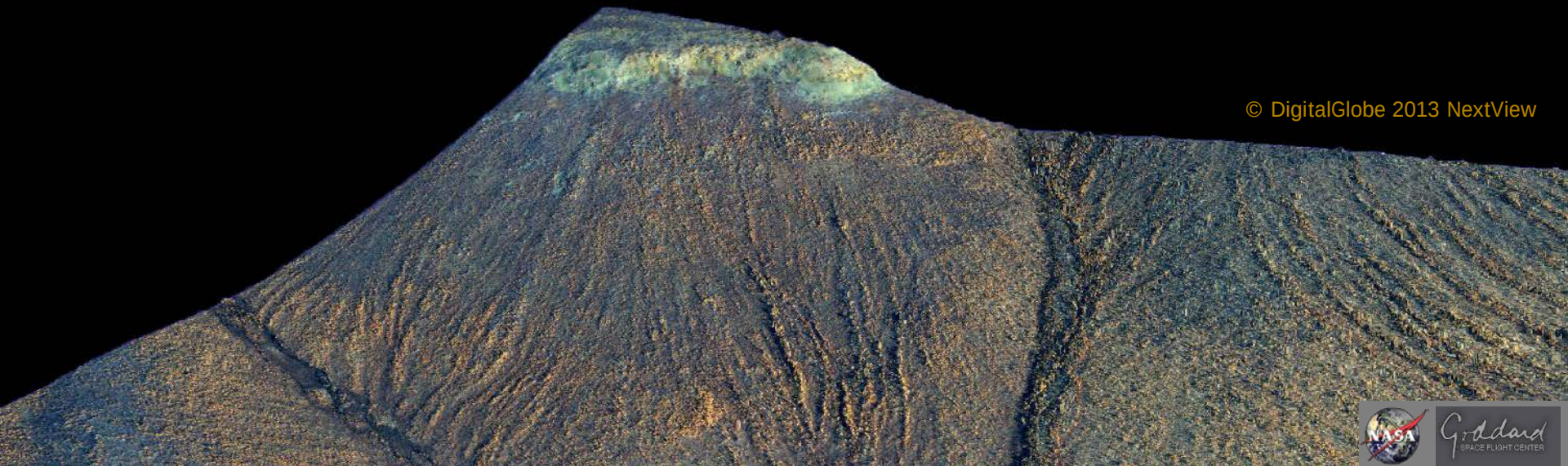


Combine Landsat forest products with available commercial stereo and next gen. spaceborne LiDAR to close the knowledge gap in the spatial distribution of terrestrial C stocks.

2
~2-4 yrs

ICESat-1 & 2

Techniques/methods developed will support data fusion & modeling for existing and future missions.



© DigitalGlobe 2013 NextView

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E-mail: christopher.s.neigh@nasa.gov; Phone: 1-301-614-6681

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2014 Montesano, P.M., Sun, G., Dubayah, R.O., Ranson, K.J. (2014). The Uncertainty of Plot-Scale Forest Height Estimates from Complementary Spaceborne Observations in the Taiga-Tundra Ecotone. *Remote Sensing*, 6:10070-10088.

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Thank You!