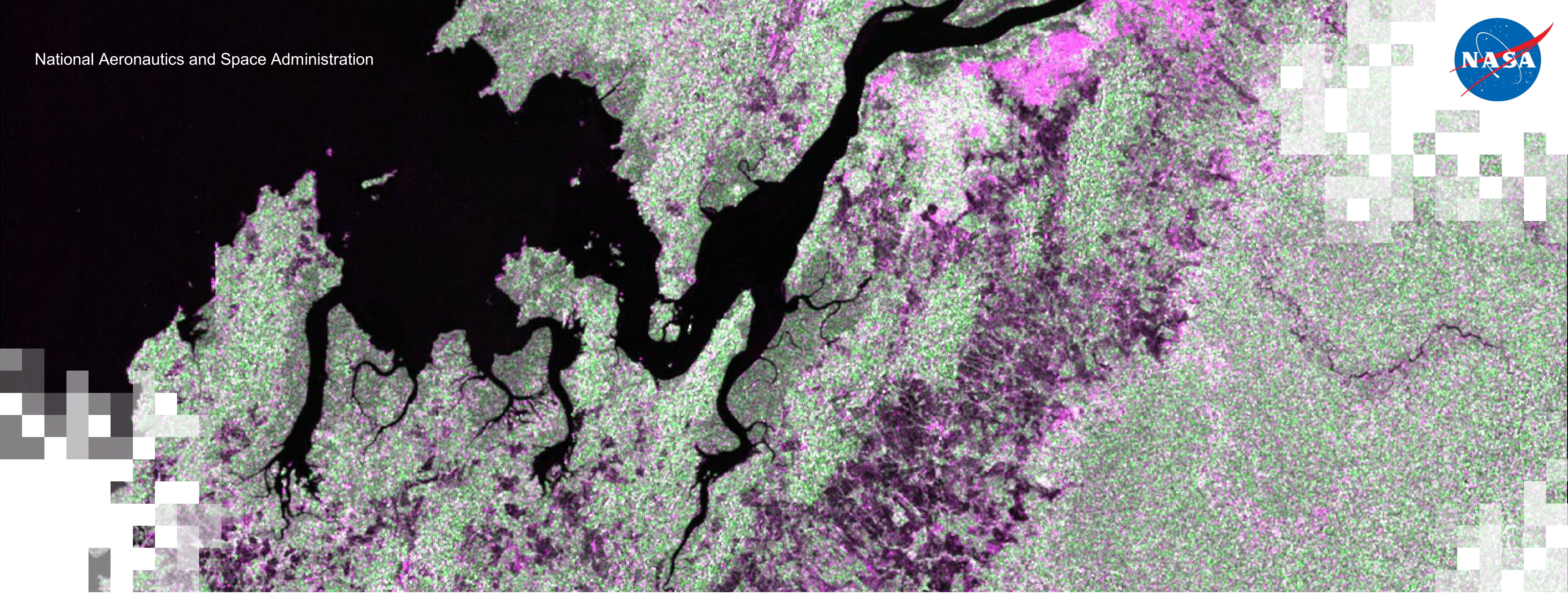


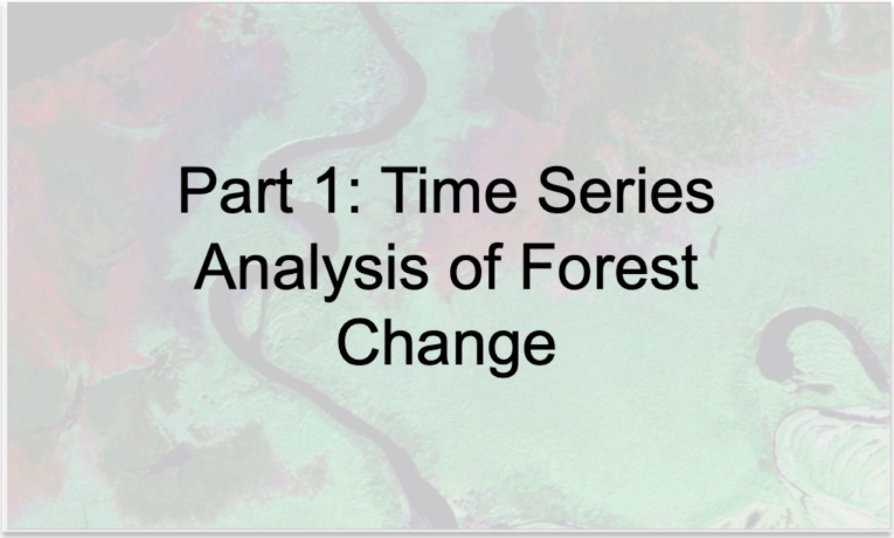
Forest Mapping and Monitoring with SAR Data: InSAR Processing and Forest Stand Height

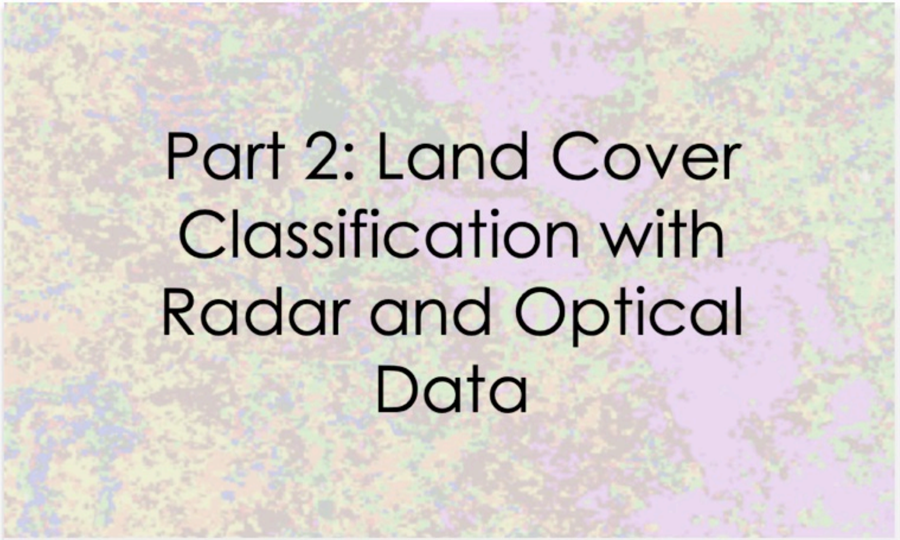
Erika Podest &

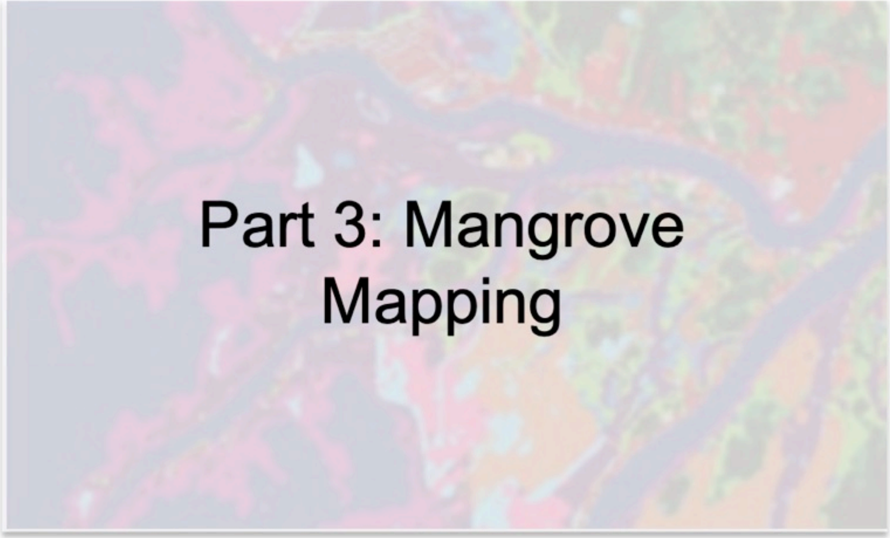
Paul Siqueira, Yang Lei, Tracy Whelen, Simon Kraatz (University of Massachusetts)

May 21, 2020

Course Outline







A little something about FSH (Forest Stand Height)

Algorithms exist with varying complexity

- Simple classification (one image)
- Time-series & Machine learning
- Polarimetry
- Multi-frequency & Data fusion

So far, with Forest Mapping and Monitoring, you have used:

- Time-Series Analysis of Basic Change
- Land Cover classification with radar and optical data
- Mangrove mapping using the double-bounce signature

FSH is another level of complexity that requires good knowledge of:

- SAR processing
- InSAR
- NASA DAAC Data inquiries

Today is meant to be an introduction to that process

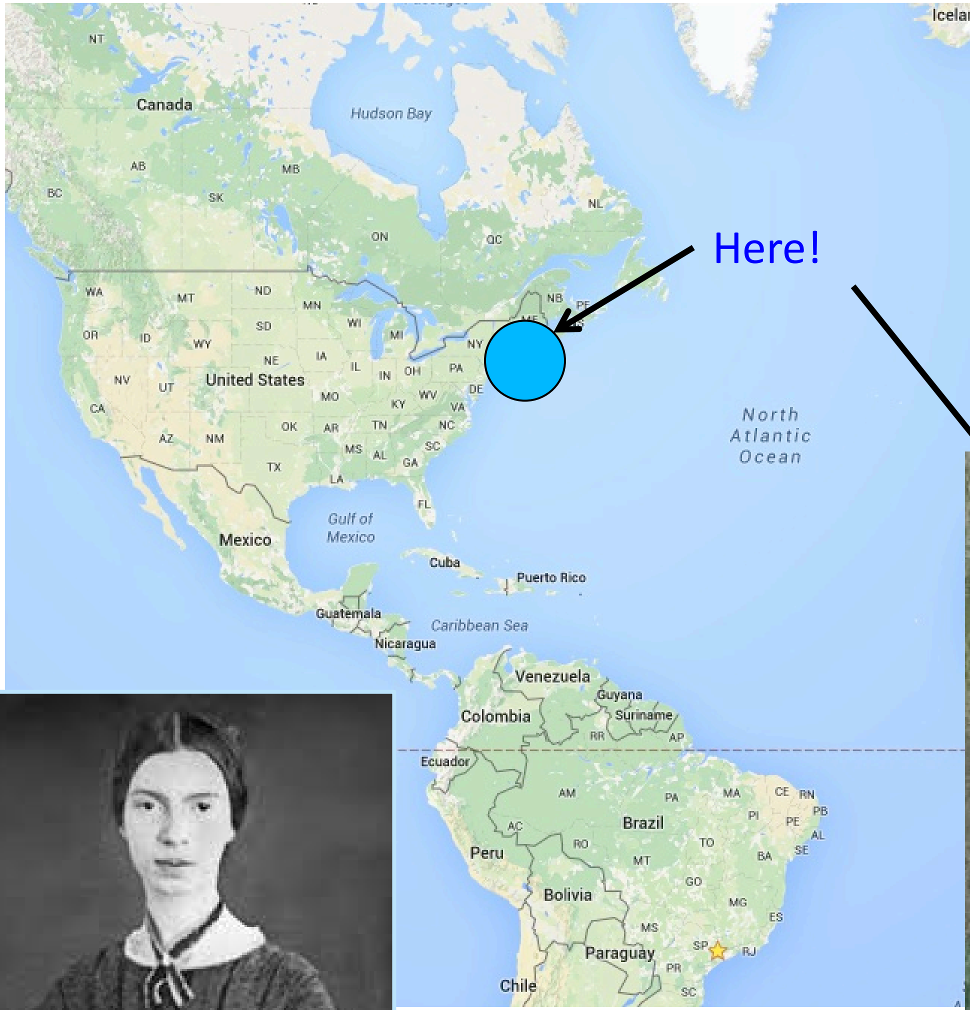
Microwave Remote Sensing Laboratory

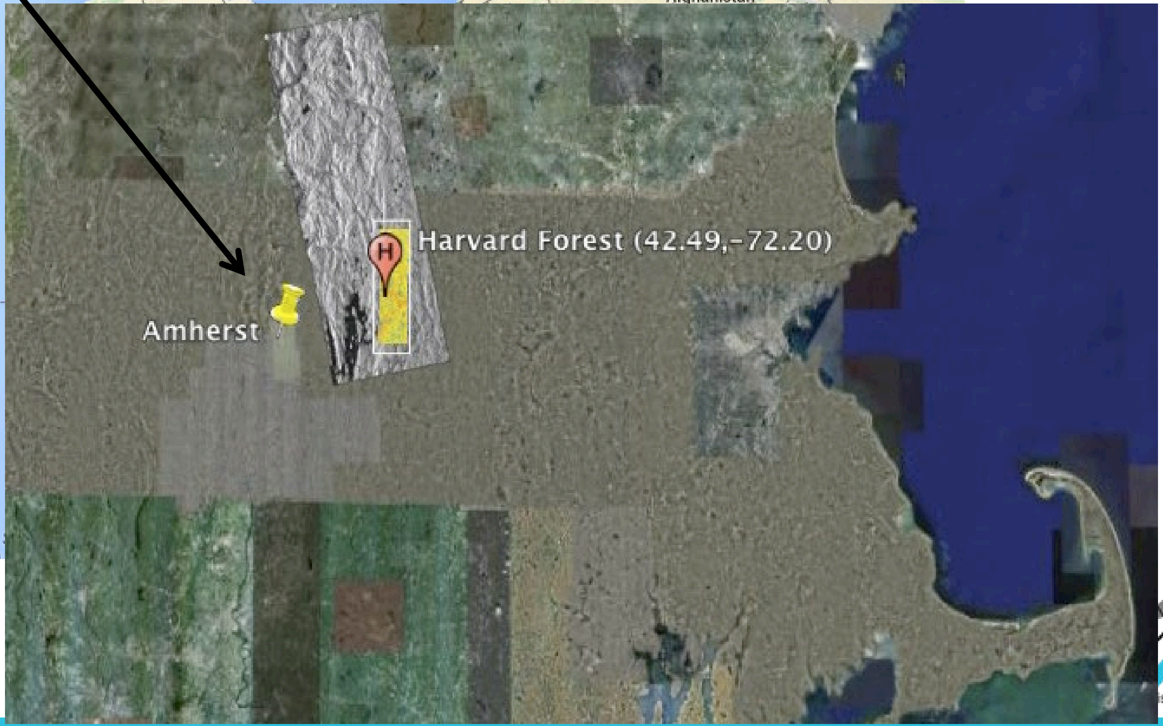
Dept. of Electrical and Computer Engineering

- 40-year history of microwave sensor development
- Core skills in microwaves and remote sensing system development
- Research expertise in radar, SAR, InSAR, lidar and Hyperspectral imaging
- Application areas in forest, crops, atmospheric & ocean monitoring

- ✧ Close interaction with national space agencies, research institutes, and commercial industry
- ✧ Faculty have international reputation in microwave engineering, hyperspectral science, electromagnetics

Where is Amherst?



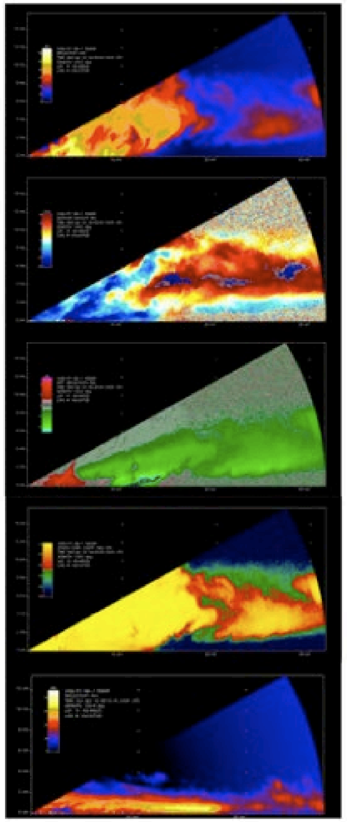
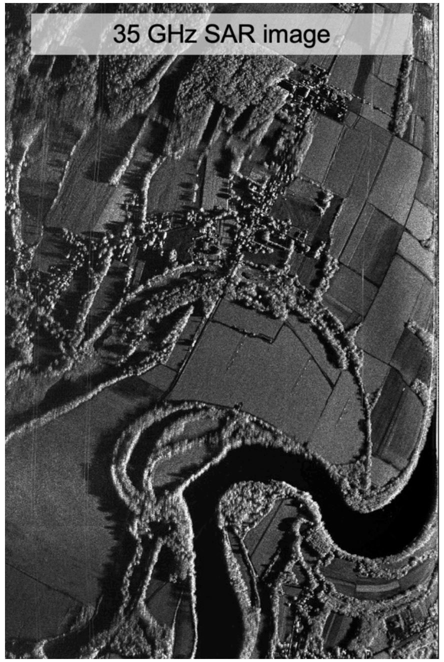


Mission

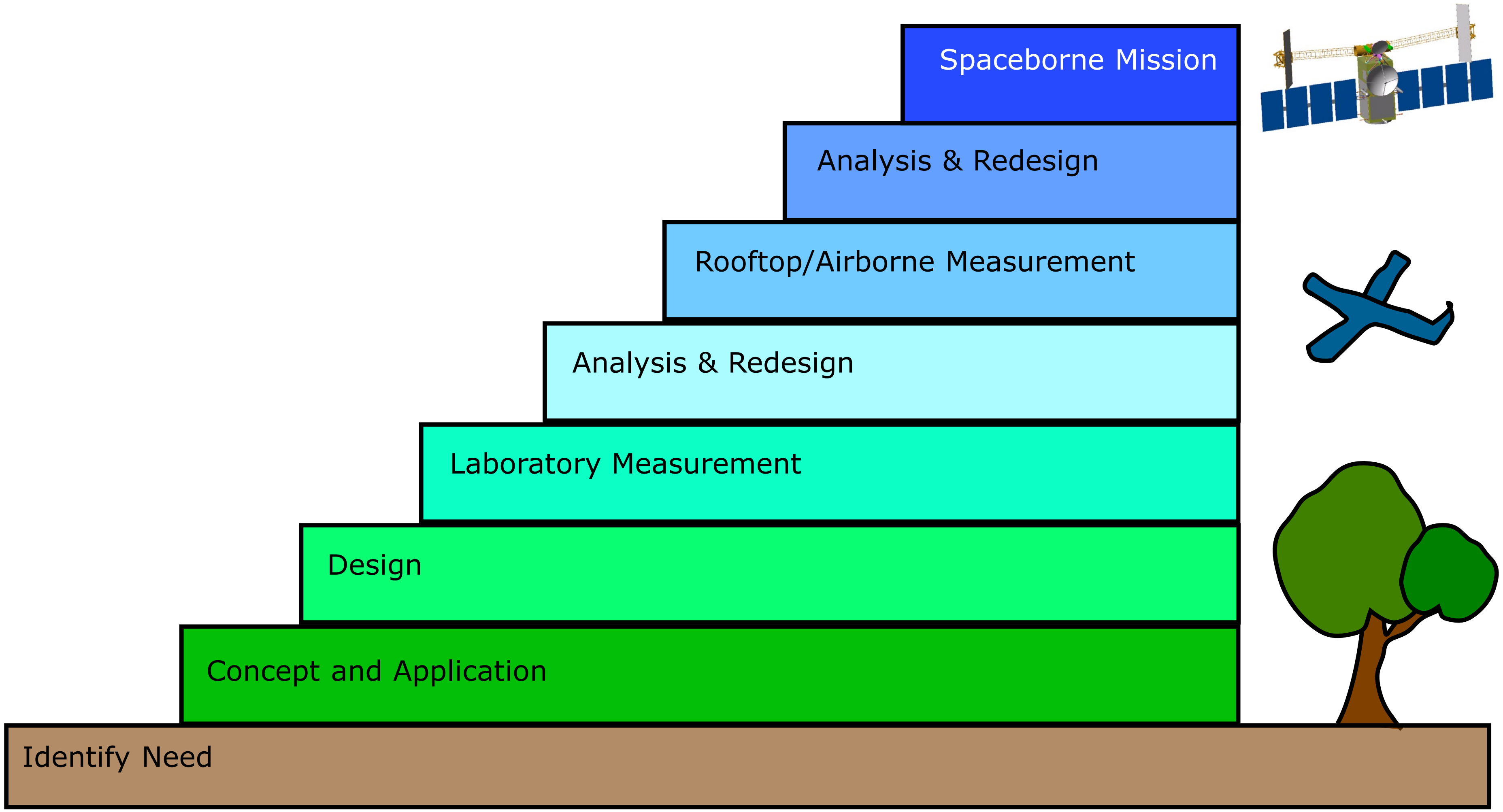
- Design, build, and use microwave systems for studying the environment.
- Instrument capability from DC to 215 GHz (most systems between 100 MHz and 100 GHz).





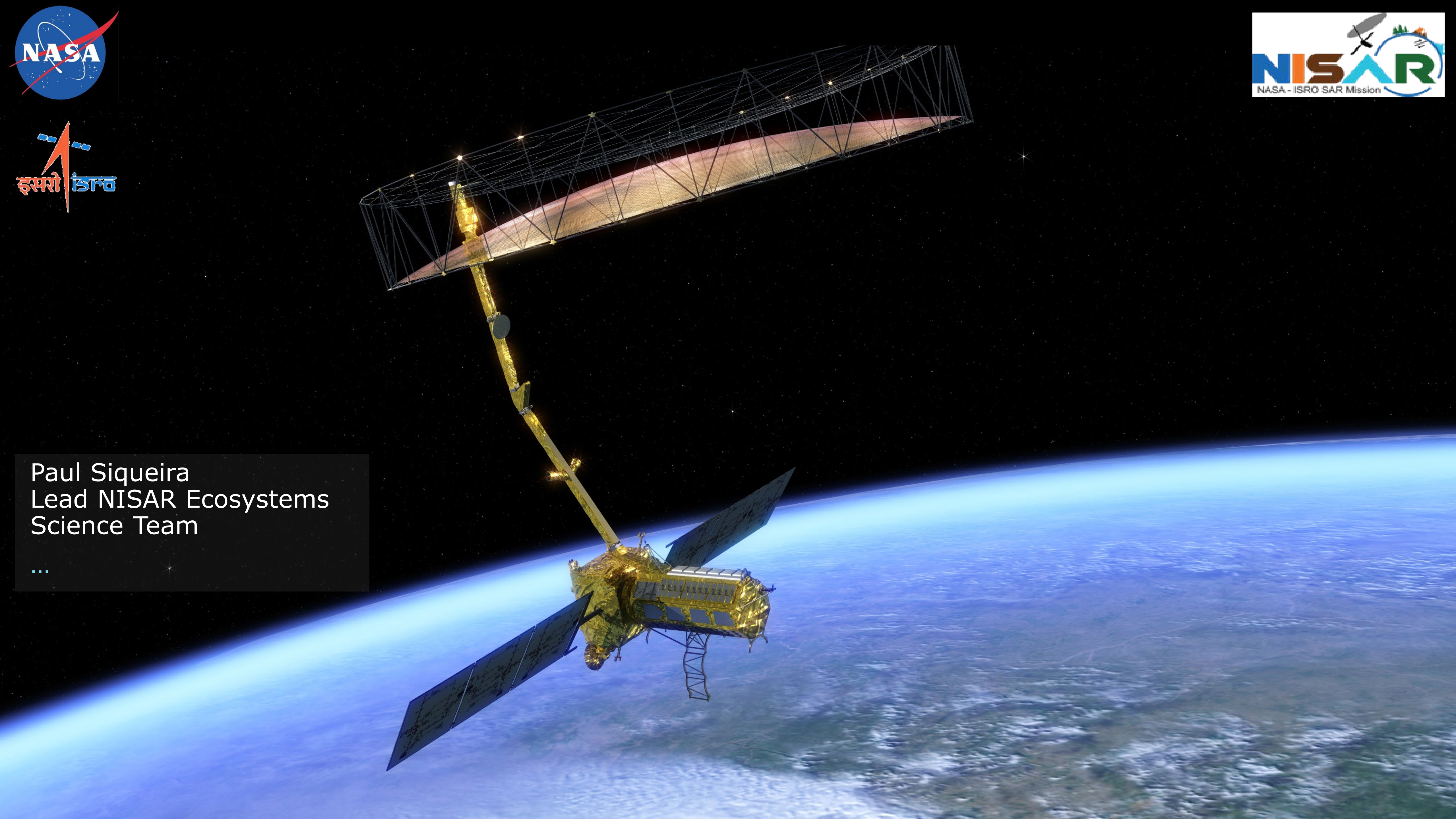



The Ladder to Space



Outline of Today's Interaction

- A little something about InSAR versus SAR
- The use of SAR data for mapping Forest Stand Height (FSH)
- Exercise: Estimating Forest Stand Height
- Q&A Session

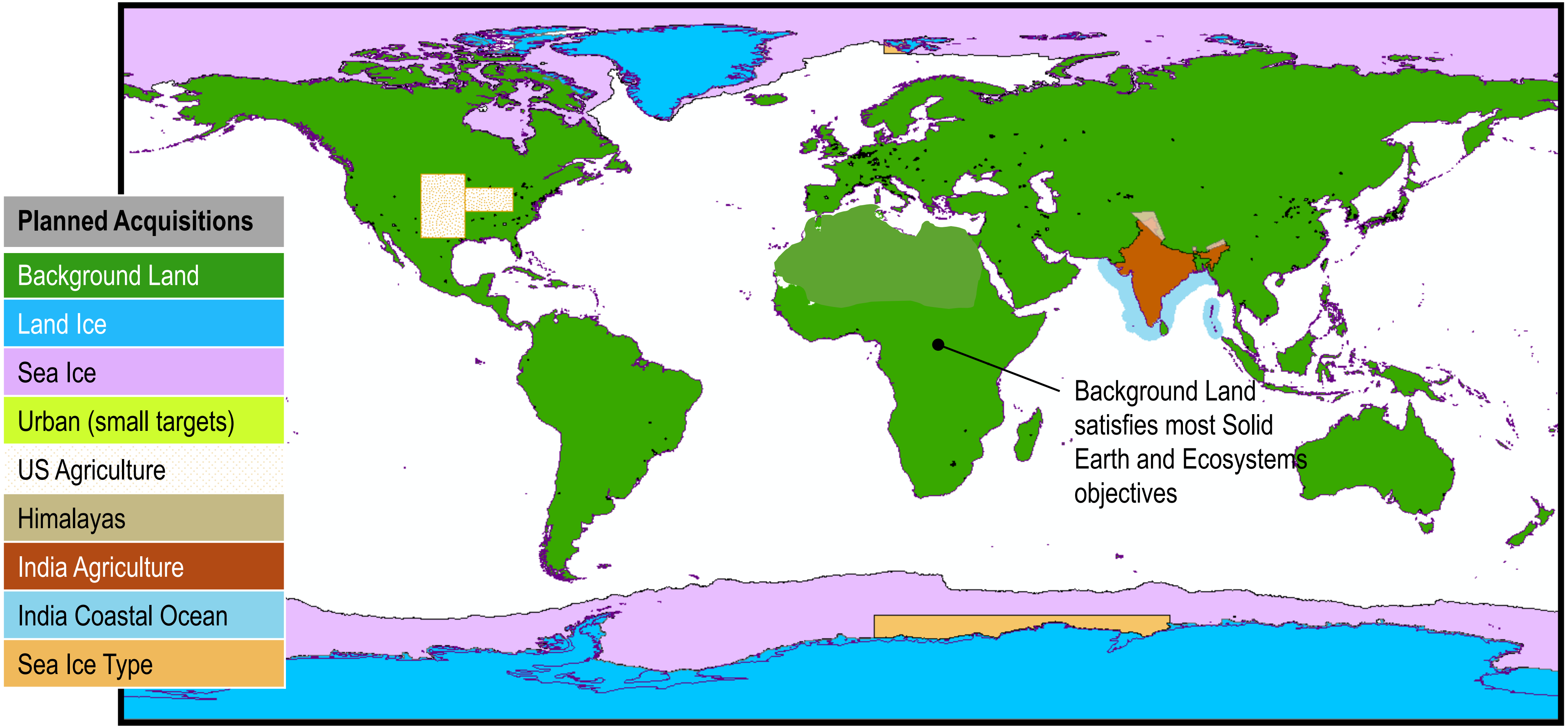


Paul Siqueira
Lead NISAR Ecosystems
Science Team

…

Mode-Specific Science Targets in Observation Plan

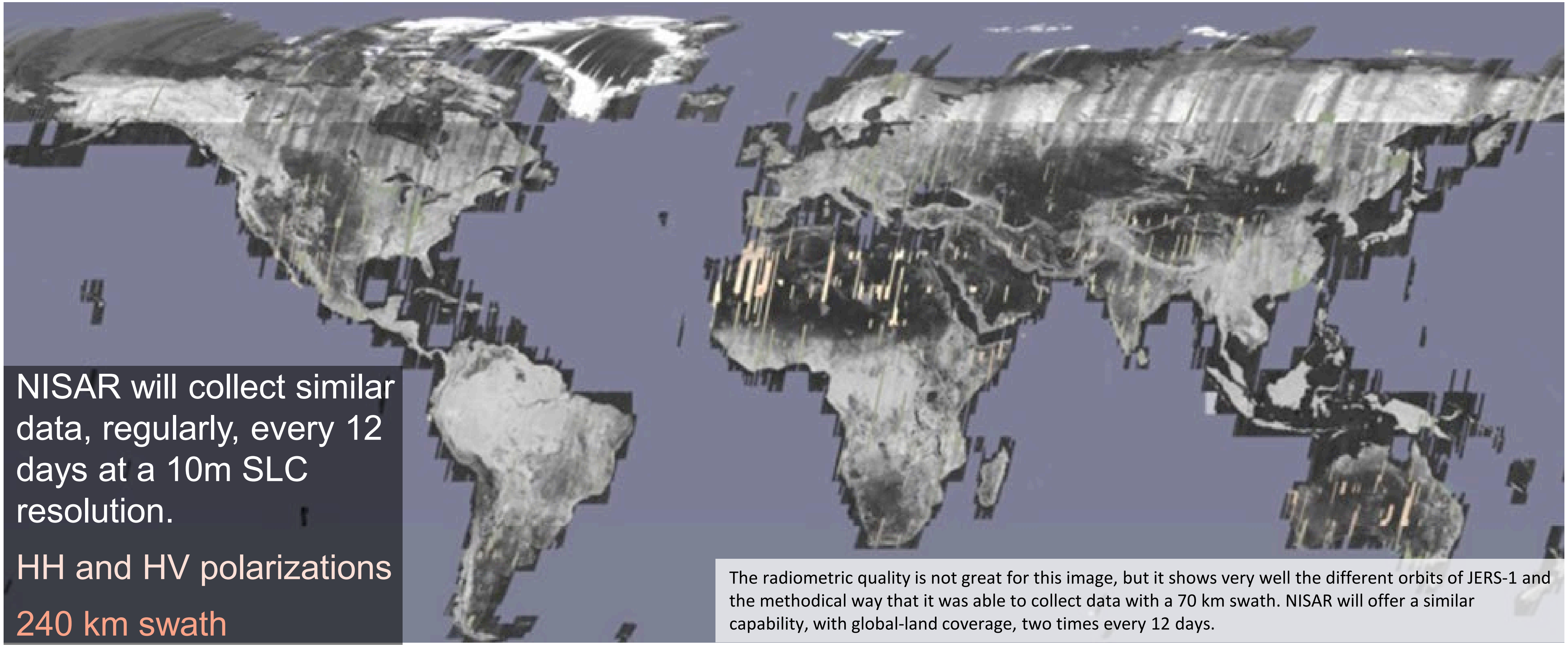
- Each colored region represents a single radar mode chosen to satisfy multiple science objectives over that area.
- Avoids mode contention that would interrupt time series



US-Quad-pol collection is likely to occur for the states of Illinois, Michigan, Ohio, and parts of Alaska.

SAR Coverage (JERS-1)
What Global L-Band Looks Like

- Active sensor and weather tolerance improves dependability
- For JERS-1, Every 44 days, a partial view of the Earth's surface could be made



NISAR will collect similar data, regularly, every 12 days at a 10m SLC resolution.

HH and HV polarizations

240 km swath

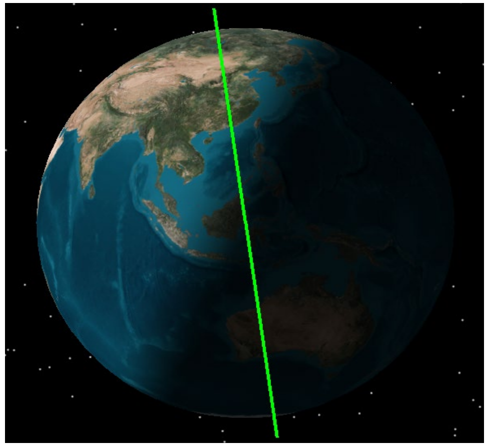
The radiometric quality is not great for this image, but it shows very well the different orbits of JERS-1 and the methodical way that it was able to collect data with a 70 km swath. NISAR will offer a similar capability, with global-land coverage, two times every 12 days.

NISAR Concept Science Observation Overview

NISAR Characteristic:	Would Enable:
L-band (24 cm wavelength)	Low Temporal Decorrelation and Foliage Penetration
S-band (9.4 cm wavelength)	Sensitivity to Light Vegetation
SweepSAR technique with Imaging Swath > 240 km	Global Data Collection
Polarimetry (Single/Dual/Quad)	Surface Characterization and Biomass Estimation
12-day exact repeat	Rapid Sampling
3 – 10 meters mode-dependent SAR resolution	Small-Scale Observations
3 years science operations (5 years consumables)	Time-Series Analysis
Pointing control < 273 arcseconds	Deformation Interferometry
Orbit control < 500 meters	Deformation Interferometry
> 30% observation duty cycle	Complete Land/Ice Coverage
Left/Right pointing capability	Polar Coverage, North and South

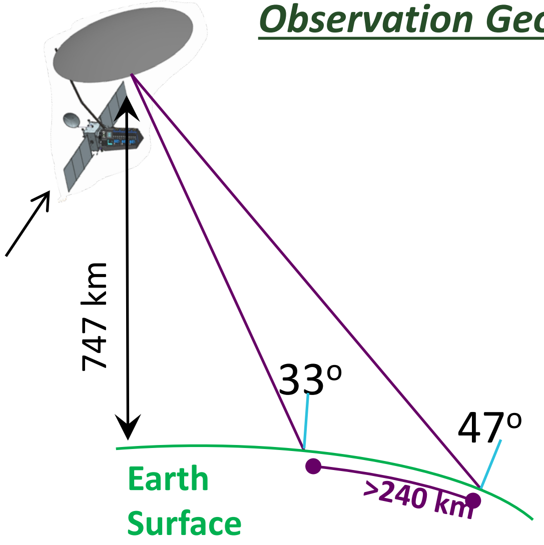
NISAR Uniquely Captures the Earth in Motion

Orbit



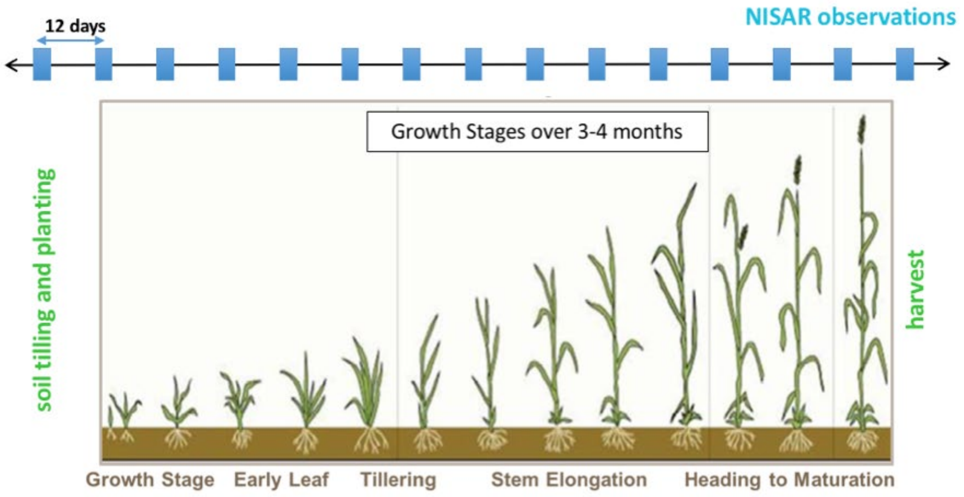
6 AM / 6 PM

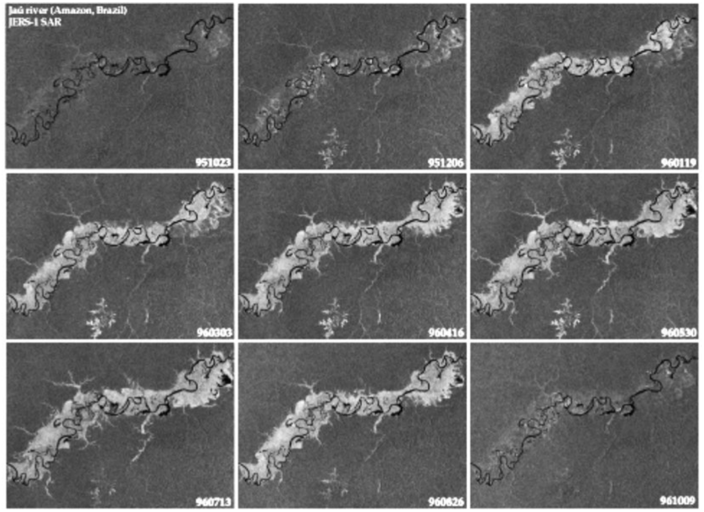
Observation Geometry



NISAR Ecosystems Science Drivers*

- Biomass Estimation
- Disturbance Monitoring
- Inundation Extent
- Agricultural Area Mapping
- Coastal Wetlands



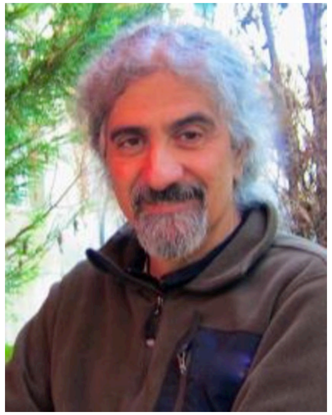


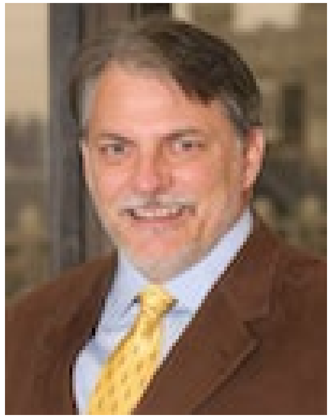

Paul Siqueira


Sassan Saatchi


Josef Kellndorfer

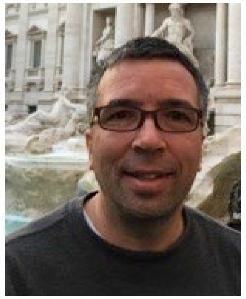

Bruce Chapman

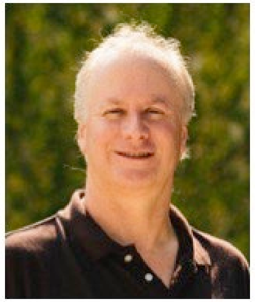

Ralph Dubayah


Kyle McDonald

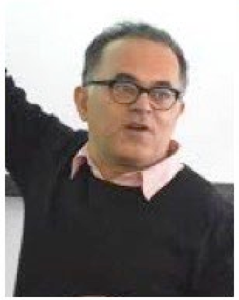

Nathan Torbick

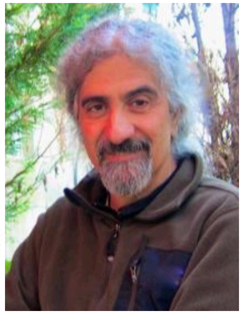
NISAR Ecosystems
NASA & ISRO Teams


Paul Siqueira

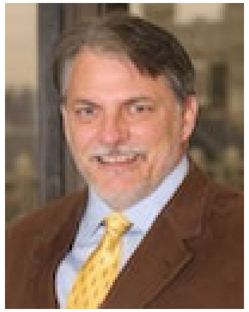

Bruce Chapman


Josef Kellndorfer


Sassan Saatchi


Ralph Dubayah


Nathan Torbick

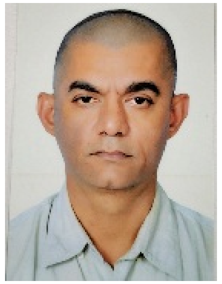

Kyle McDonald


Anup Das


C. Patnaik


K.R. Majunath


Hitendra Padalia


G. Rajashekar


K.V. Ramana


Saroj Maity


Praveen Kumar Gupta

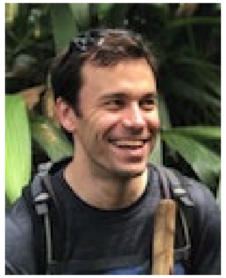

Shashi Kumar


Ratheesh Ramakrishnan


Darmendra Pandey

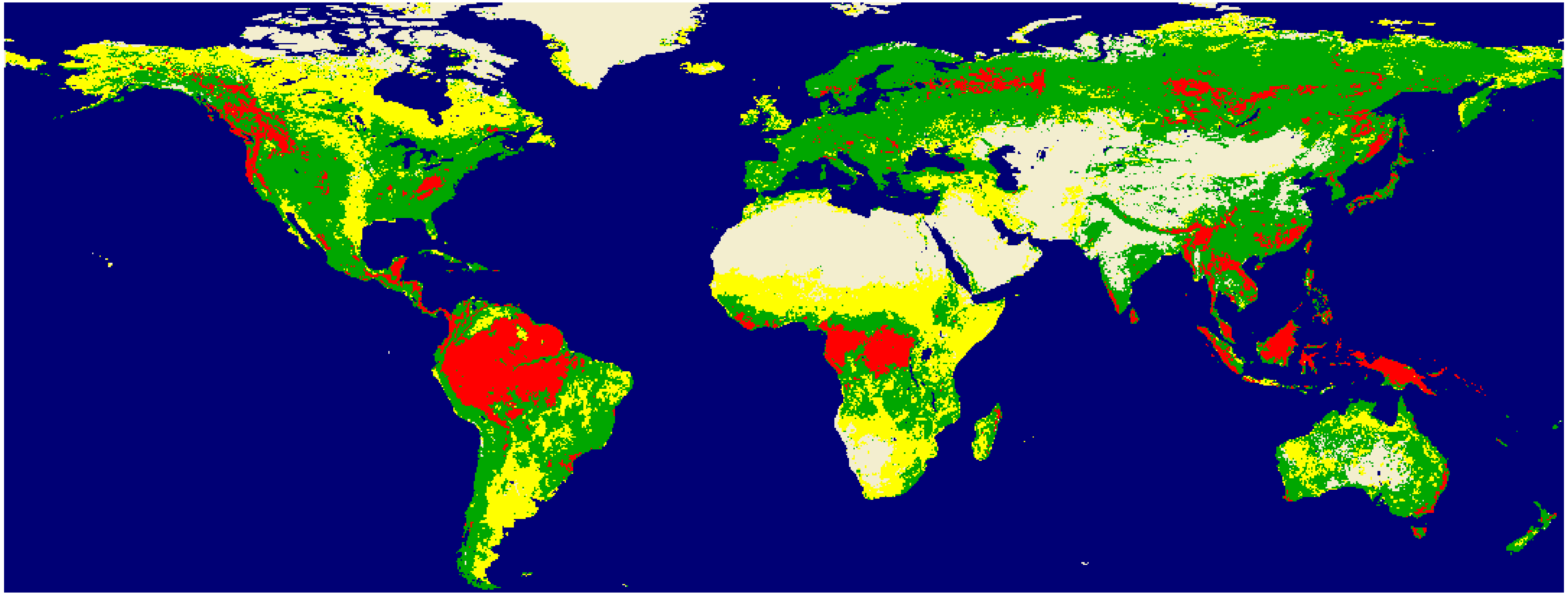
?

More??


John Armston


Erika Podest

NISAR Biomass Areas (< 100 tons/ha)



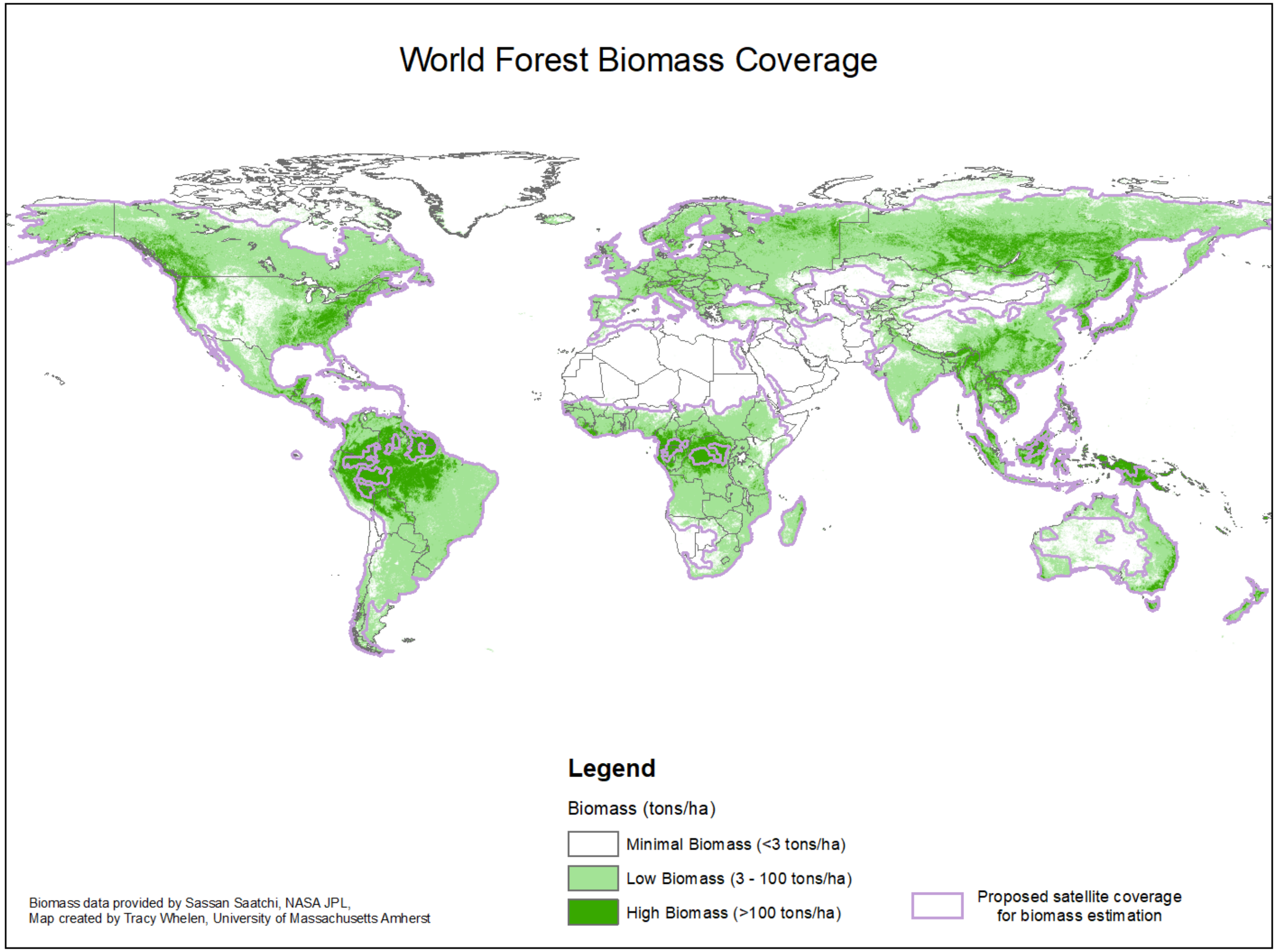
The global distribution of regions dominated by woody biomass < 100 Mg/ha

Green	Regions with AGB < 100 Mg/ha 50% of area
Red	Regions with AGB > 100 Mg/ha 50% of area
Yellow	Regions with AGB < 20 Mg/ha 50% of area
Cream	Regions with no woody vegetation
Dark blue	Open Water

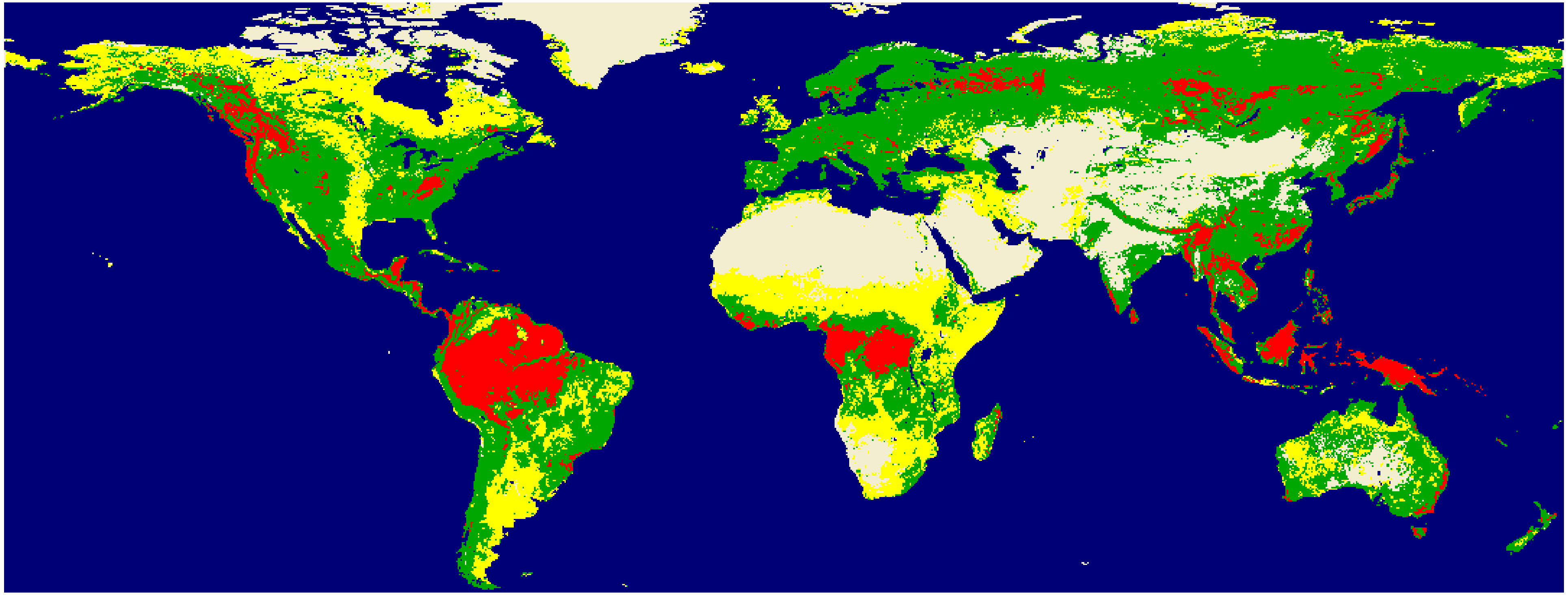
NISAR Biomass Requirement

- Measure aboveground woody vegetation biomass annually at the hectare scale (1 ha) to an RMS accuracy of 20 Mg/ha for 80% of areas of biomass less than 100 Mg/ha.
- This requirement must be validated after launch.
- This is a NASA requirement on the L-band SAR.

NISAR background land observations of 60 HH/HV observations per year over all land surfaces is meant to be an abling data set to allow many different algorithms and applications that are relevant to biomass and vegetation mapping.



NISAR Biomass Areas (< 100 tons/ha)

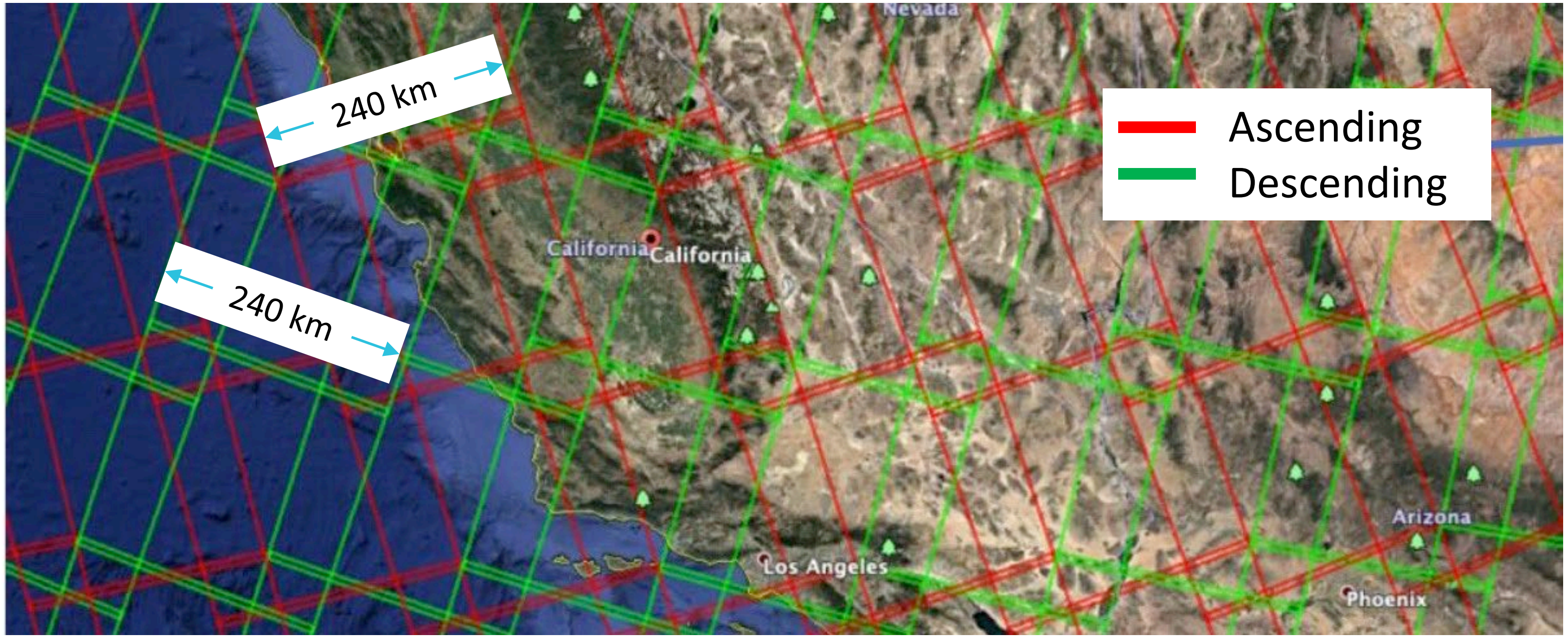


The global distribution of regions dominated by with woody biomass < 100 Mg/ha

Regions with AGB < 100 Mg/ha 50% of area	Regions with AGB > 100 Mg/ha 50% of area	Regions with AGB < 20 Mg/ha 50% of area	Regions with no woody vegetation	Open Water

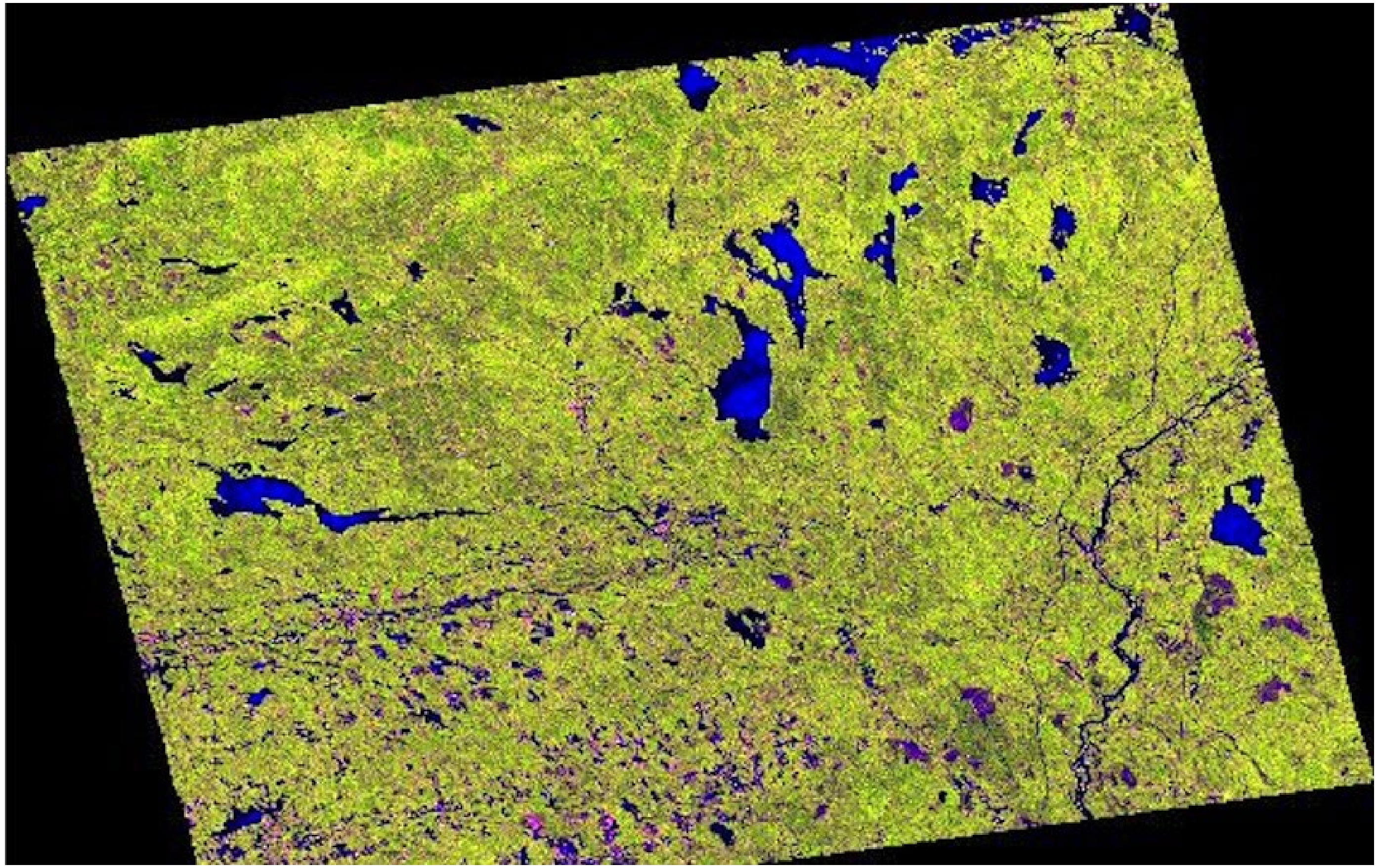
Track/Frame Data Collection

- Data are planned to be collected in track/frame coordinate system
- 173 unique tracks that comprehensively span the equator
- Within a single track/frame, data collection mode will be uniform, at the lowest bandwidth
- Higher bandwidth segments delivered separately



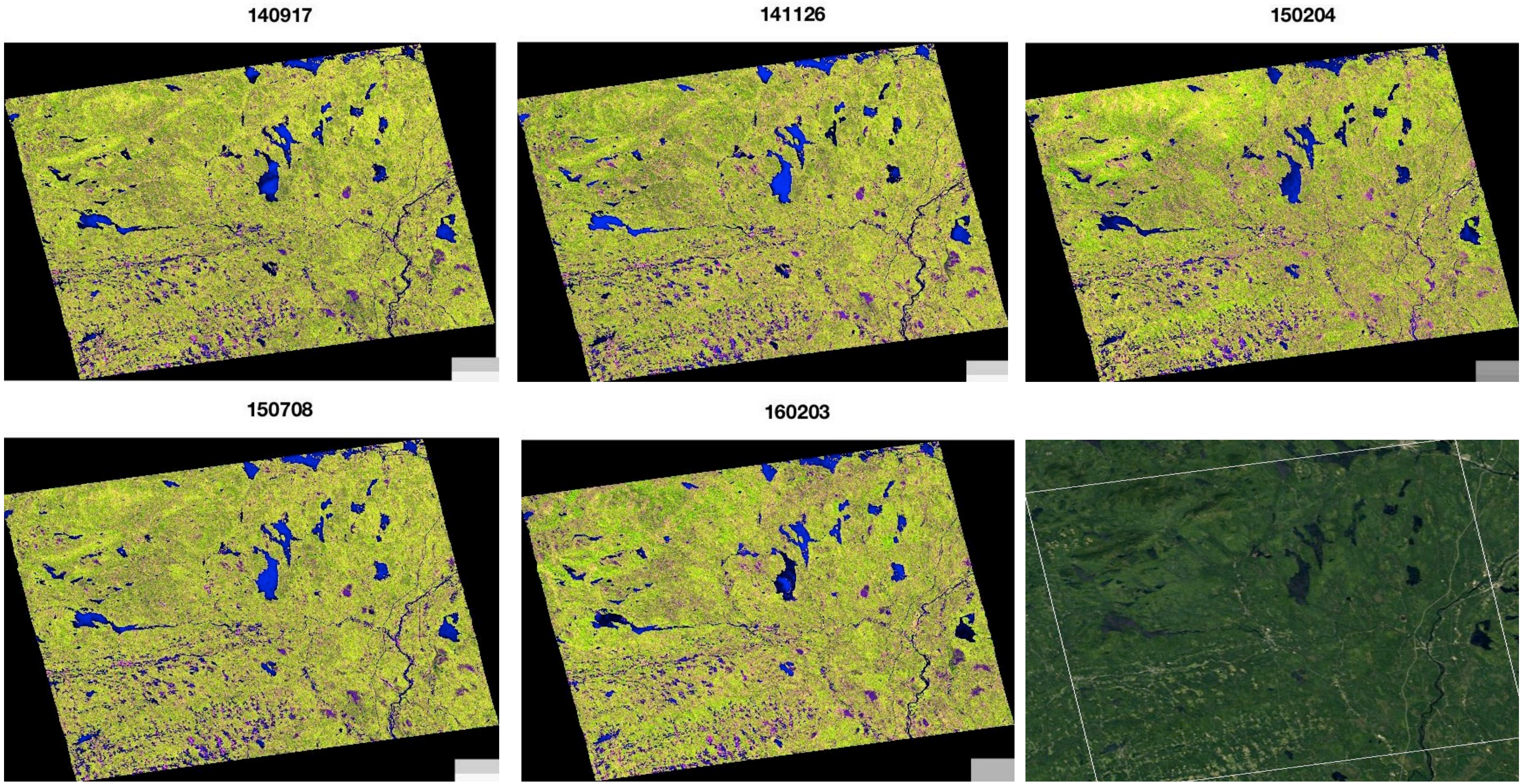
Displaying Dual-pol Data
HH, HV, HH/HV

- Vegetation is green (HV – Volume scattering)
- Water is blue (HH/HV – smooth surfaces are very bright)

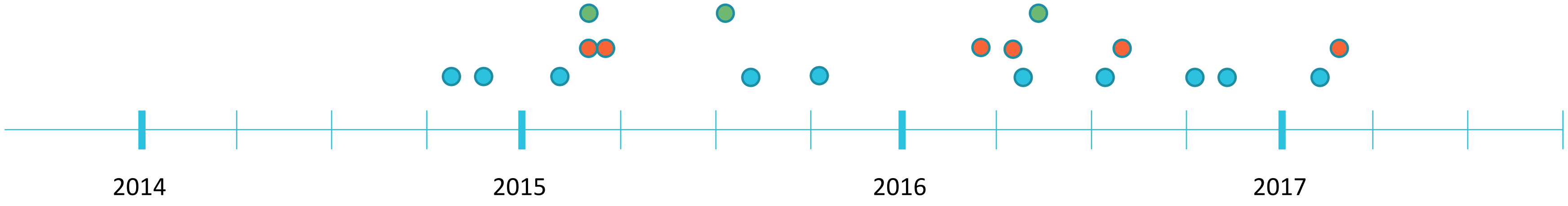


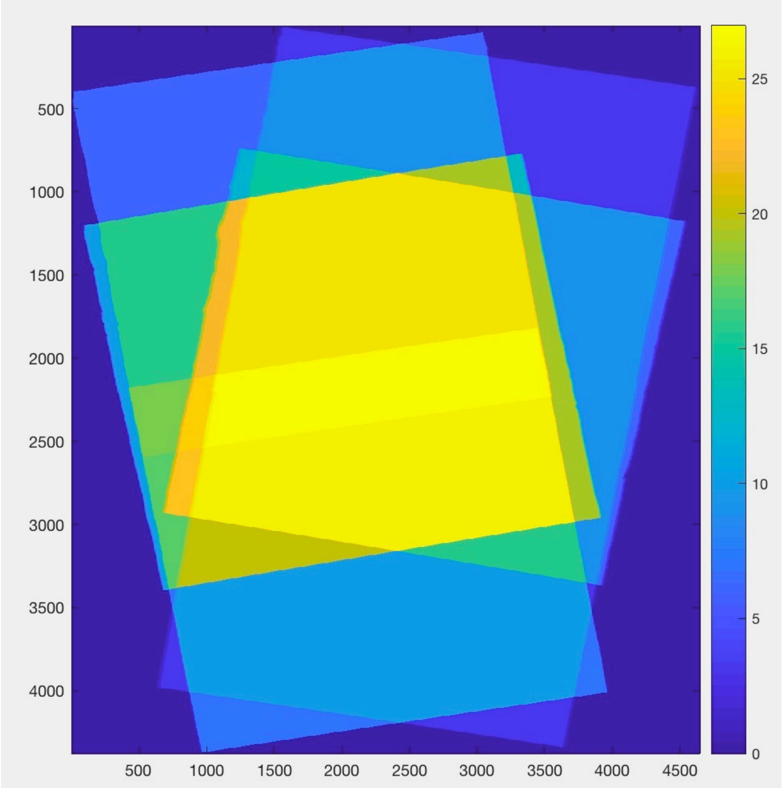
Time Series

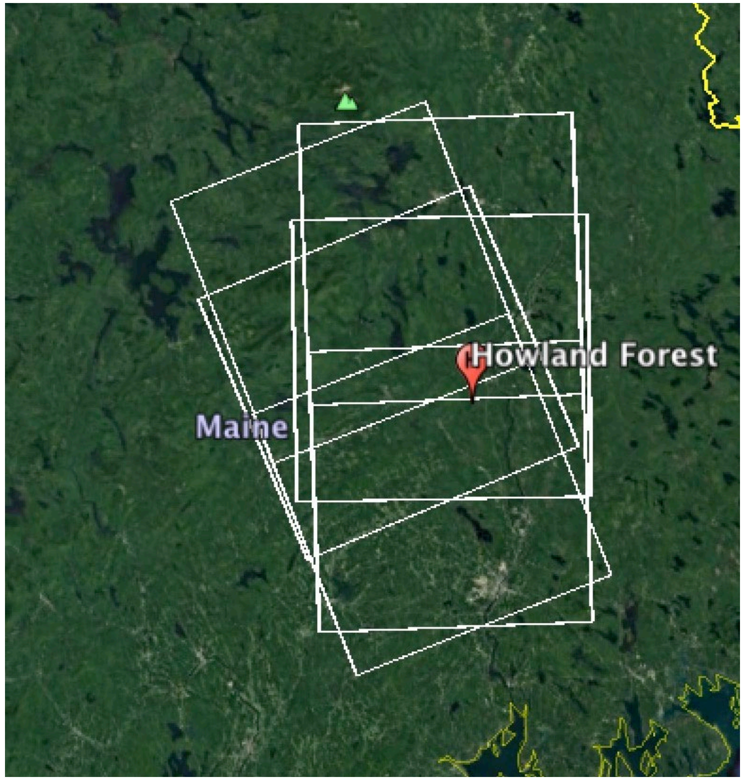
- Sensors such as Sentinel-1 and NISAR are creating unprecedented, dependable time series of SAR data.



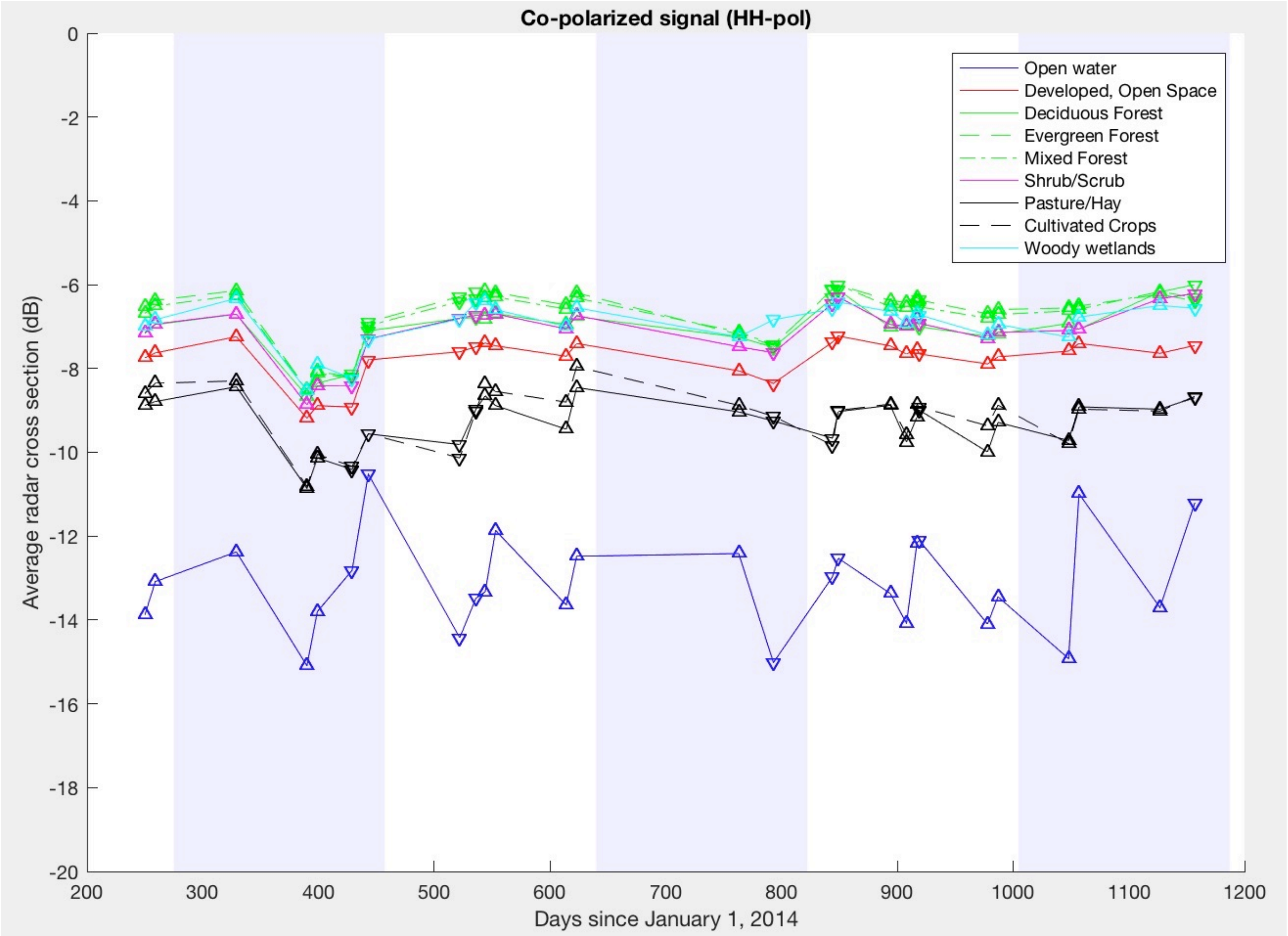
Ecosystems Summary
ALOS-2 Observations at Howland/Penobscot







- Compare HH and HV RCS for different landcovers



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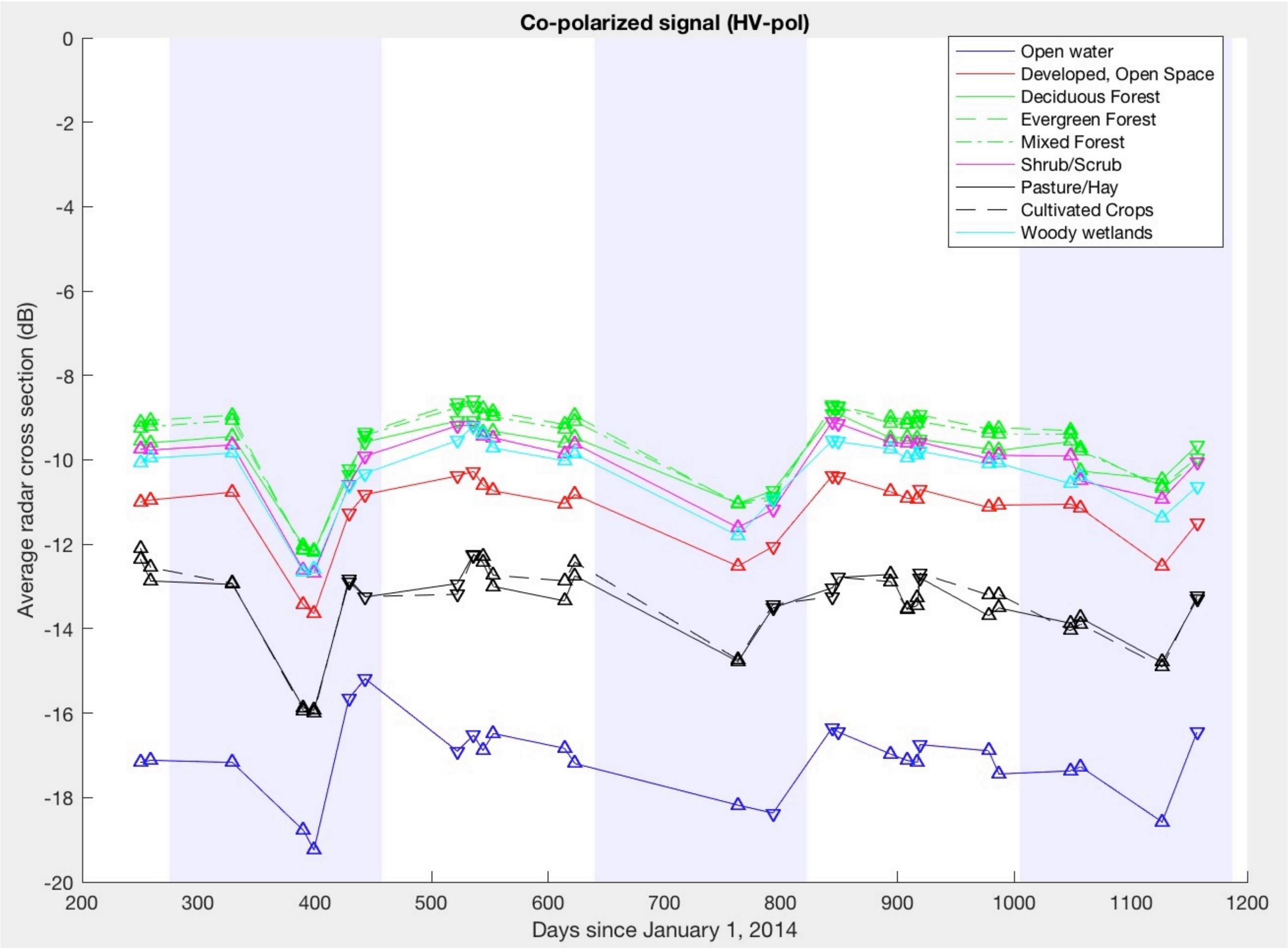
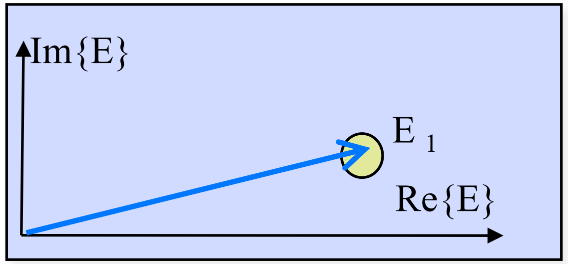
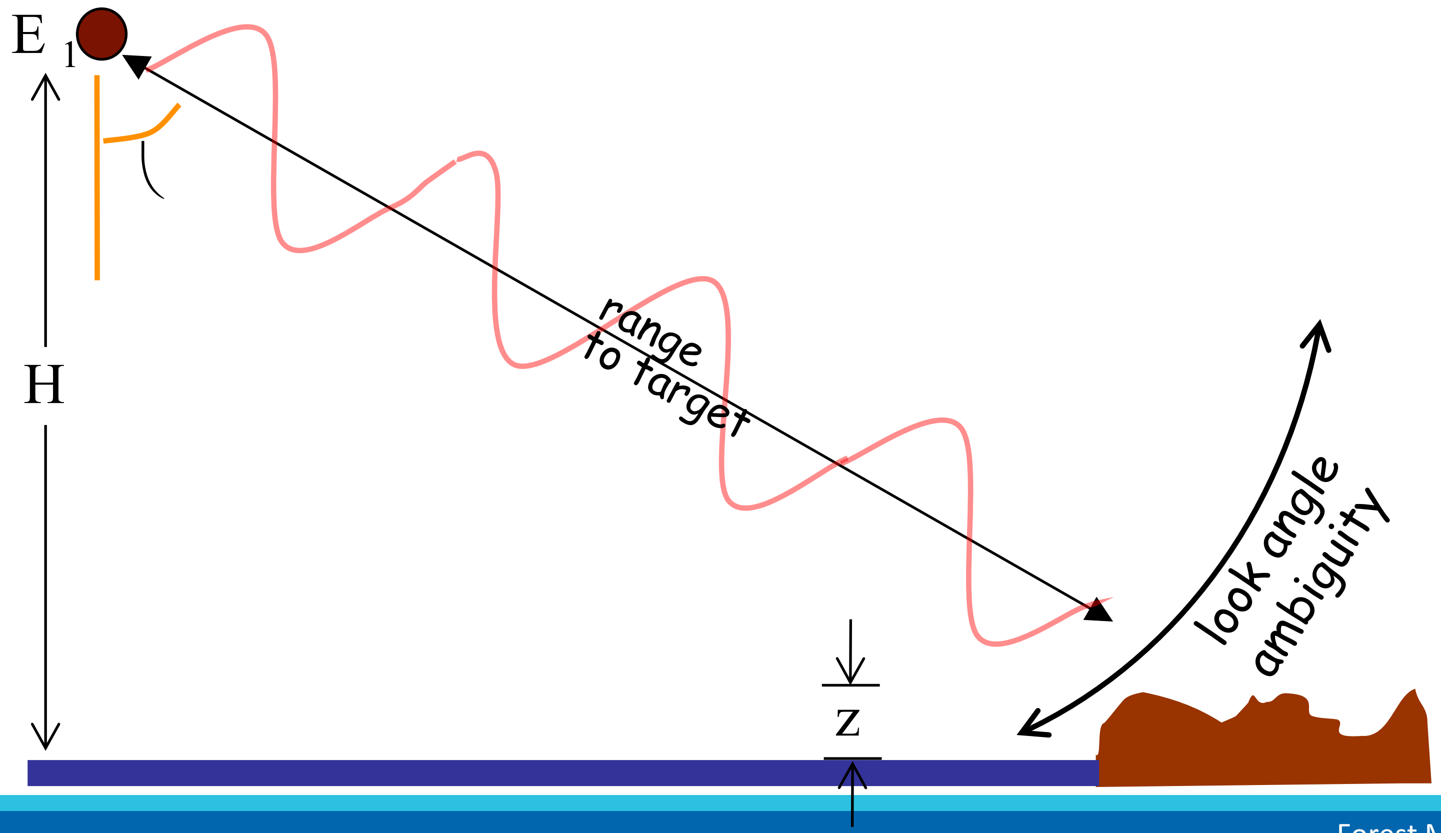


Single-Look Complex (SLC) Imagery

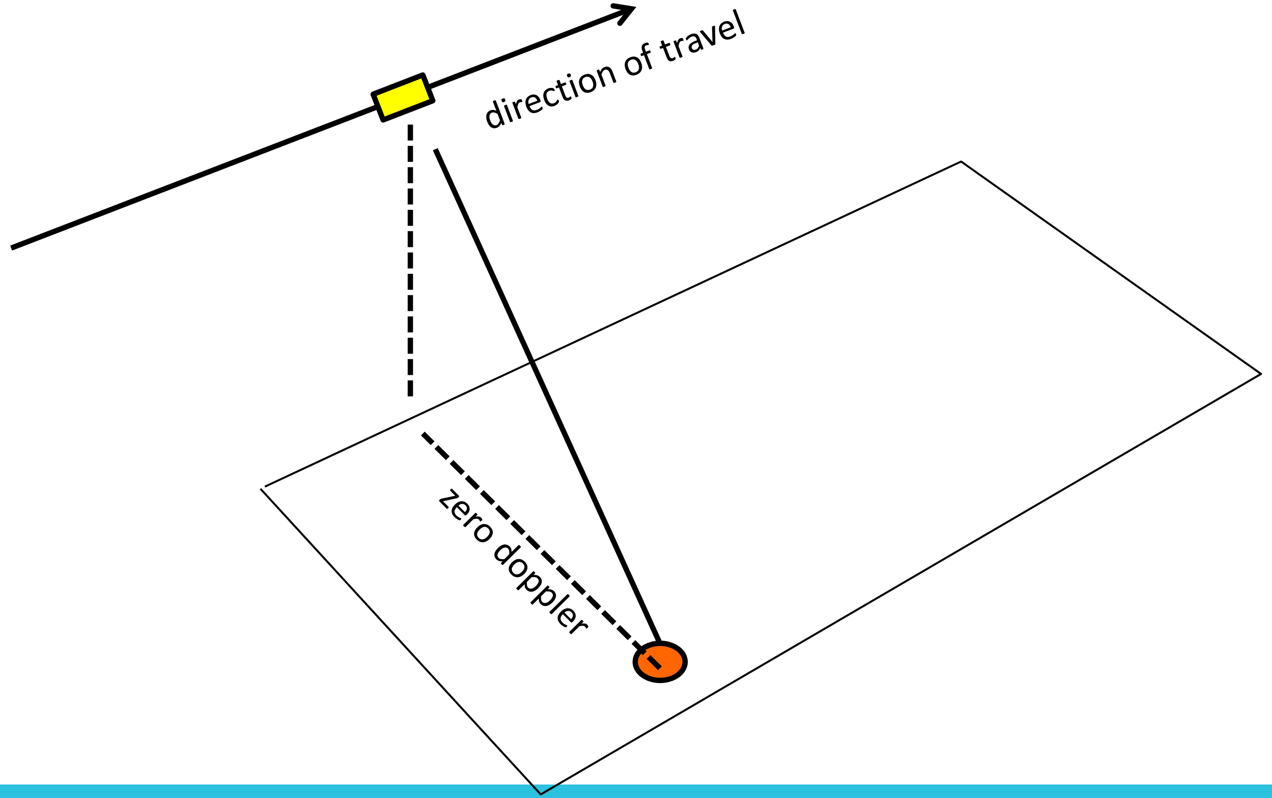
- Single-Look Complex (SLC) images are radar data that have been processed to their full resolution.
- The units of each pixel in an SLC is the complex electric field.
- The magnitude of the field is proportional to the Radar Cross Section and the distance to the target, measured in phase (fractions of a wavelength; 360 deg = 24 cm for L-band).





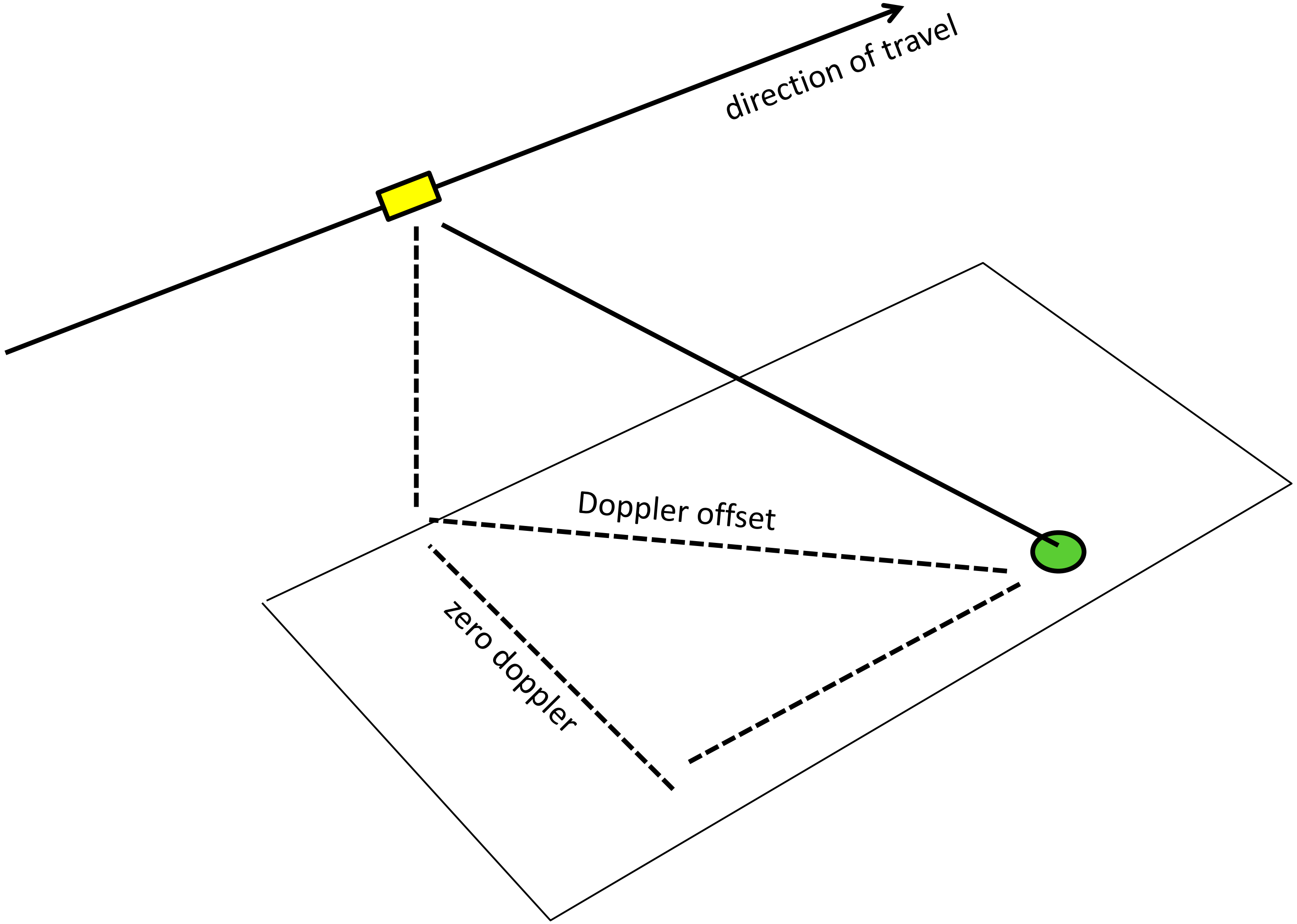
Doppler Interpretation

- Another way to interpret the resolution of SAR is through the concept of the Doppler Shift.
- As a target is approaching the radar, its frequency is shifted up.
- As the target recedes from the radar, its frequency is shifted down.
- At broadside, the Doppler shift is zero, also called Zero Doppler.

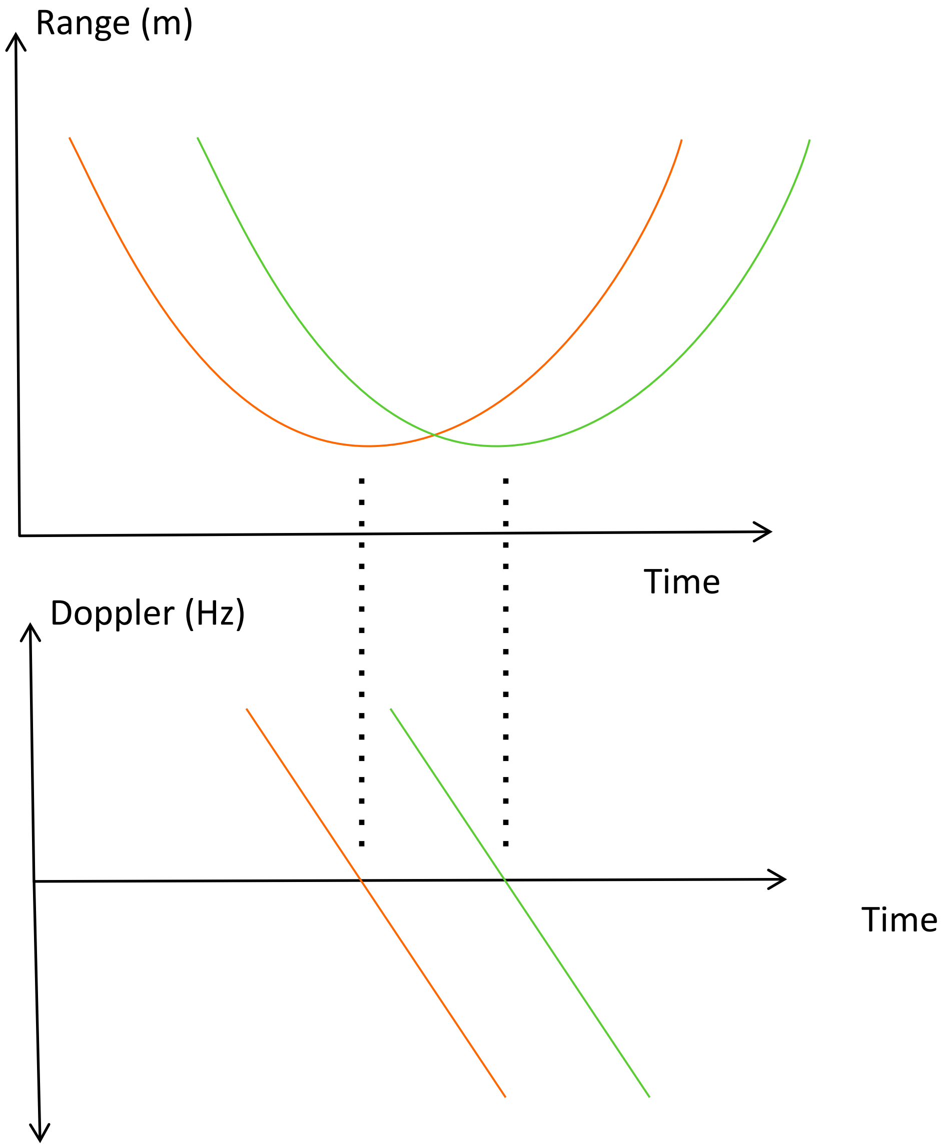


Doppler History

- Each target in a given radar scene will have a unique range and Doppler history.



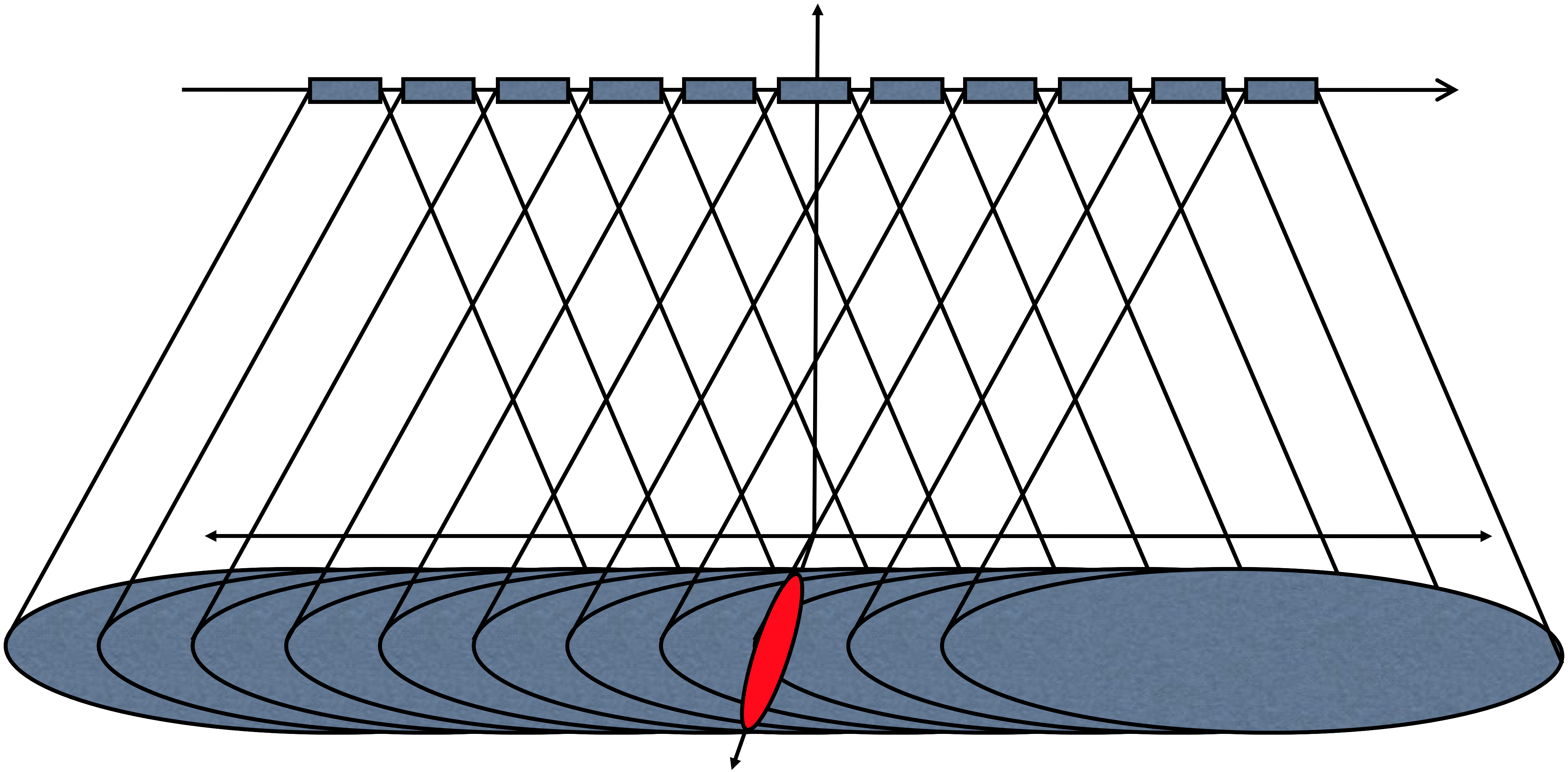
Range and Doppler Histories



- All targets in the imaged region will have unique range-doppler histories.
- With matched filtering, these histories can be extracted to make a high-resolution image.
- Results are based on well known metrics such as the Nyquist sampling theorem and the relationship between bandwidth and resolution (Δf and Δt).

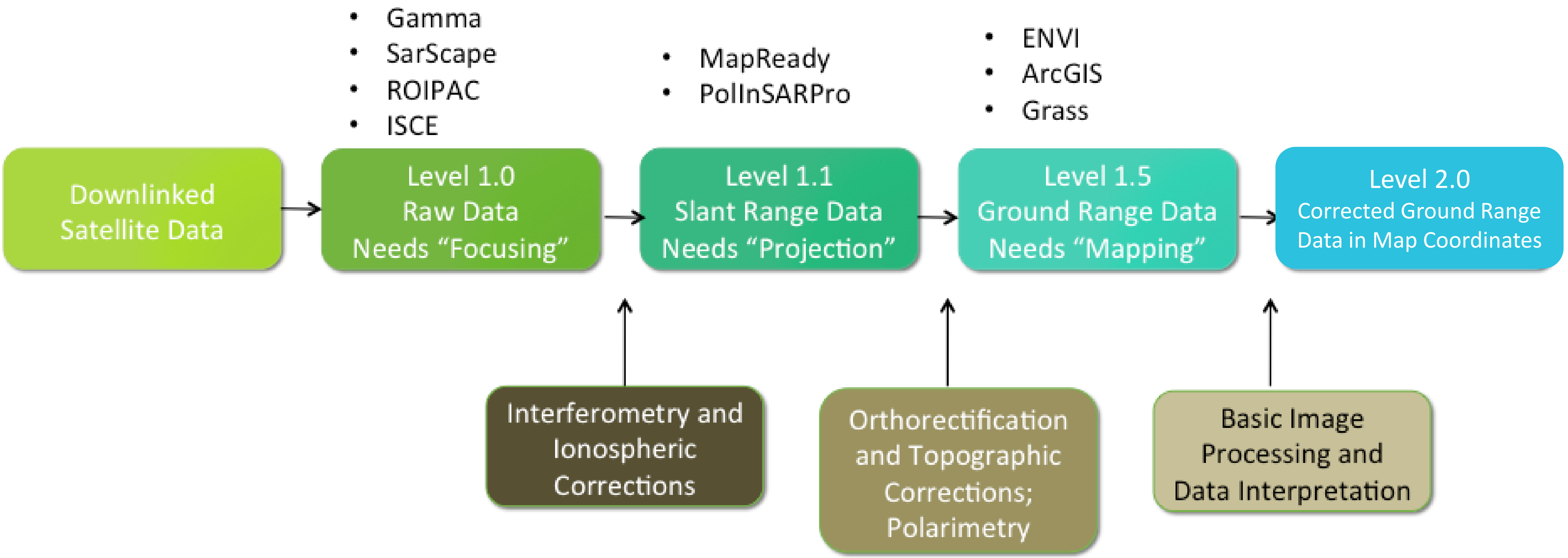
Aperture Synthesis

Timing information onboard a satellite can be used to mimic (or synthesize) a large antenna array, fixed in space.



Processing Flow

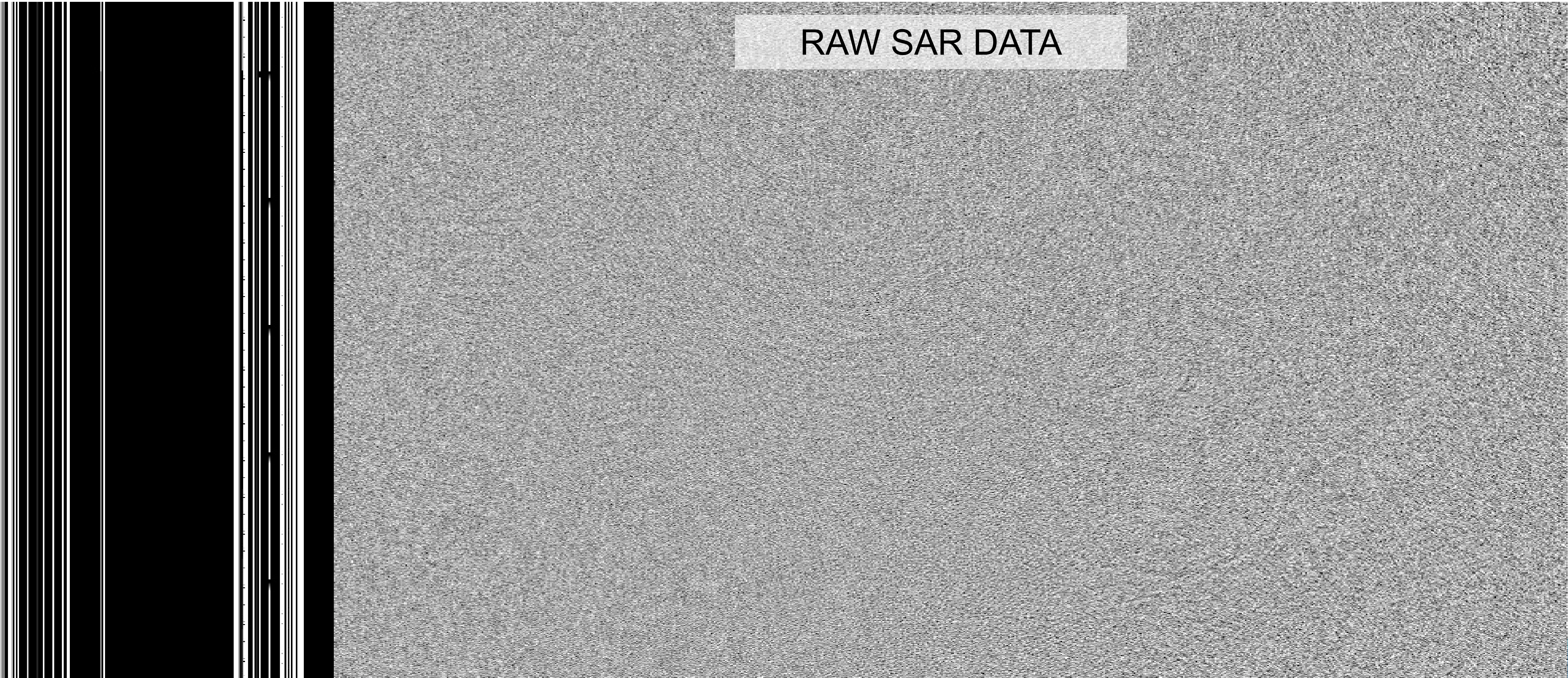
- The processing flow of raw radar data (collected as numbers flowing out of an analog-to-digital converter) to SLC and higher-level products is the processing flow of radar data.
- Different processing packages are used to carry the data to the next level of processing.
- These levels, and some common processing packages, are listed below.



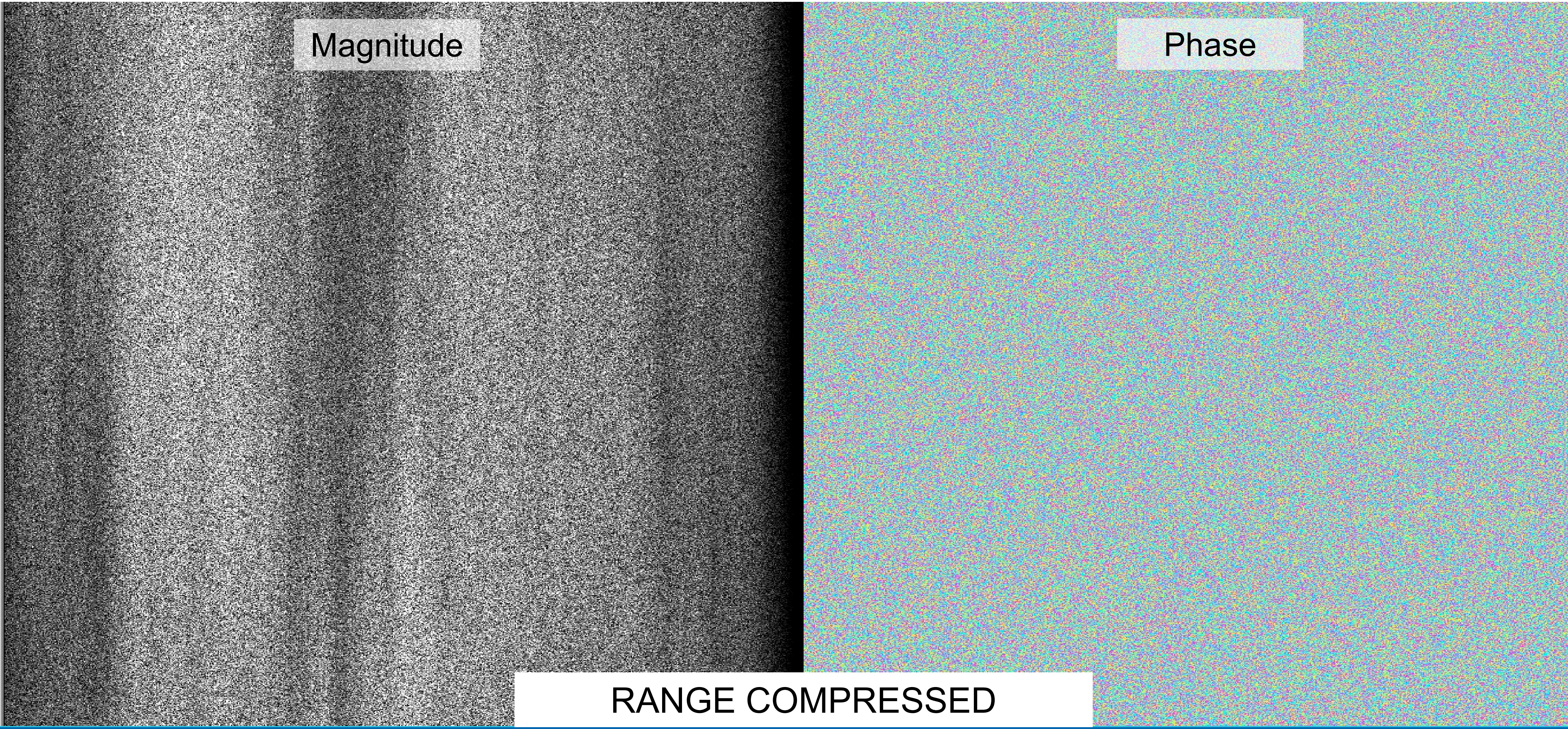
Raw Radar Data

Header Information (720 bytes)

IQ A/D Samples (10800 bytes)



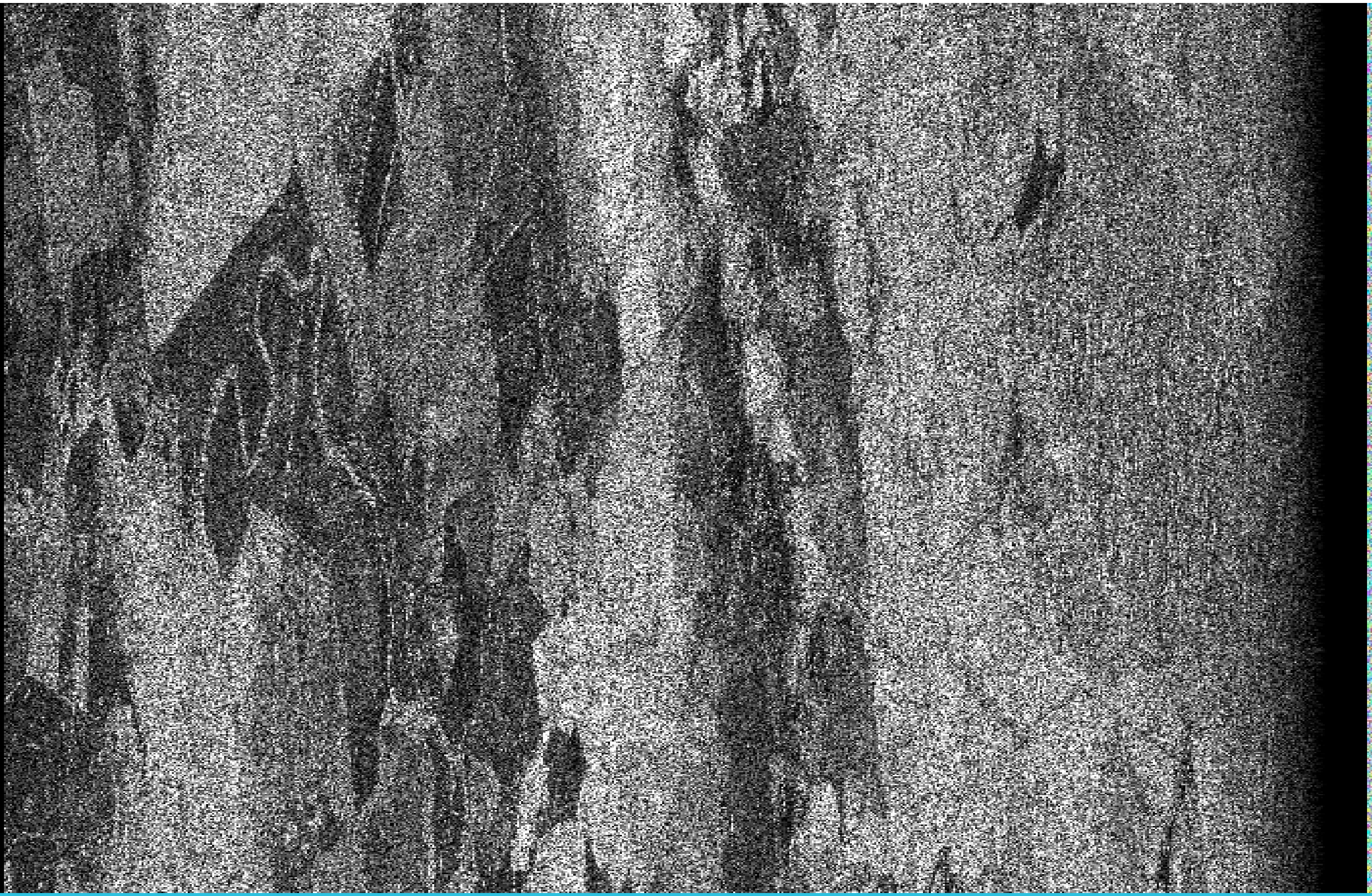
After Range Compression



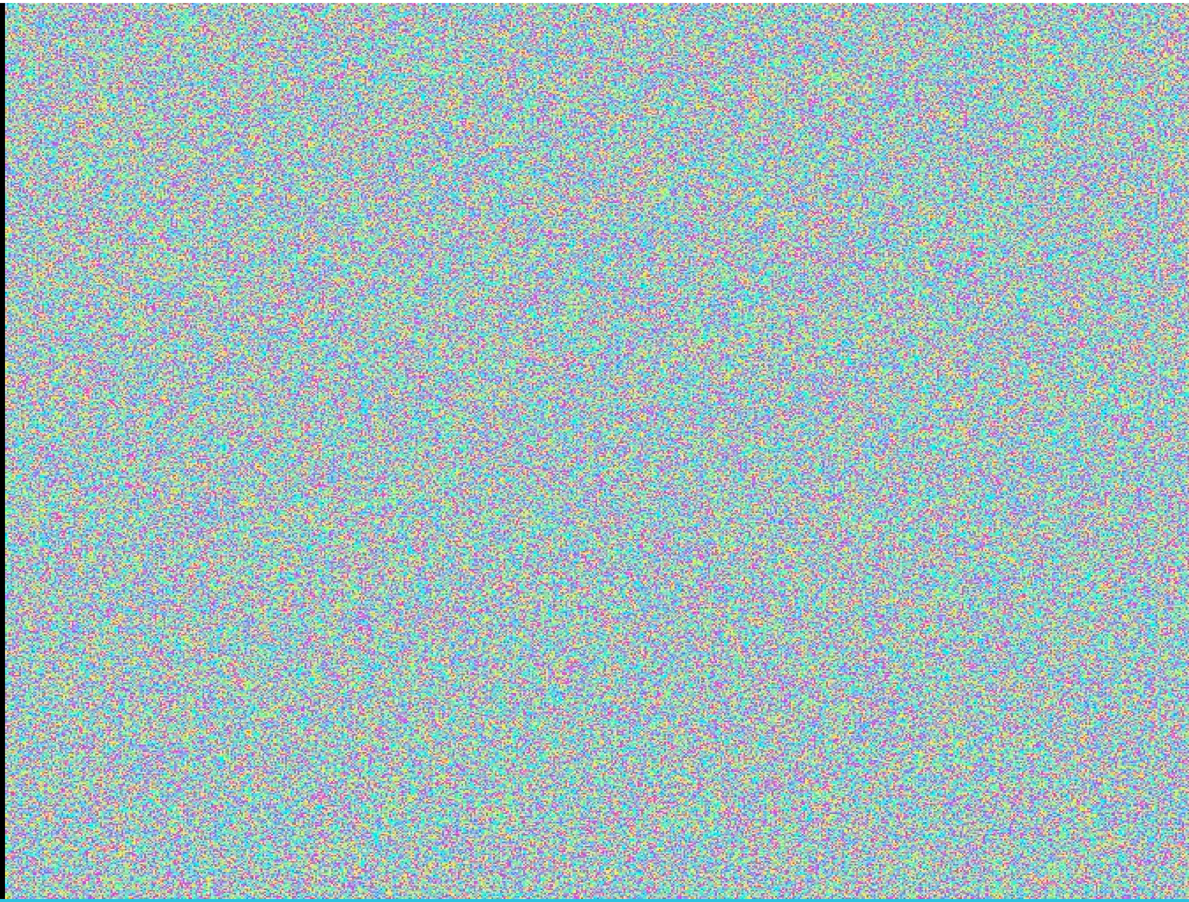
Slant Range, SLC Image

- After range compression and correction for range migration, the data is compressed in the azimuth direction, yielding a Slant-Range SLC image that has both magnitude and phase.

Magnitude



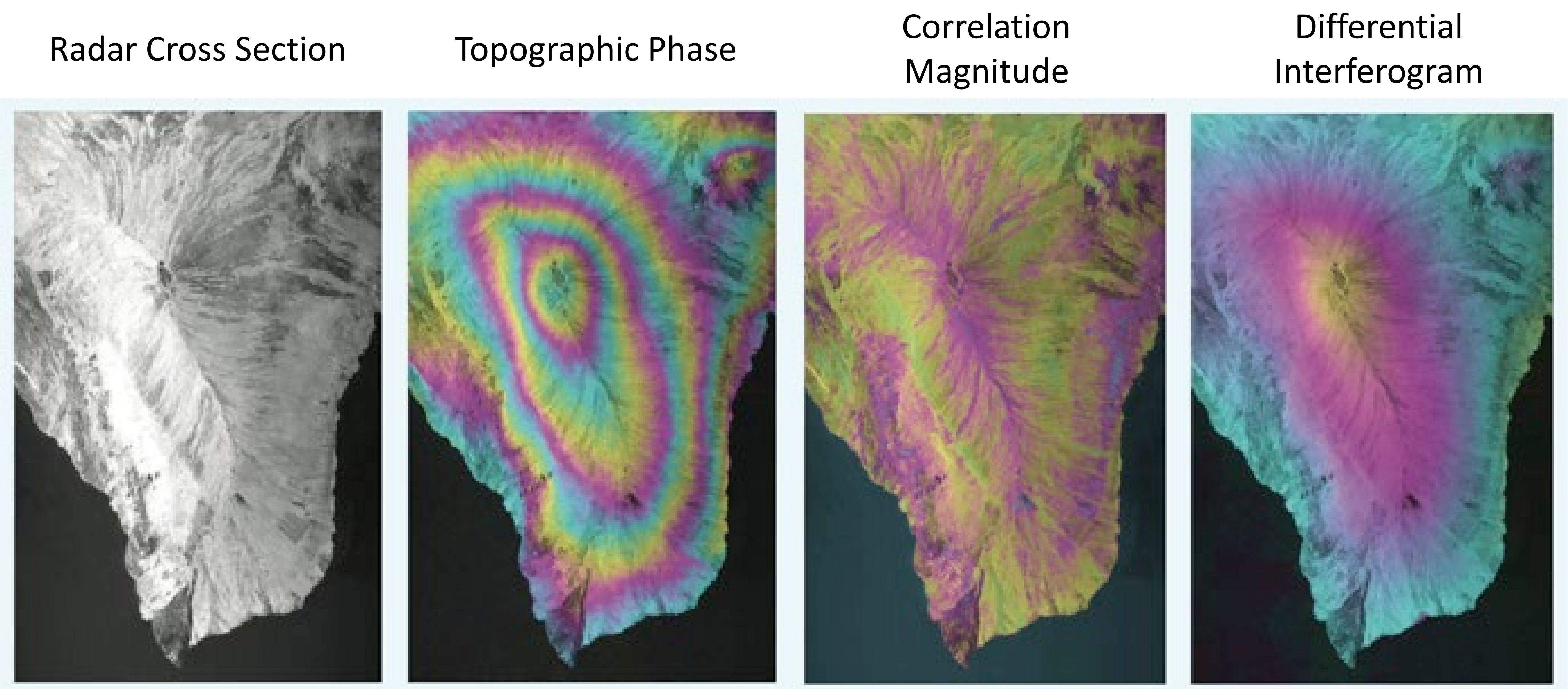
Phase



Ground Range

- Once projected into ground range, features in the imagery become much more apparent.
- Because of the projection, some information is lost in the process.

Output Products



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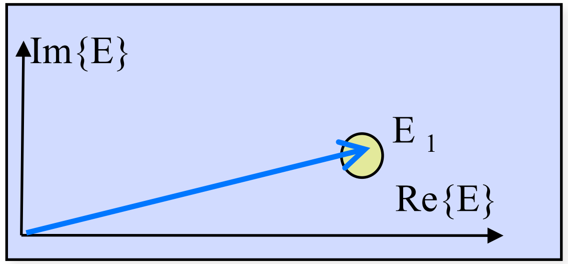
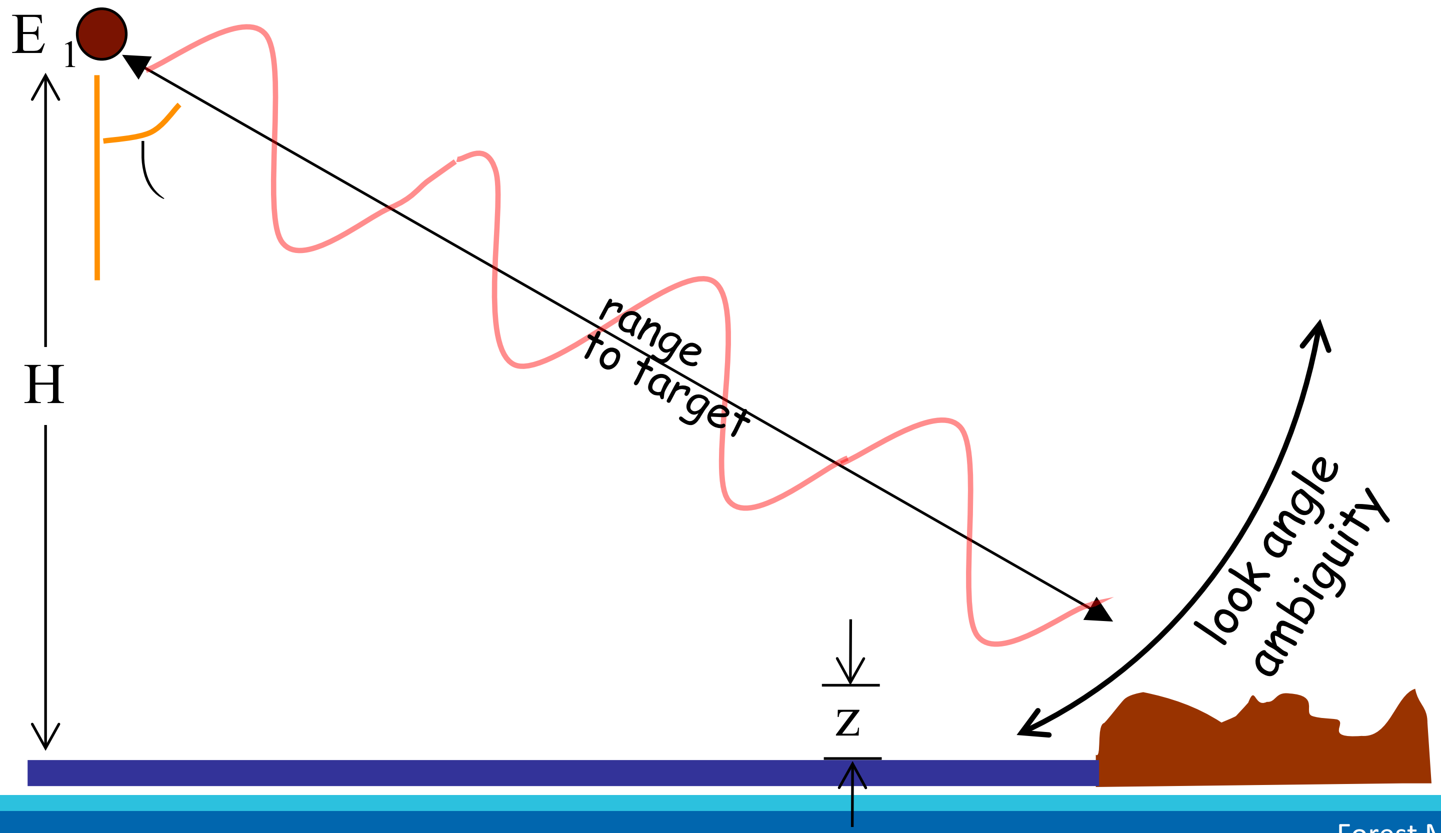
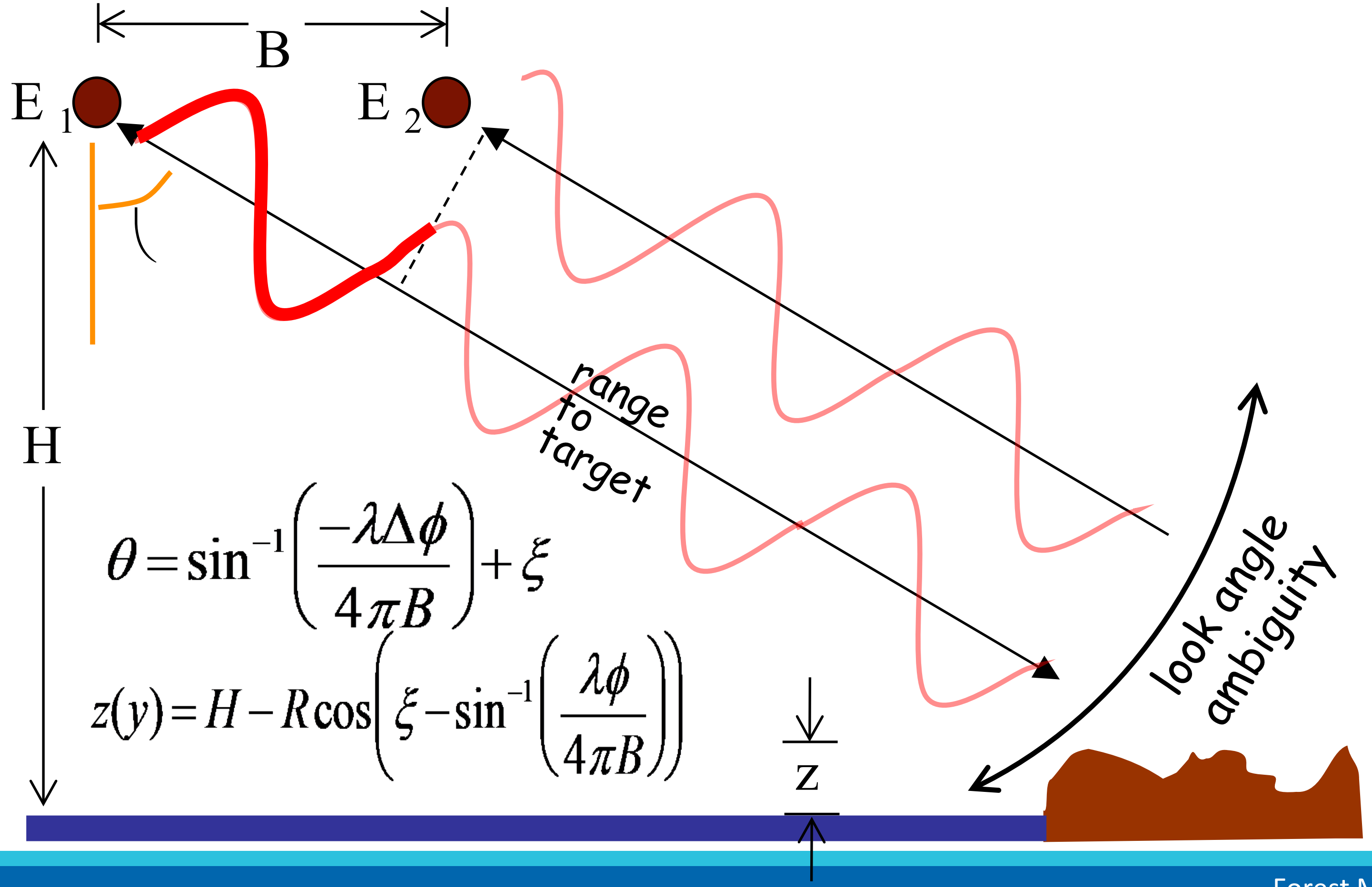
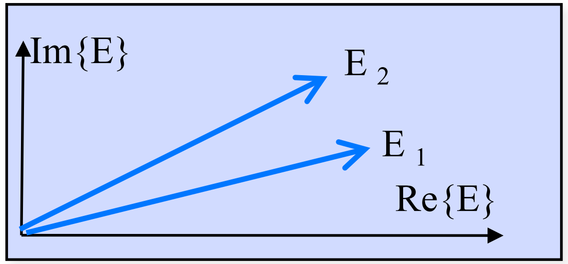


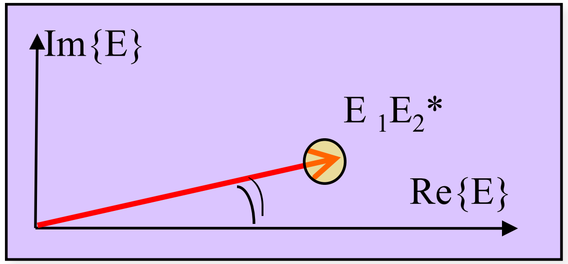


Interferometry

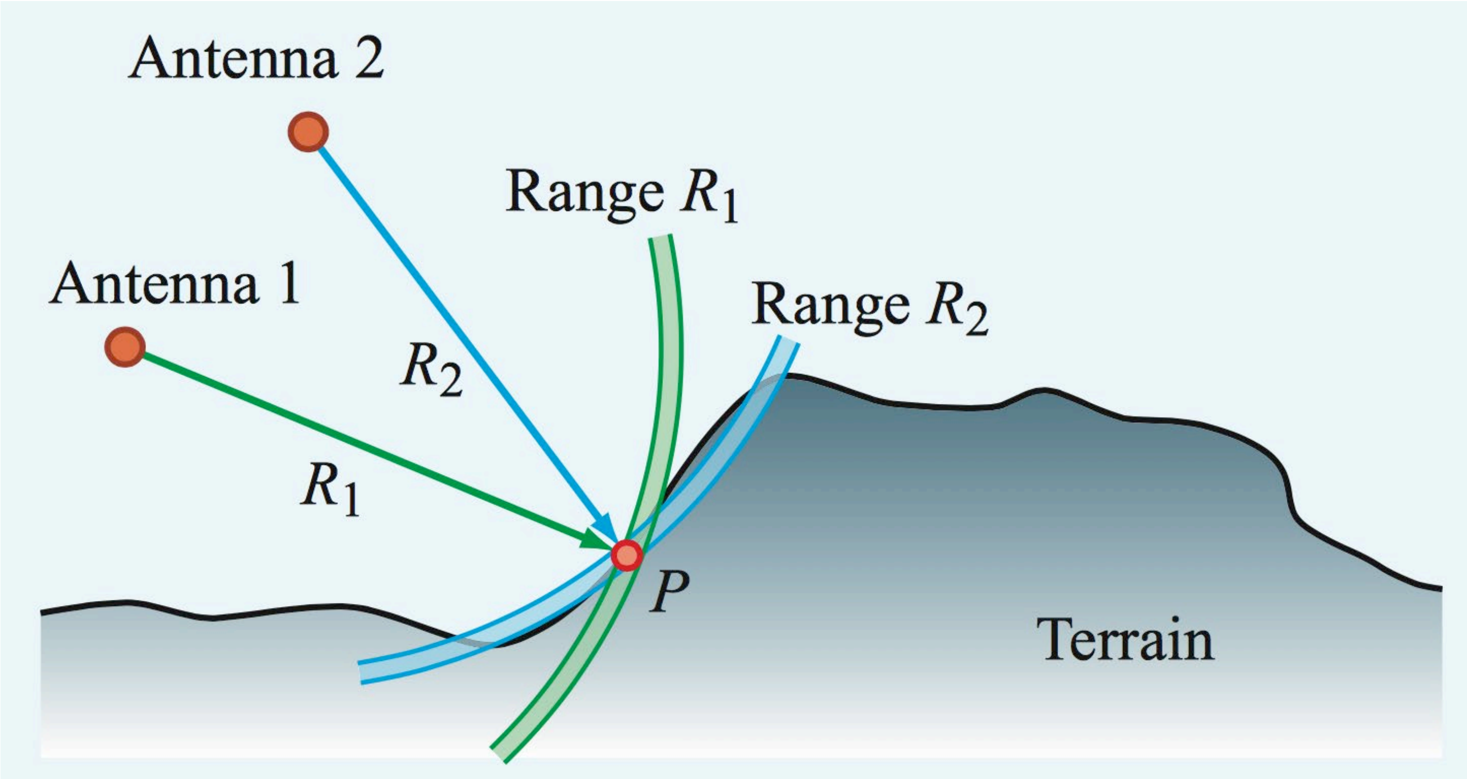
- When working with interferometry, the return from a target at a given range is compared for two antennas at the end of a baseline.
- This provides the interferometric phase.



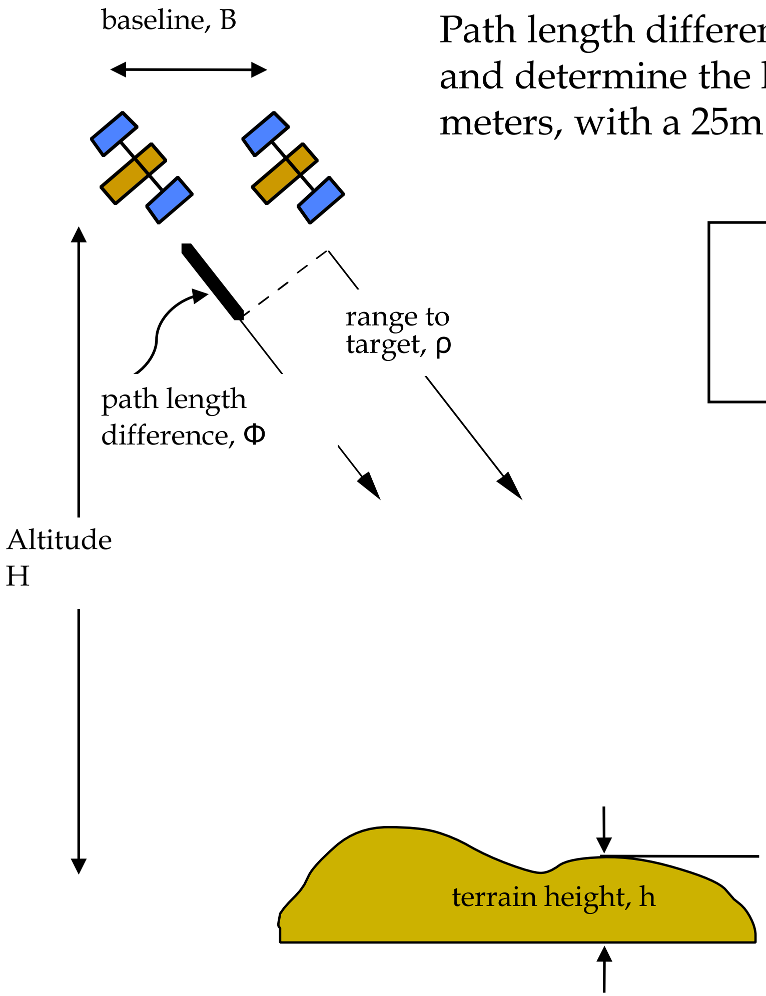




- Different antenna positions, separated by a baseline, are used for uniquely determining the angle of arrival for the signal return.



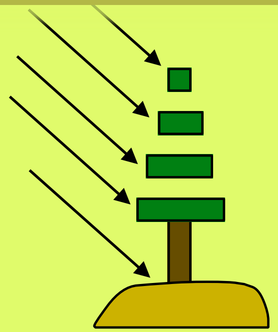
Sensitivity to Volume Scattering



Path length difference can be used to resolve positional ambiguity and determine the height of the terrain. Accuracy is on the order of meters, with a 25m resolution.

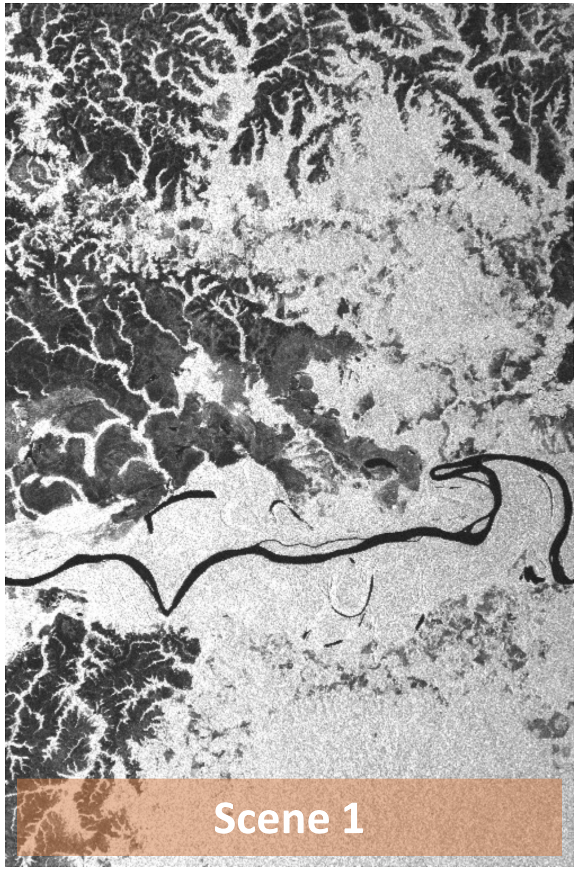
$$h = H - \rho \cos\left(\sin^{-1}\left(\frac{\lambda\phi}{4\pi B}\right)\right)$$

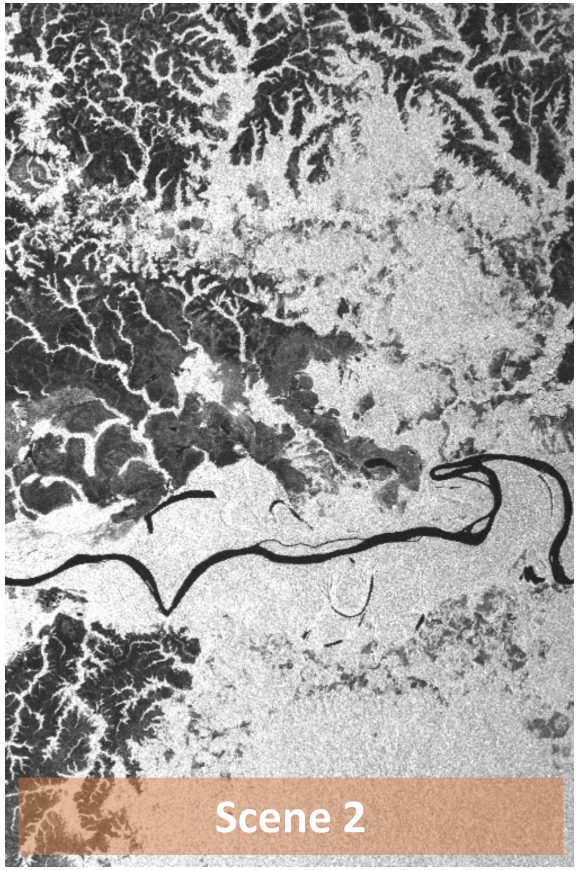
When the signal return comes from multiple heights, a unique signature is observed by the interferometer.

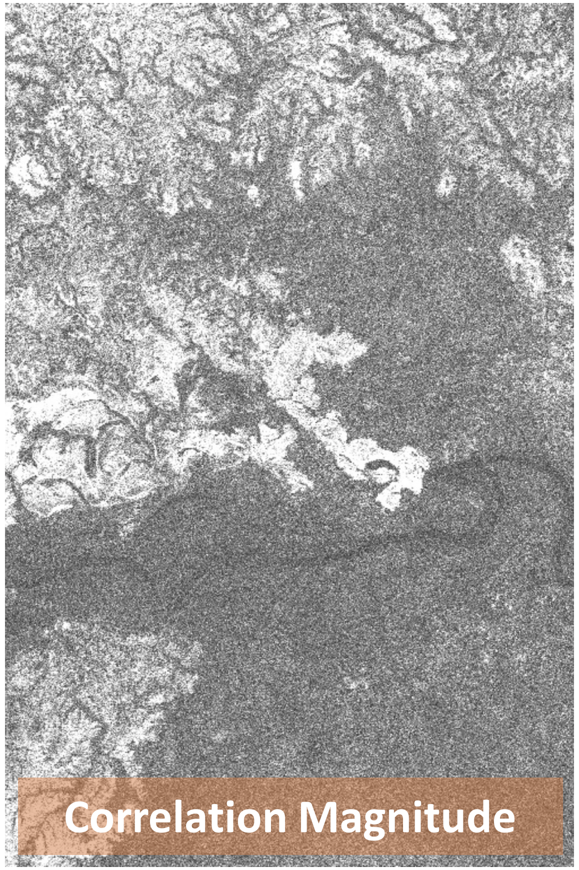


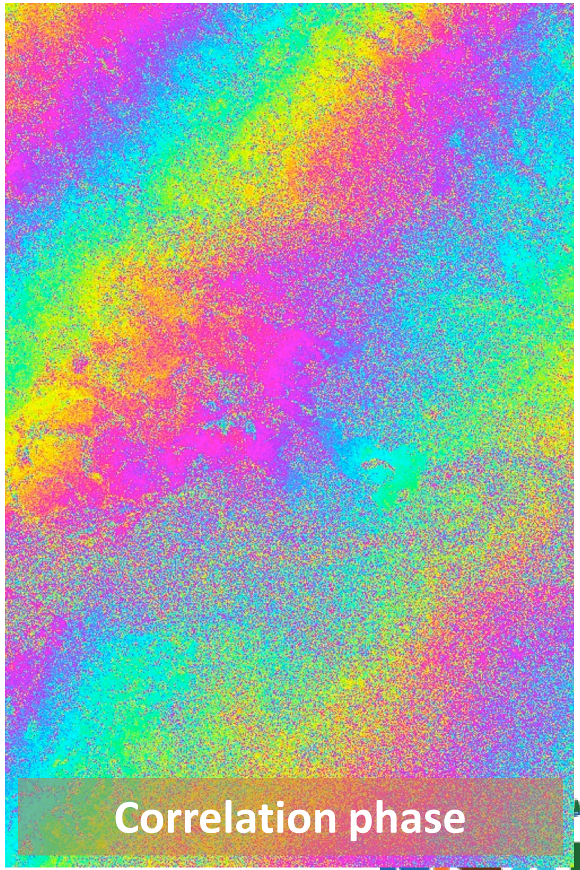
Interferometry

- Interferometry combines two radar scenes to create one, consisting of complex numbers (magnitude and phase)
- Interferometric magnitude is called the ”Coherence”.
- Interferometric phase is related to the topography

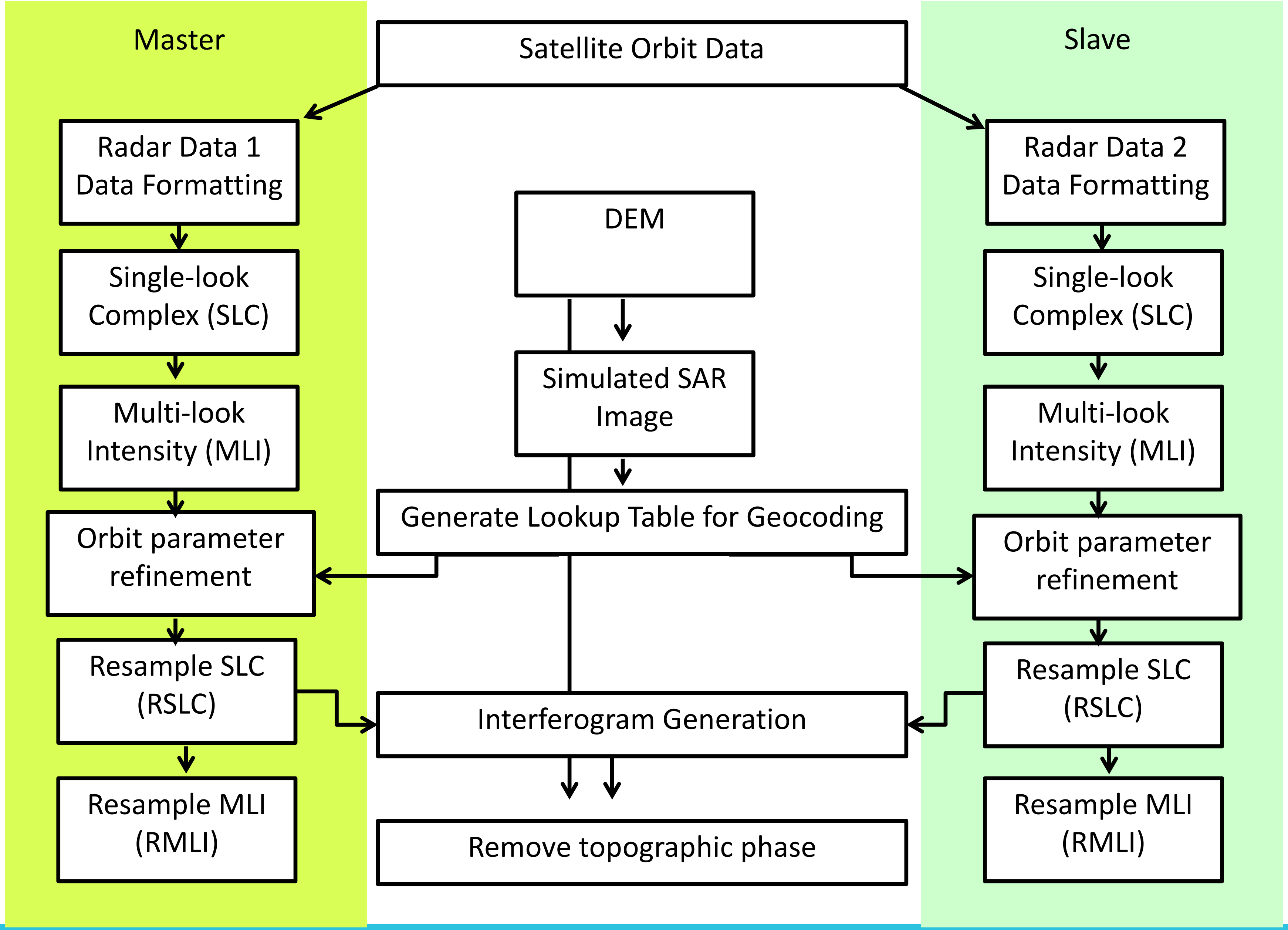






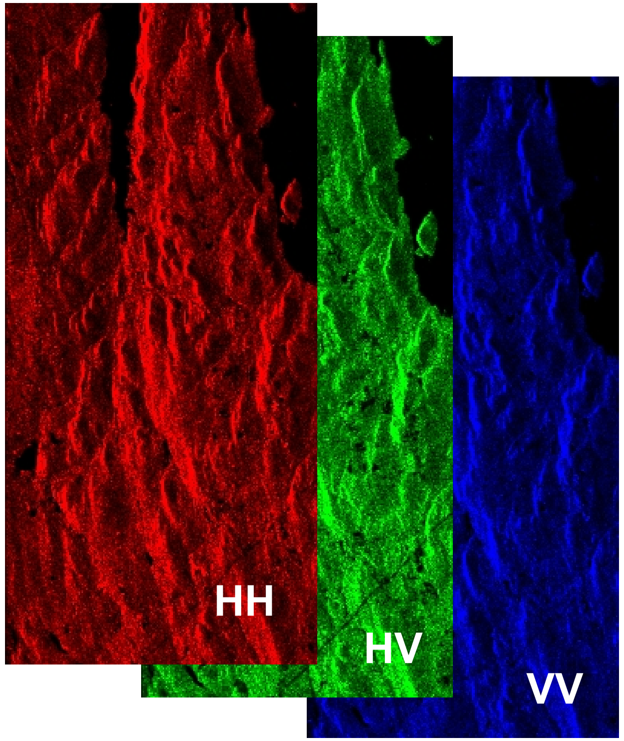


Interferometric Processing Chain

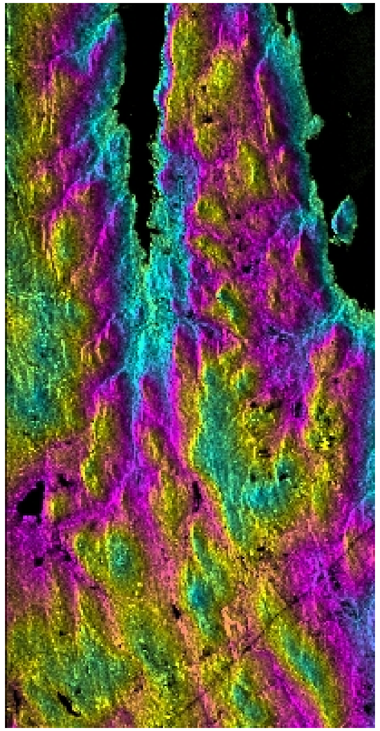


More Output Products

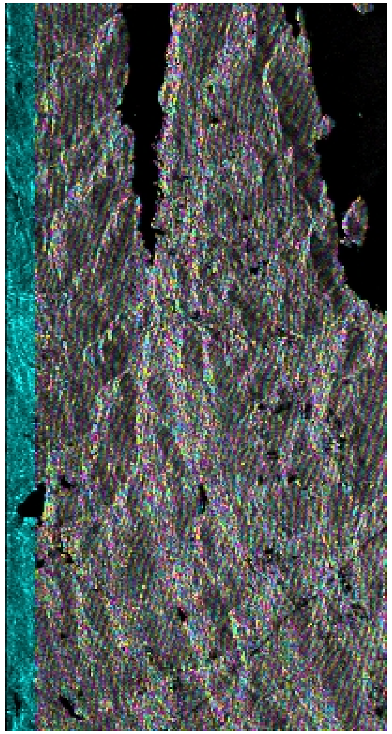
Optical



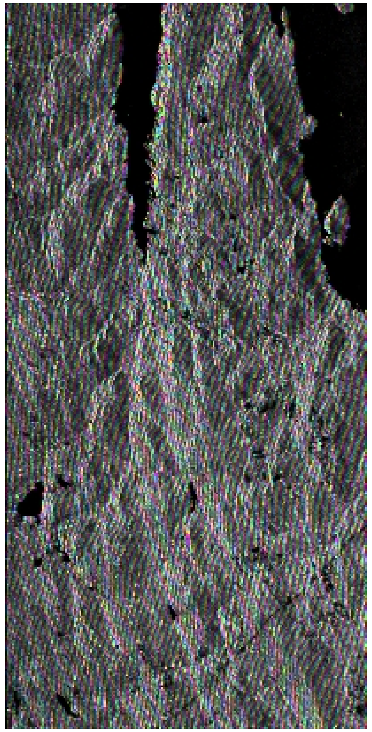
Polarizations



DEM

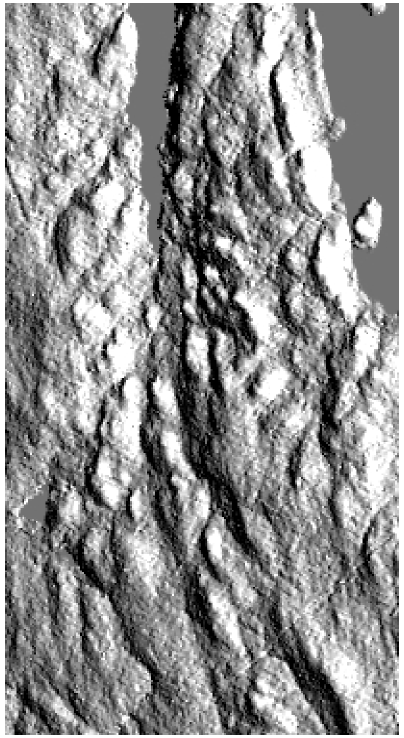


Interferogram

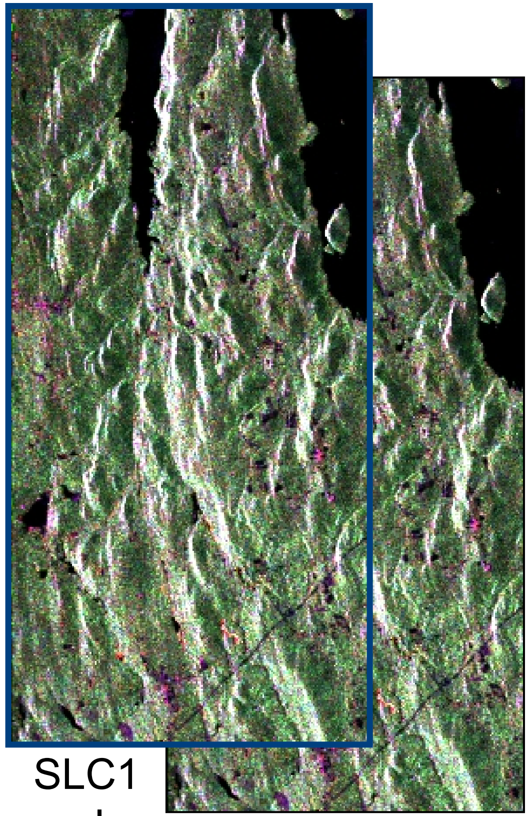


Simulated Interferogram

More Output Products

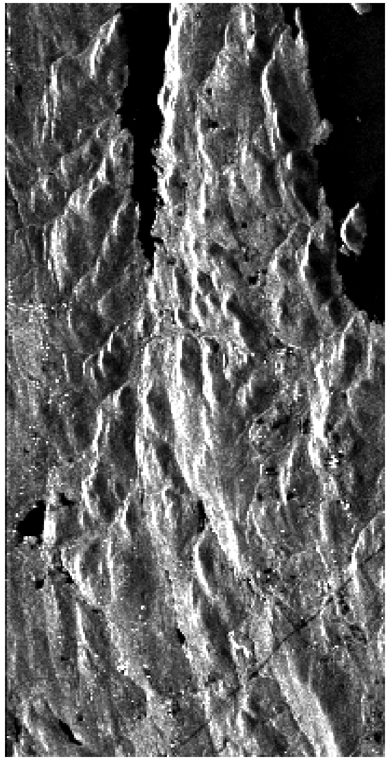


Surface Area Correction



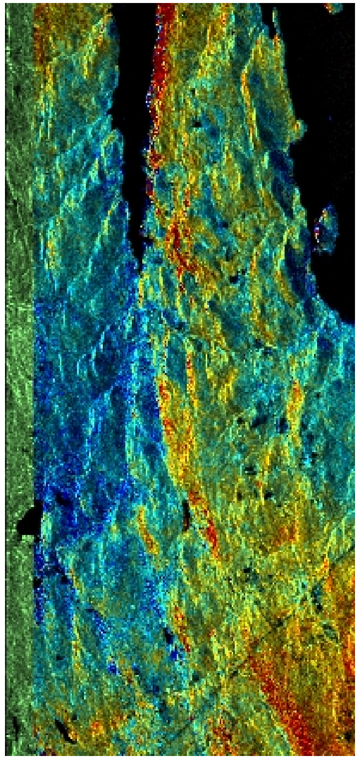
SLC1 -pol

SLC2-pol



Simulated RCS

NRCS1-pol



Differential Interferogram

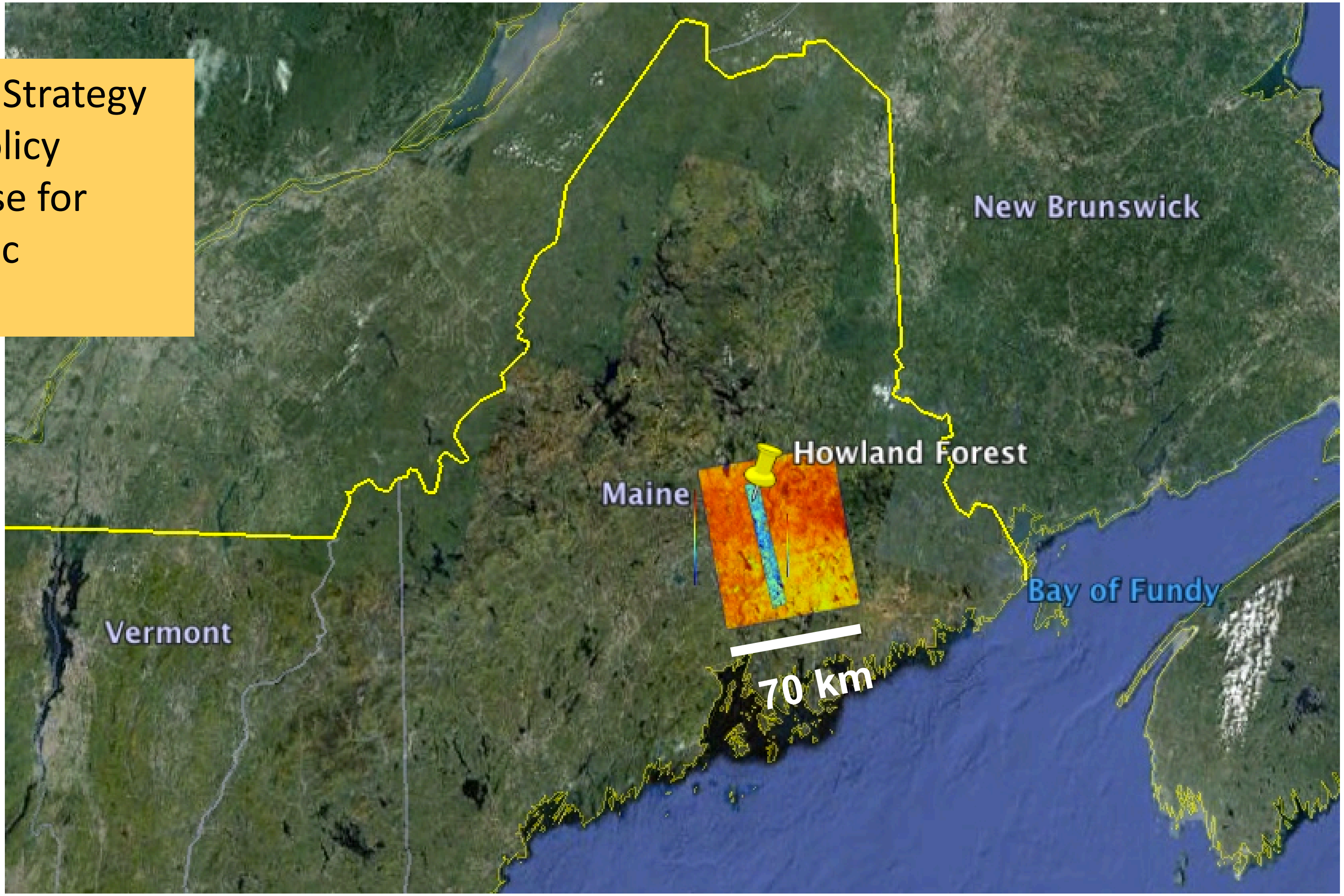
Focus is on L-band because of its relatively low frequency and sensitivity to the more permanent woody-structures of the forest

Possible approaches for measuring vertical structure of vegetation for the SAR/InSAR component of the proposed NISAR mission and the existing ALOS missions.

- Relate backscatter to biomass (scatterer counting)
- If we could measure height, like lidar, that is a possibility too.
- This requires two satellites, or a repeat-pass observation
- Temporal Decorrelation → "The $500M question"

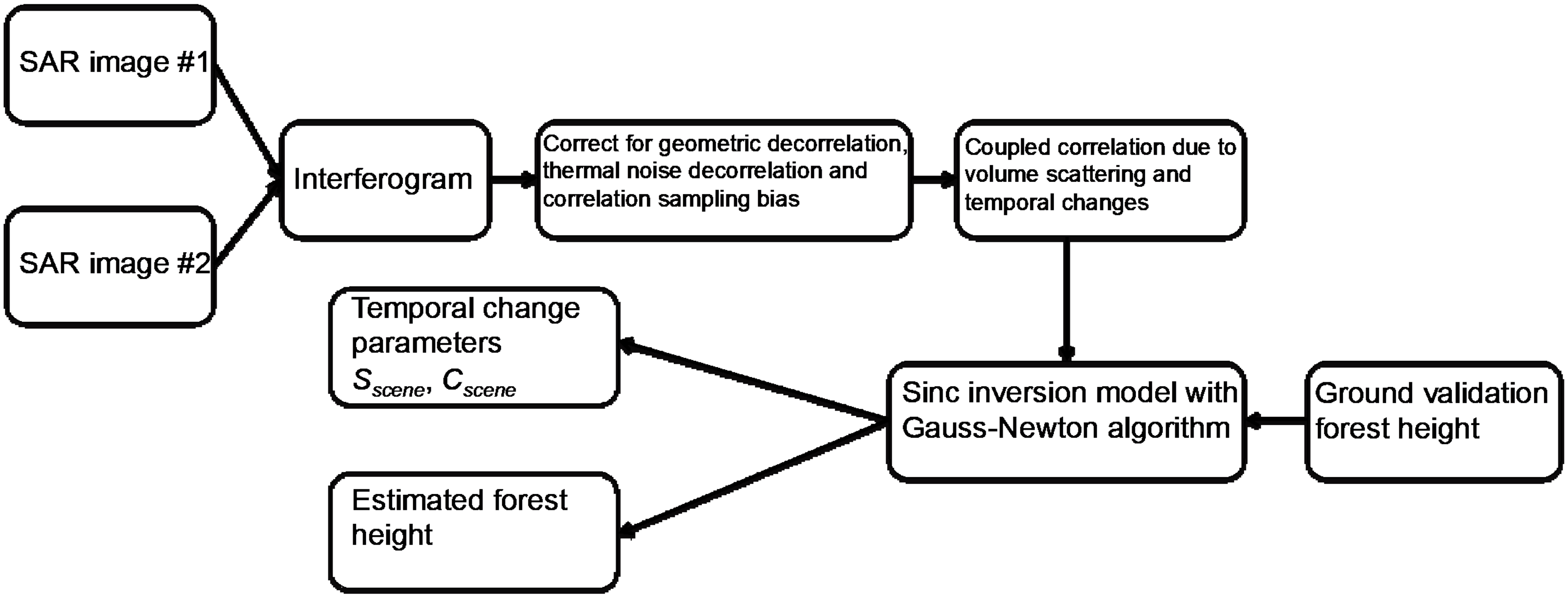
A Place to Start: Central Maine

ALOS-1 Basic Observing Strategy and newly open data policy provides a large database for exploring interferometric correlation.



Workflow of Forest Stand Height Inversion

$$\gamma_{obs} = \gamma_{SNR} \cdot \gamma_{vol} \cdot \gamma_{temporal} \cdot \gamma_{geom} \quad \Rightarrow \quad \gamma_{v\&t} \approx \frac{\gamma_{obs}}{\gamma_{SNR}\gamma_{geom}} \propto (h_v)^{-1}$$

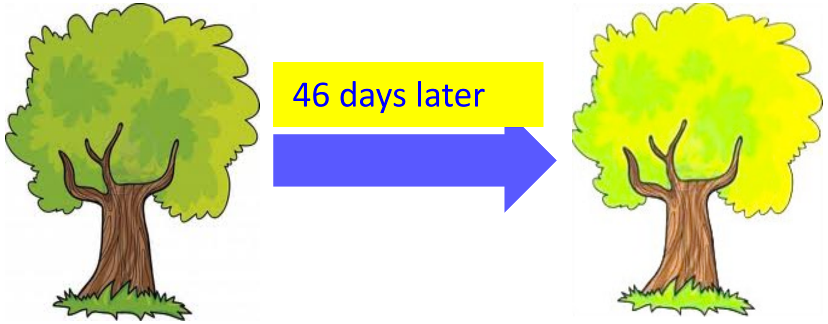


Simplified Model
(HV polarization; small kz)

$$|\gamma_{v\&t}| = S_{scene}\,\mathrm{sinc}\left(\frac{h_v}{C_{scene}}\right)$$

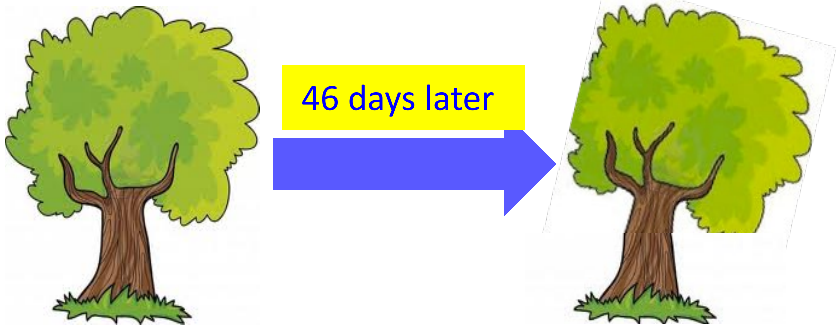
S_{scene}

(dielectric change)

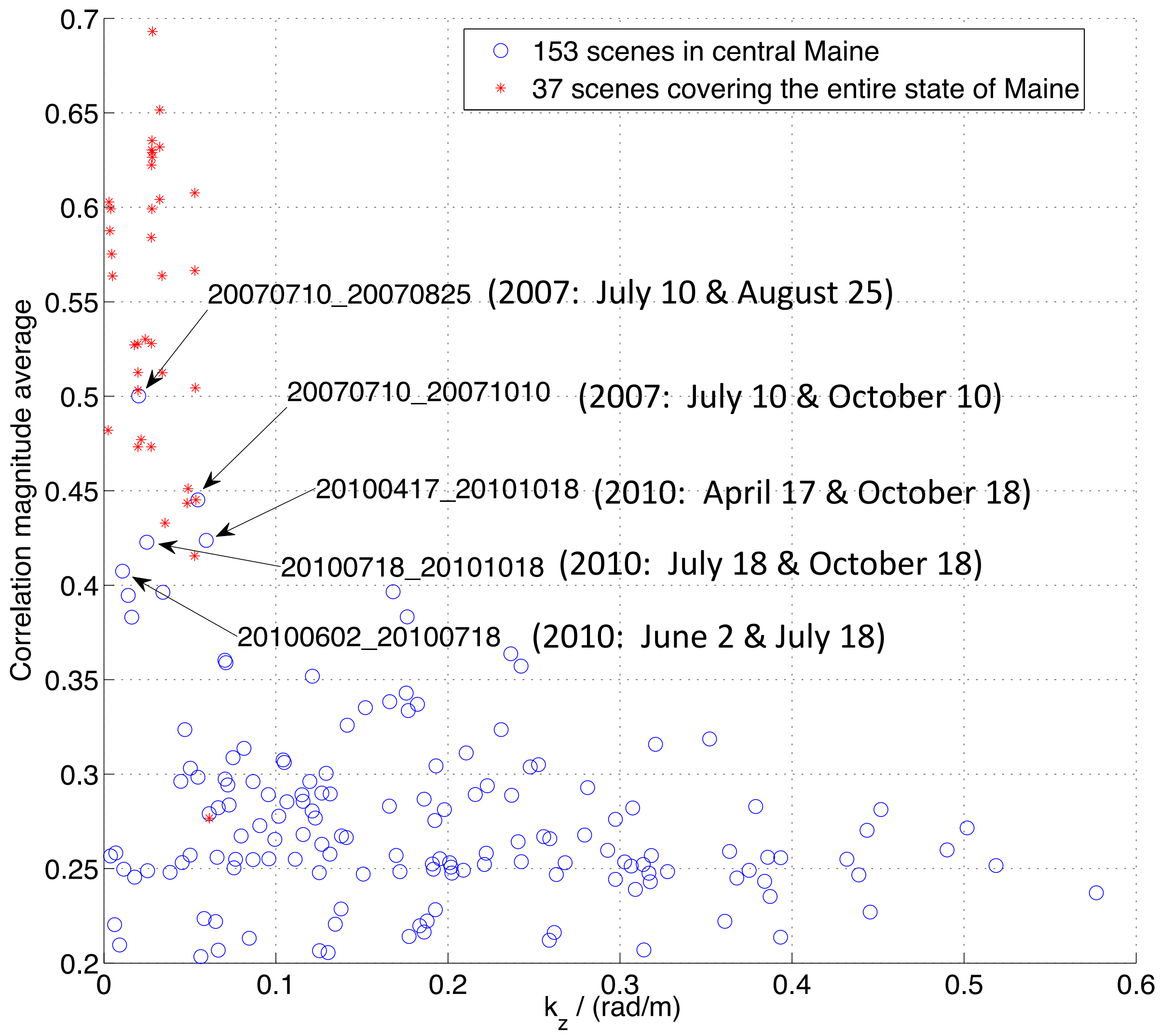


C_{scene}

(random motion)



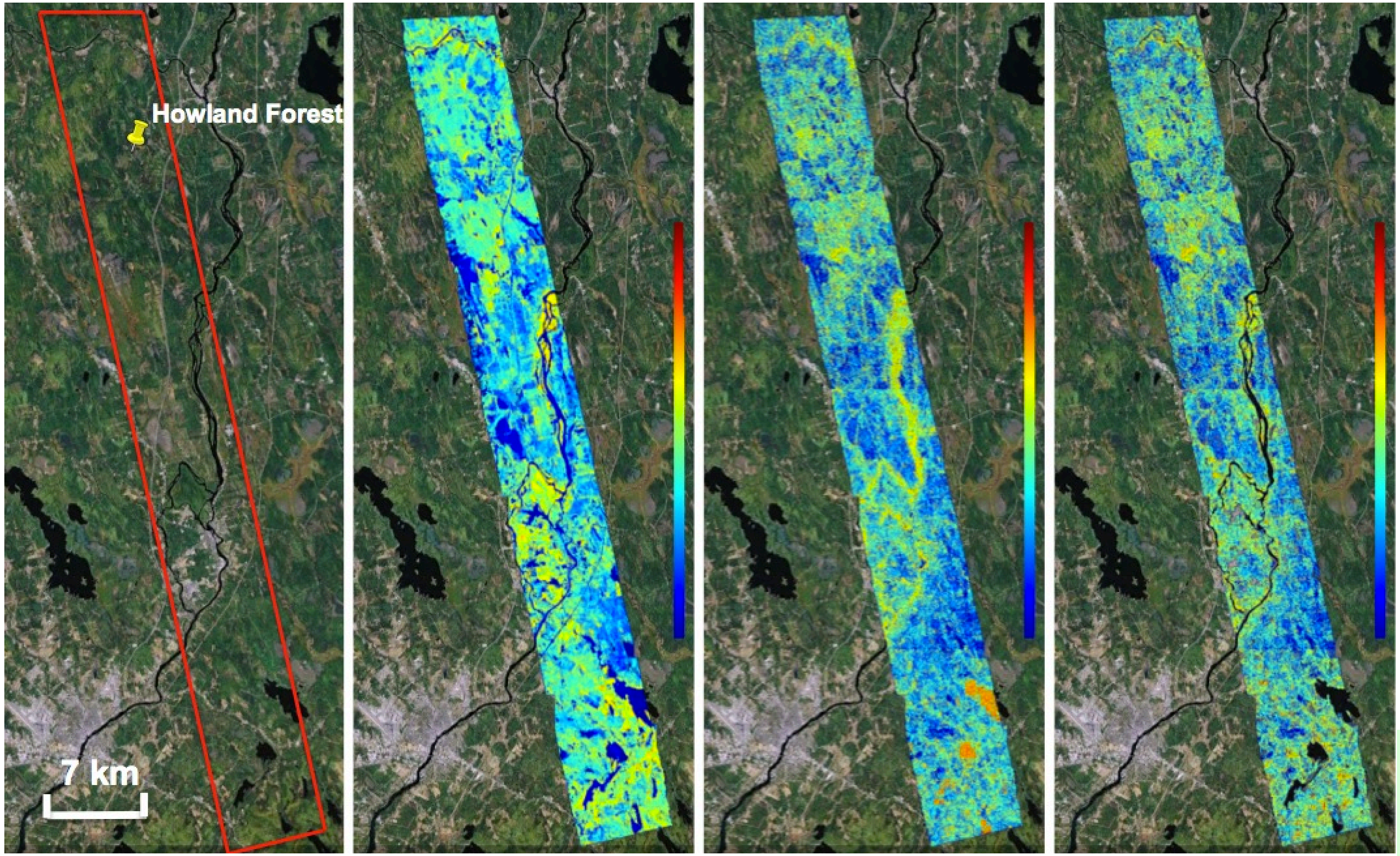
18 SAR Scenes in Central Maine (119_890)



18 separate dates collected using the same observing mode (FBD, path 119, frame 890) in Central Maine

This creates a total of 153 unique combinations

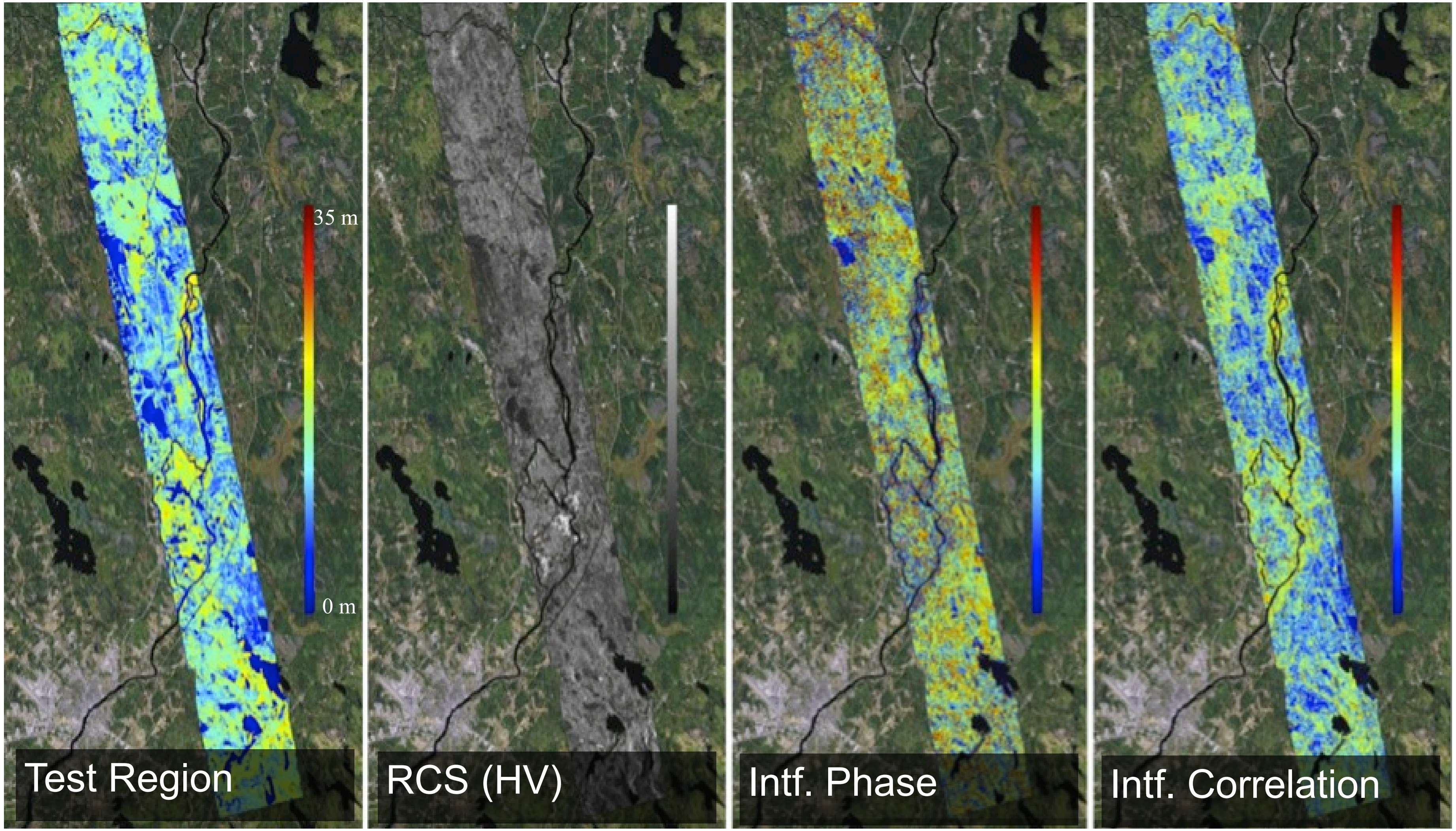
Results (Howland Forest)



Optical | LVIS | InSAR correlation magnitude | InSAR correlation magnitude w/o water

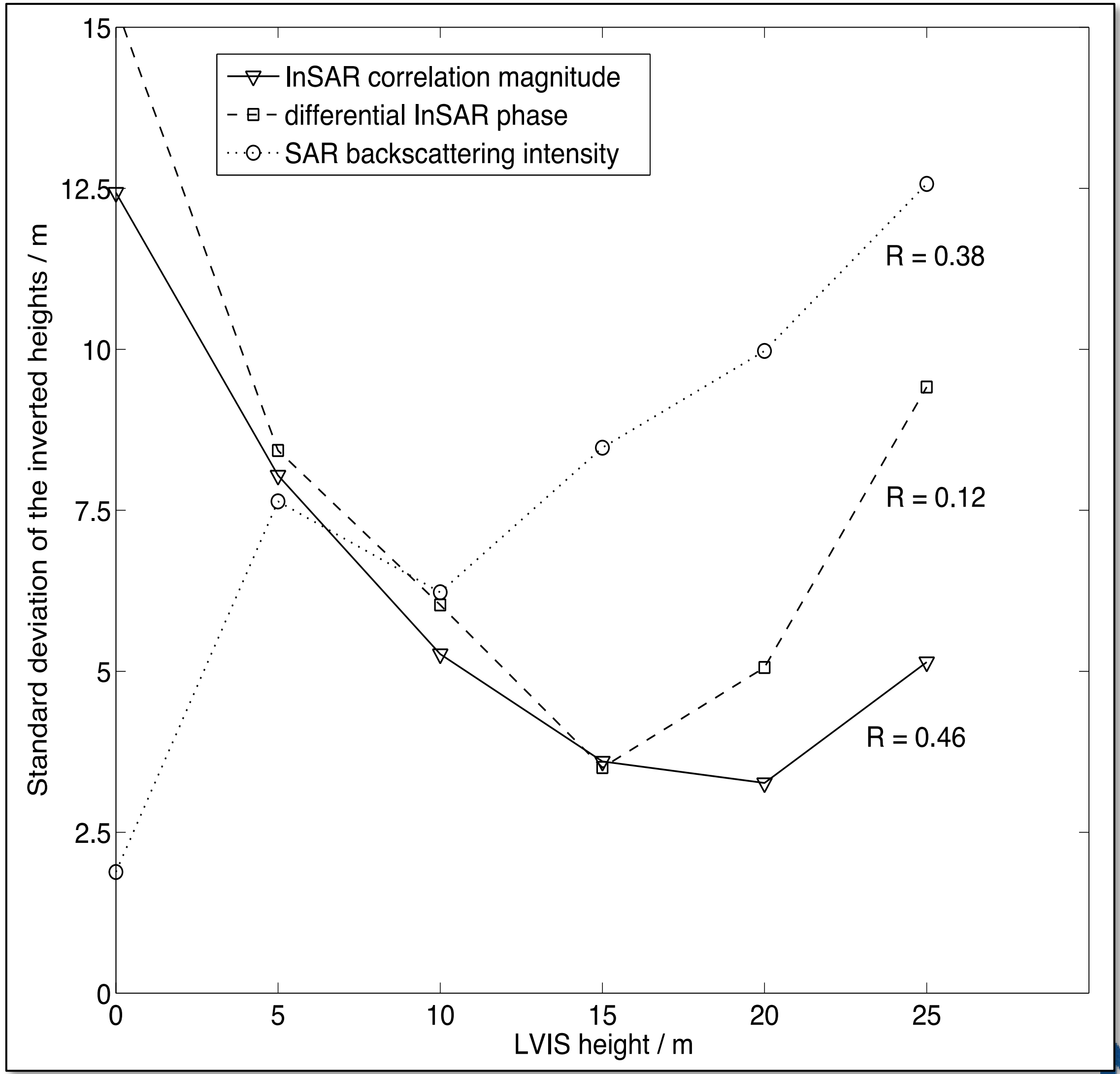
Water bodies removed by using NLCD 2006

Qualitative Comparison of Methods

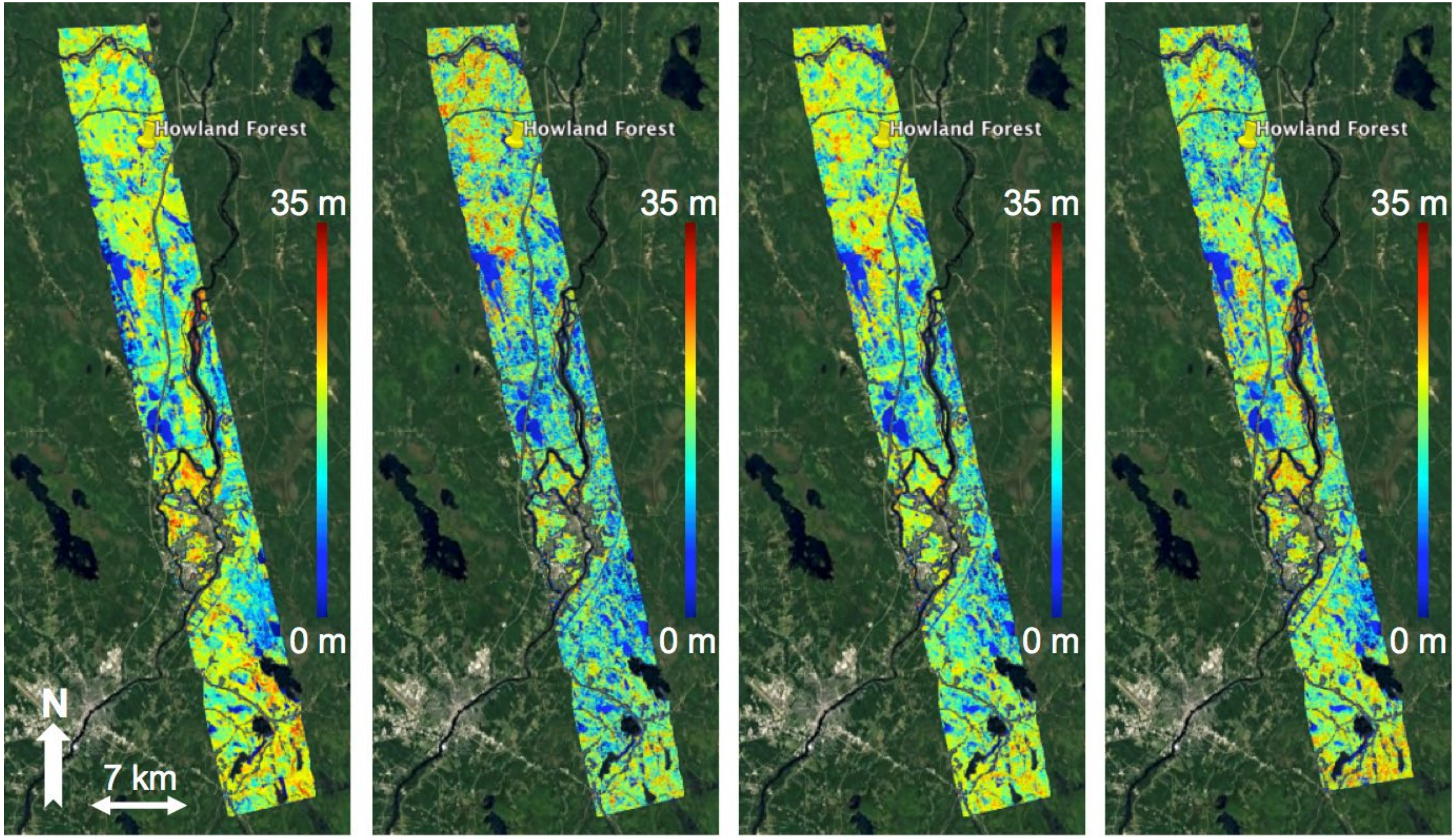


Quantitave Comparison

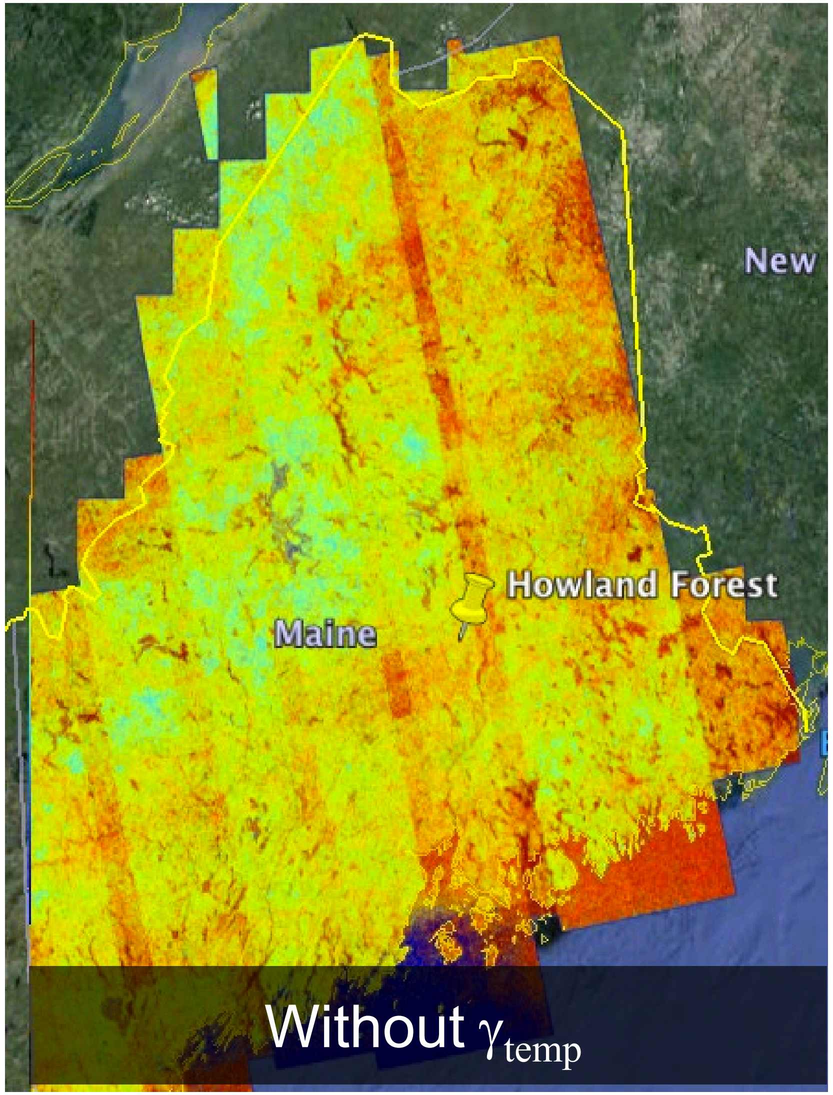
- Assuming that forest stand height (FSH) is a proxy for biomass, we can fit observations of RCS, InSAR differential height from the known DEM (phase) and the correlation magnitude height to the LVIS observed heights.
- Low heights work best with RCS.
- Large Heights have best performance with InSAR correlation magnitude.

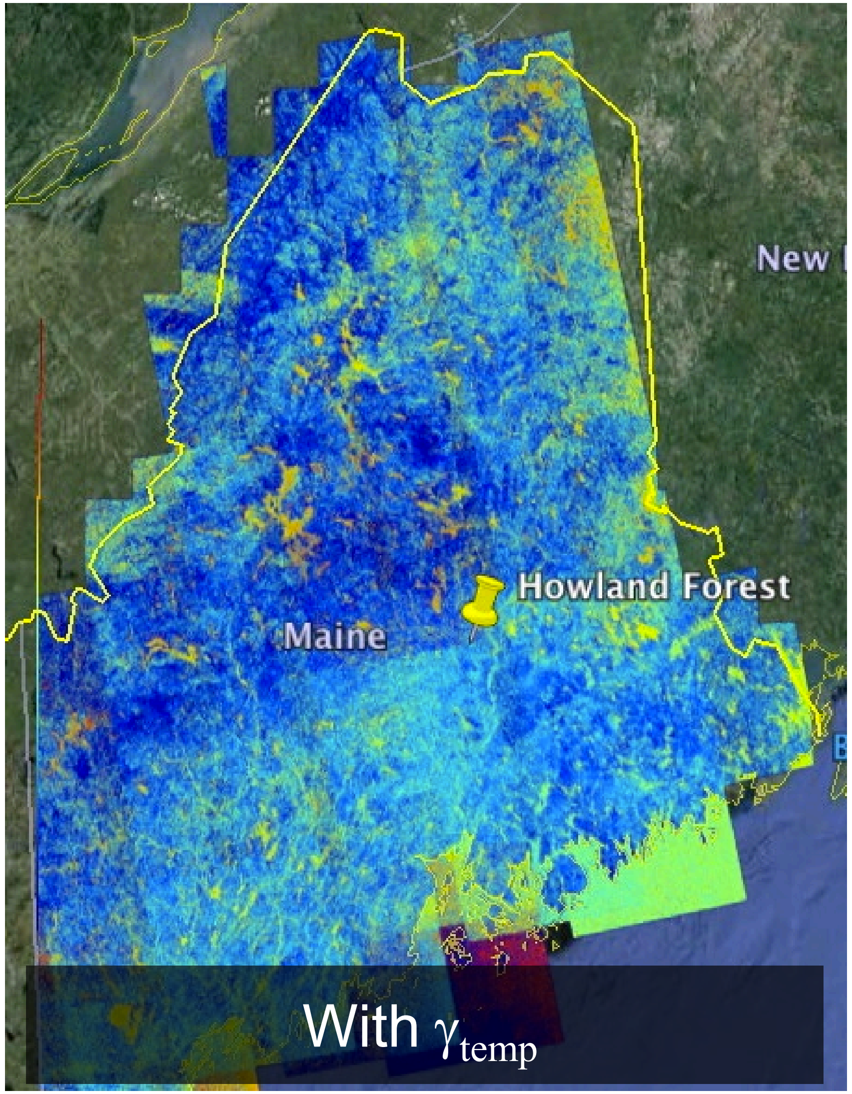


ALOS-1 and ALOS-2 Results Compared to Lidar



Lidar RH100 | ALOS-1 single | ALOS-1 mosaic | ALOS-2 single


New
Howland Forest
Maine
Without γ_{temp}


New
Howland Forest
Maine
With γ_{temp}

Dataset (Entire State of Maine)

94 ALOS/PALSAR imageries are selected to cover the entire state of Maine, from which 37 interferograms are formed and identified as having relatively high correlation magnitude.

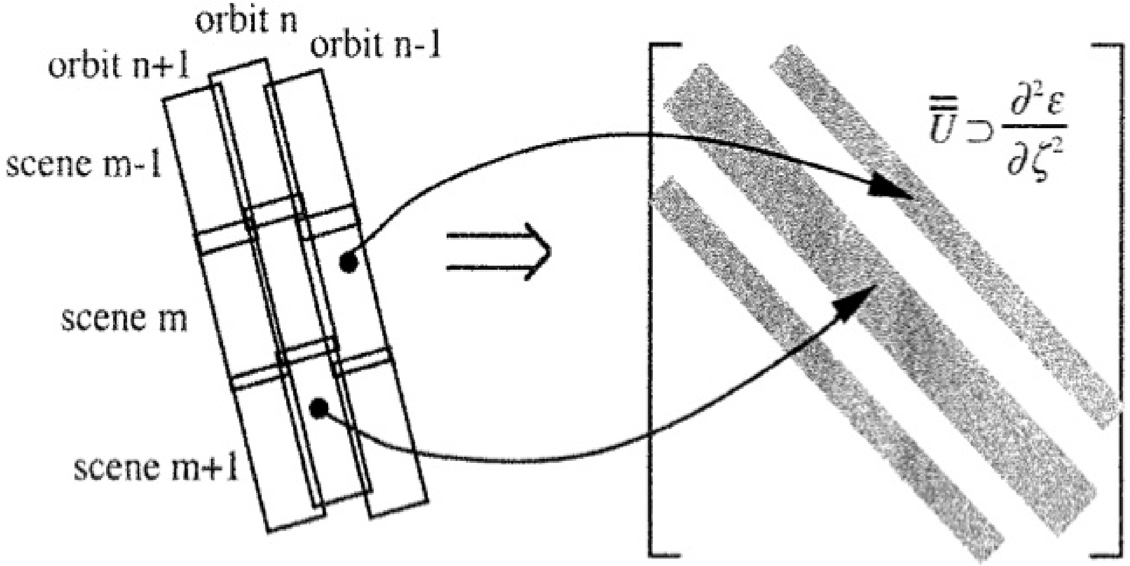
Interferometric pairs utilized for the generation of the state mosaic of forest height

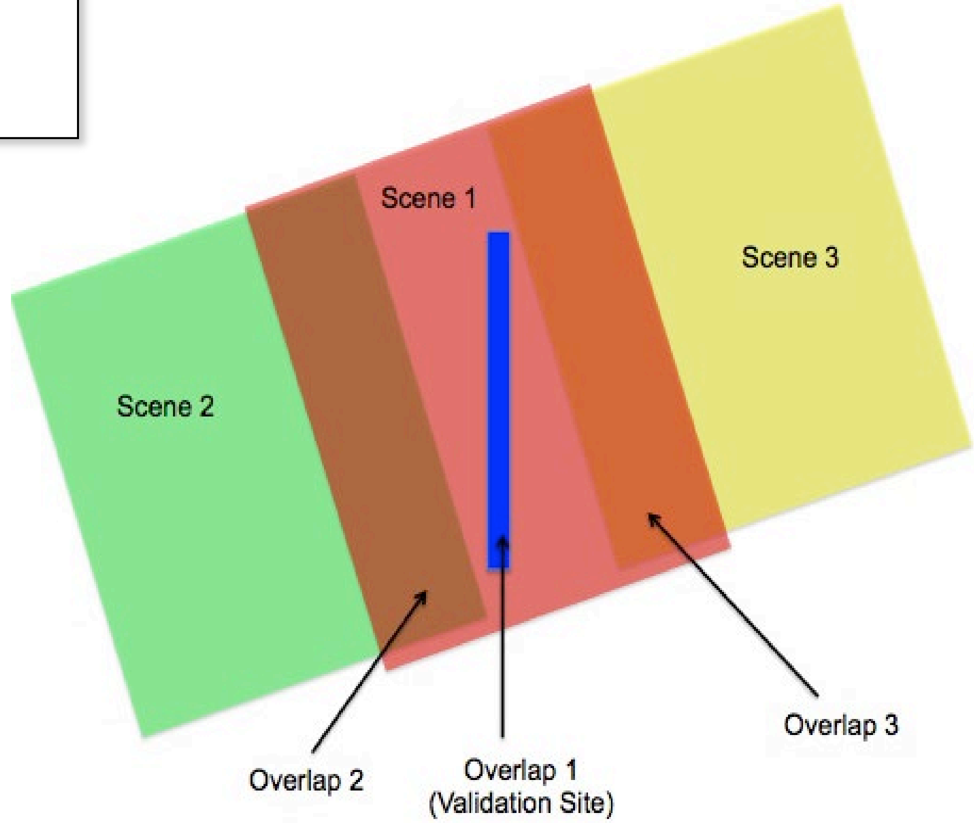
Orbit # / Frame #	124	123	122	121	120	119	118	117
930					20070727_ 20070911	20070710_ 20070825	20070808_ 20070923	
920				20100706_ 20100821	20070727_ 20070911	20070710_ 20070825	20070808_ 20070923	
910				20100706_ 20100821	20070727_ 20070911	20070710_ 20070825	20070808_ 20070923	
900			20070715_ 20070830	20100706_ 20100821	20070611_ 20070727	20070710_ 20070825	20070808_ 20070923	
890		20070616_ 20070801	20070715_ 20070830	20100706_ 20100821	20070727_ 20070911	20070710_ 20071010	20070808_ 20070923	20070722_ 20070906
880	20070703_ 20071003	20070616_ 20070801	20070715_ 20070830	20100706_ 20100821	20070611_ 20070727	20070710_ 20071010	20070808_ 20070923	
870	20070703_ 20071003	20070616_ 20070801	20100723_ 20100907	20100706_ 20100821	20070611_ 20070911			
860	20070818_ 20071003	20100809_ 20100924						

Article

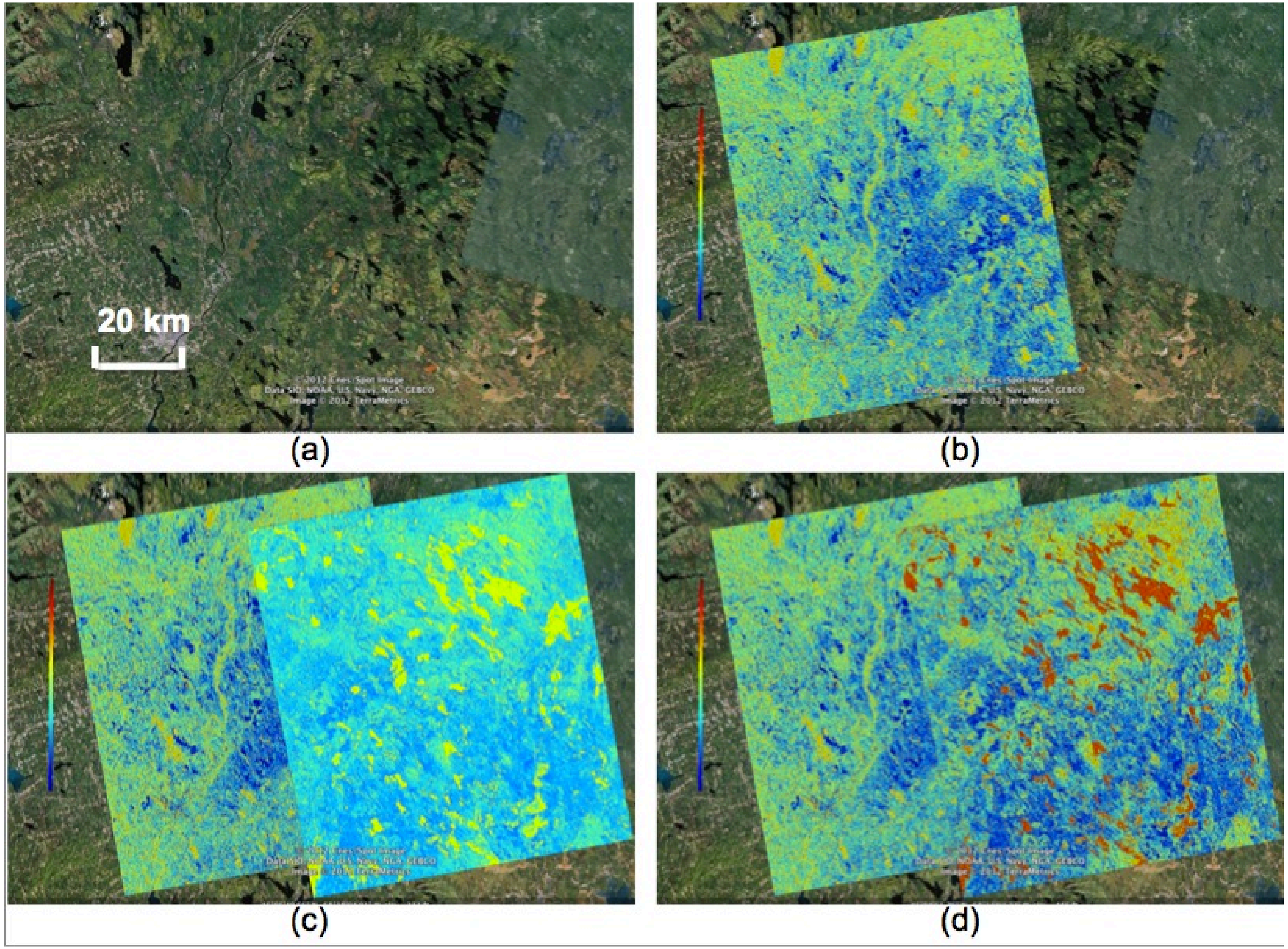
An automatic mosaicking algorithm for the generation of a large-scale forest height map using spaceborne repeat-pass InSAR correlation magnitude

Yang Lei [1], and Paul Siqueira [1]*

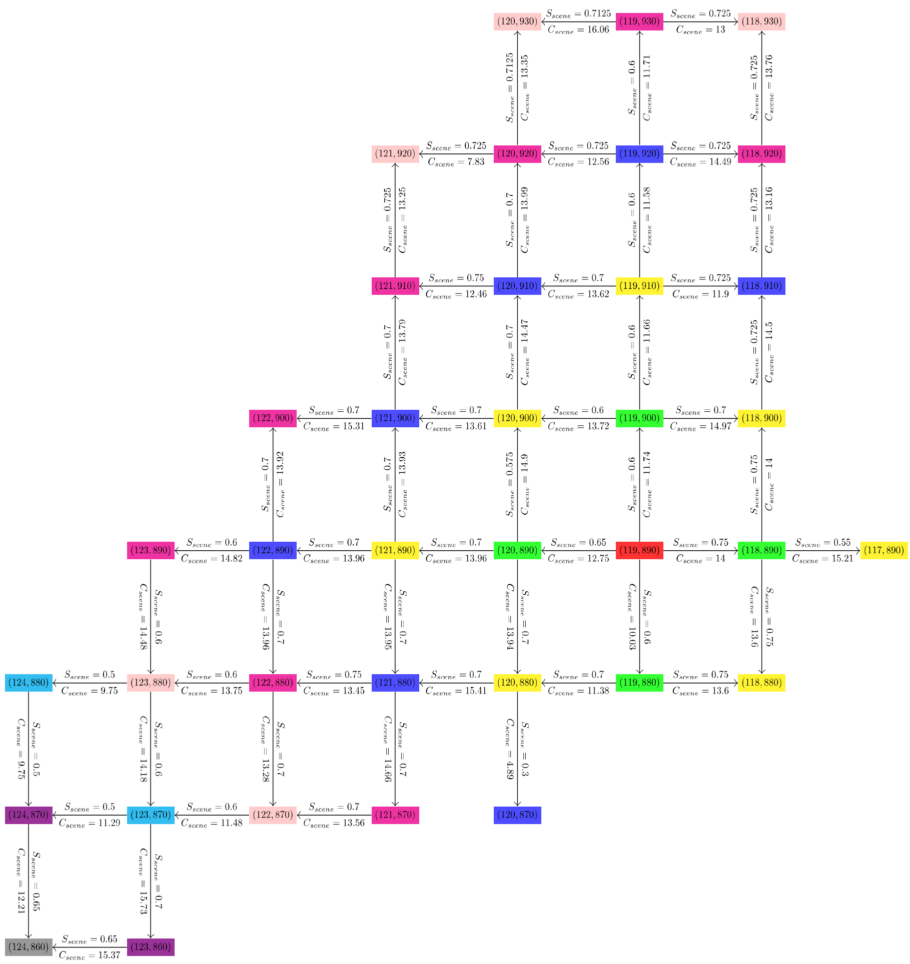


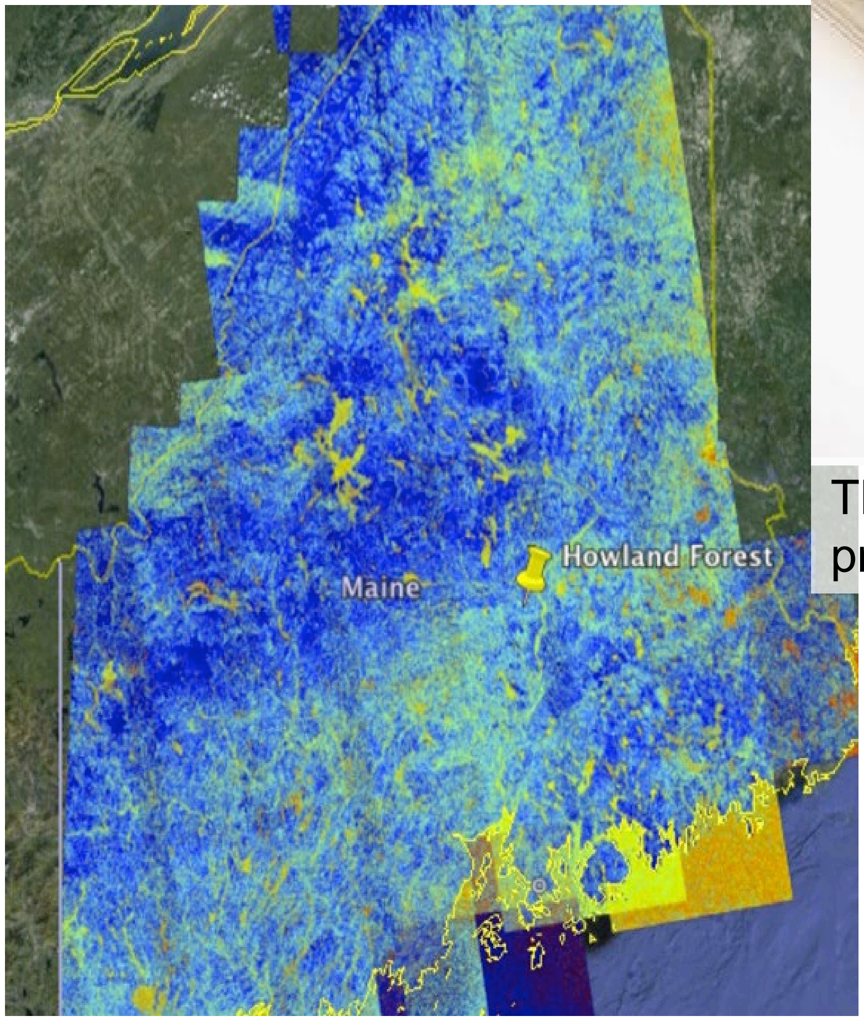


Results (From Central Maine to the State Mosaic)

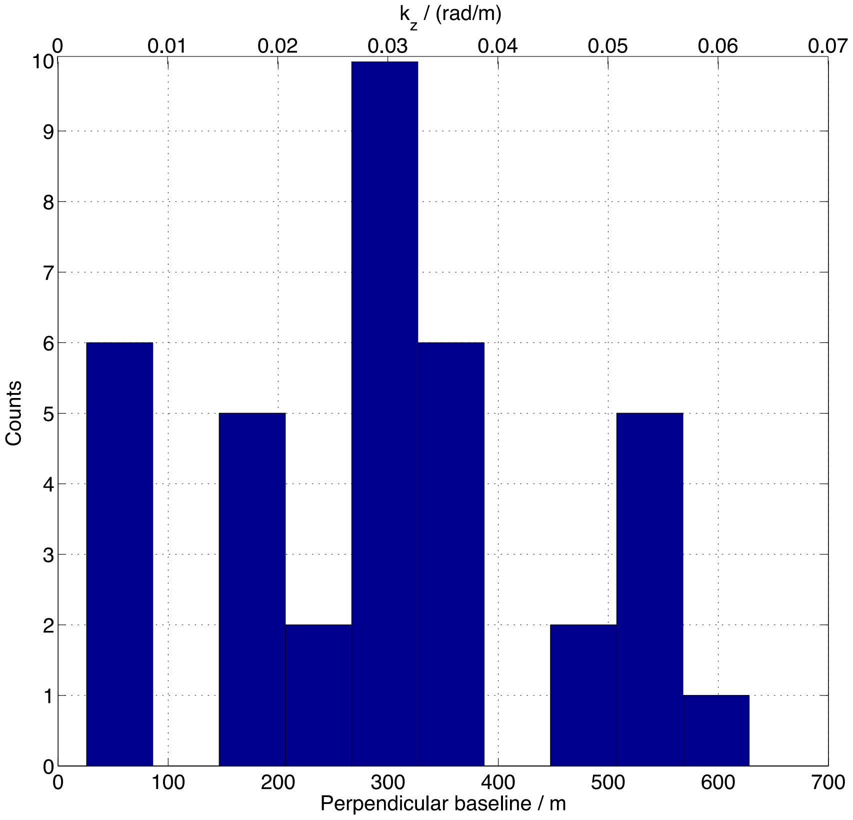


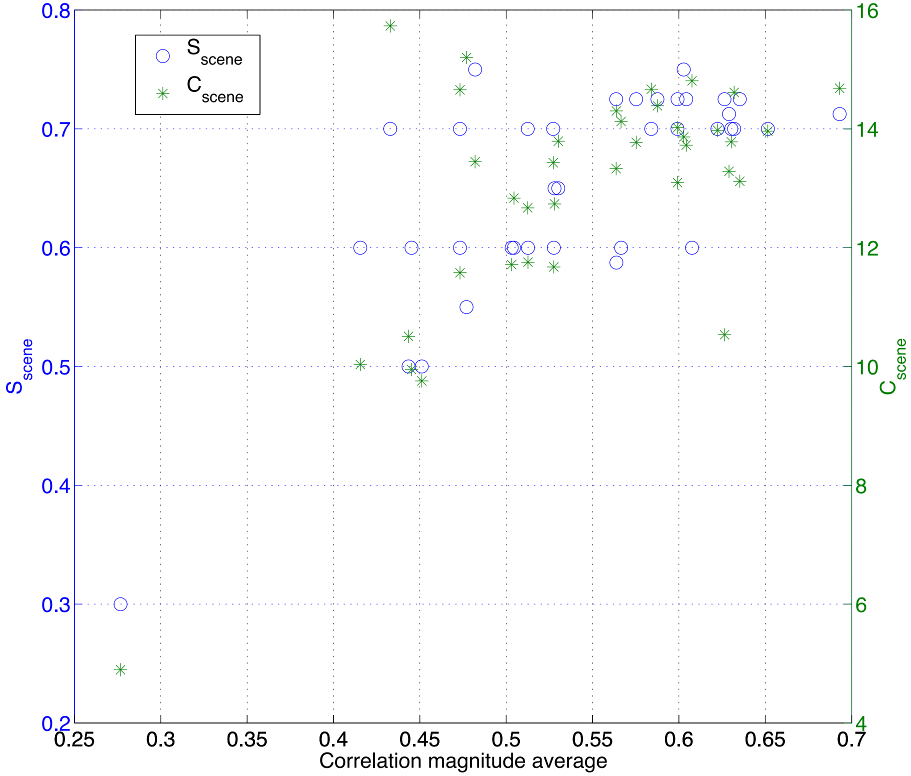
Assembling the Mosaic





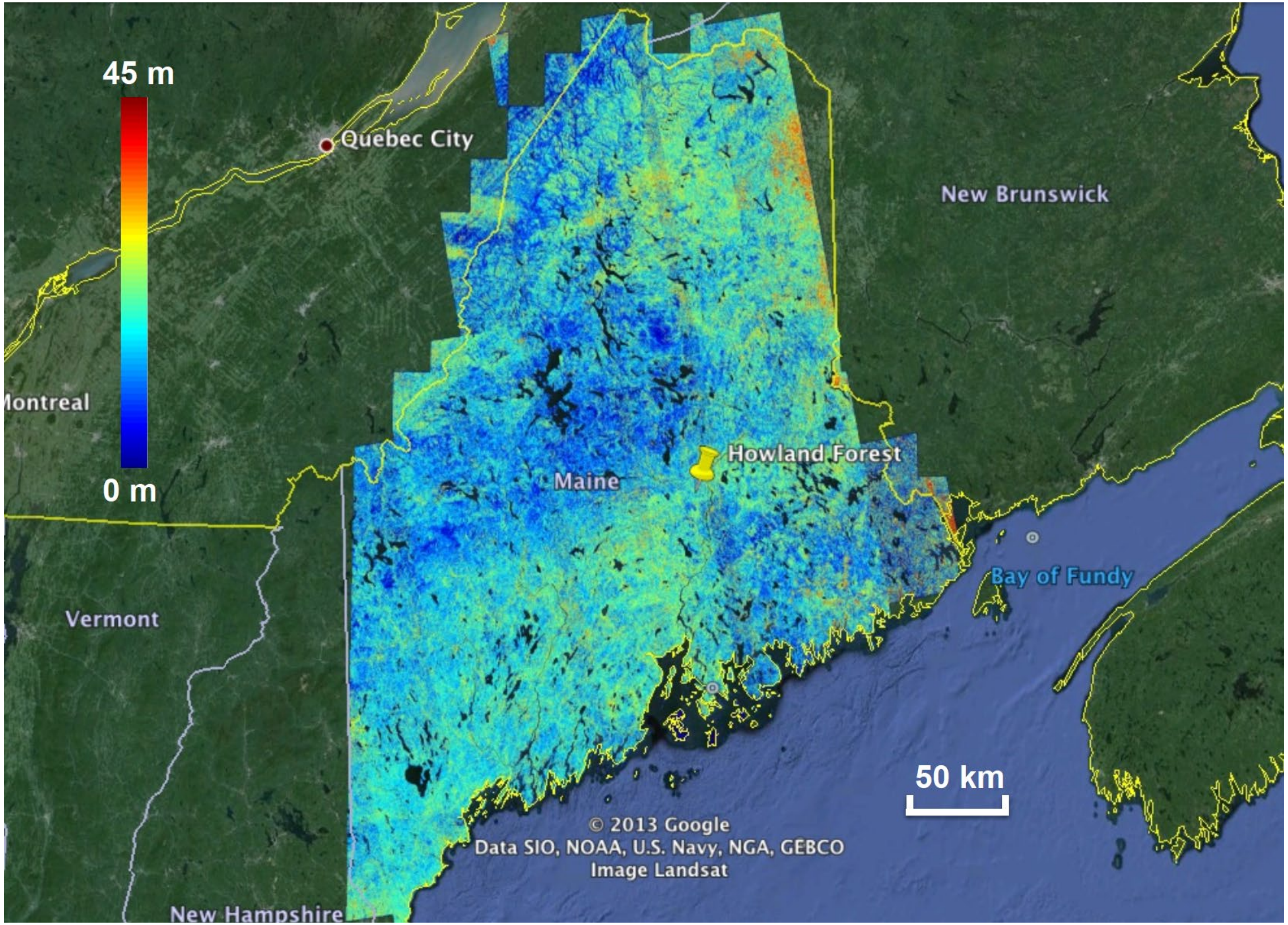
The "wallpapering" problem



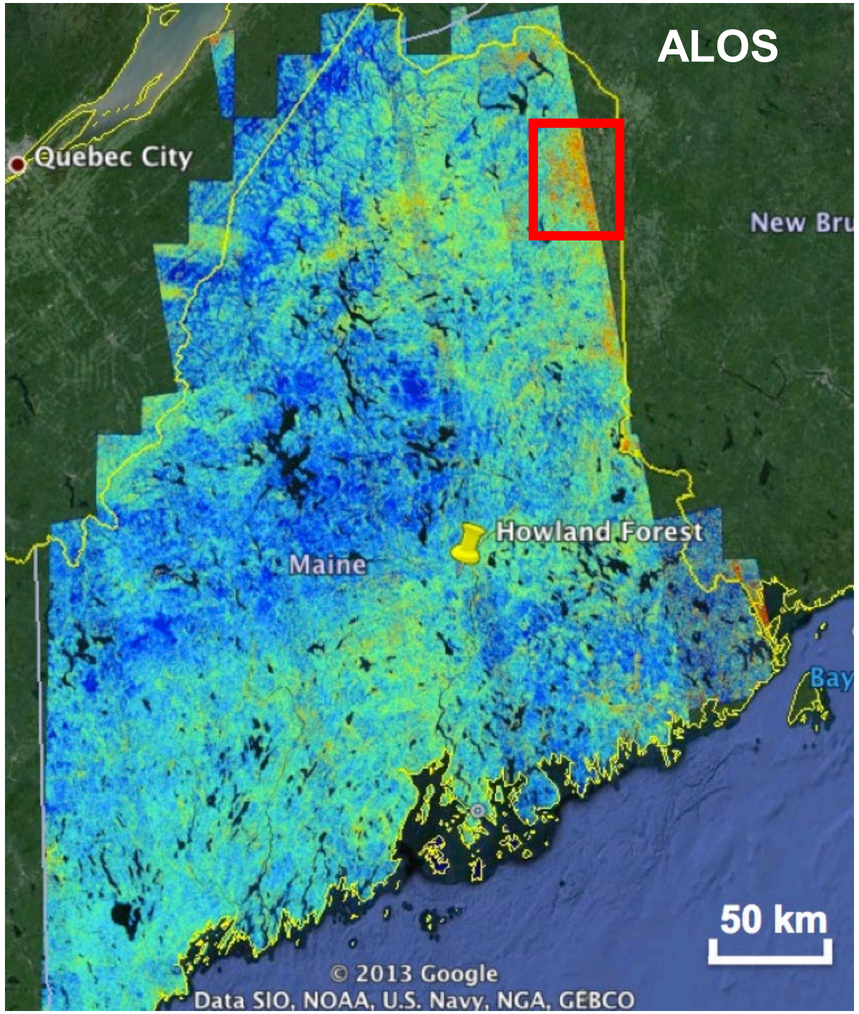


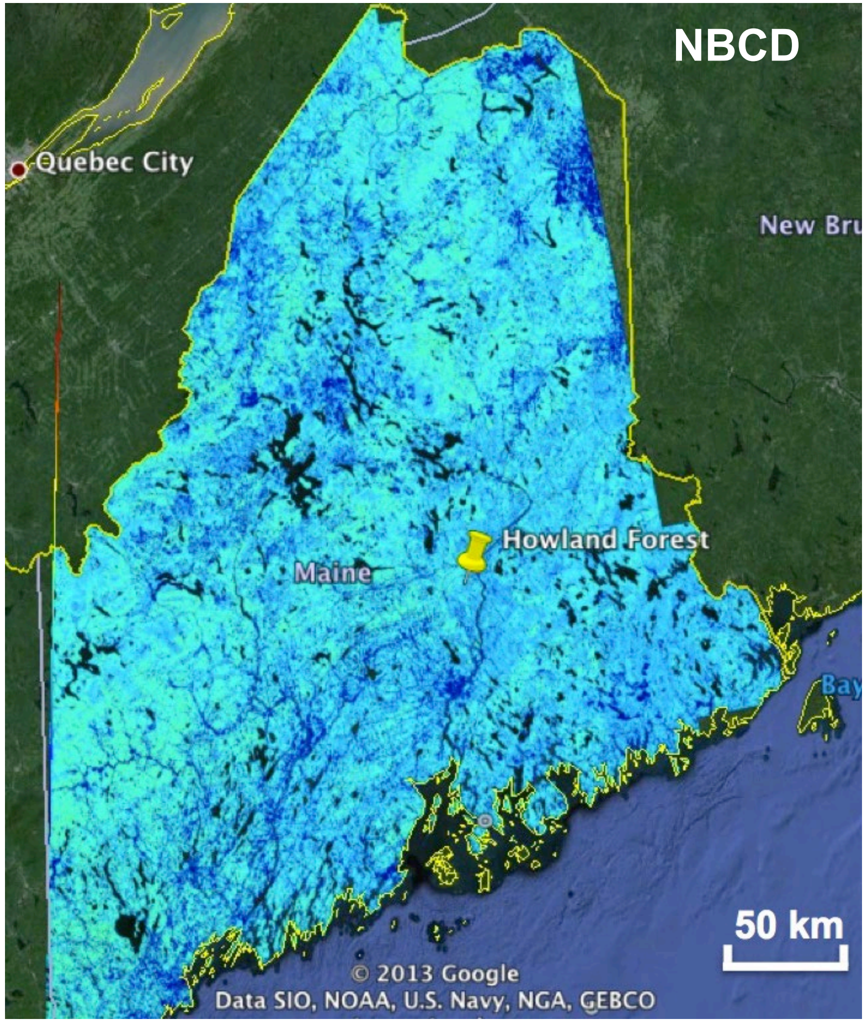
Instrumental Parameters

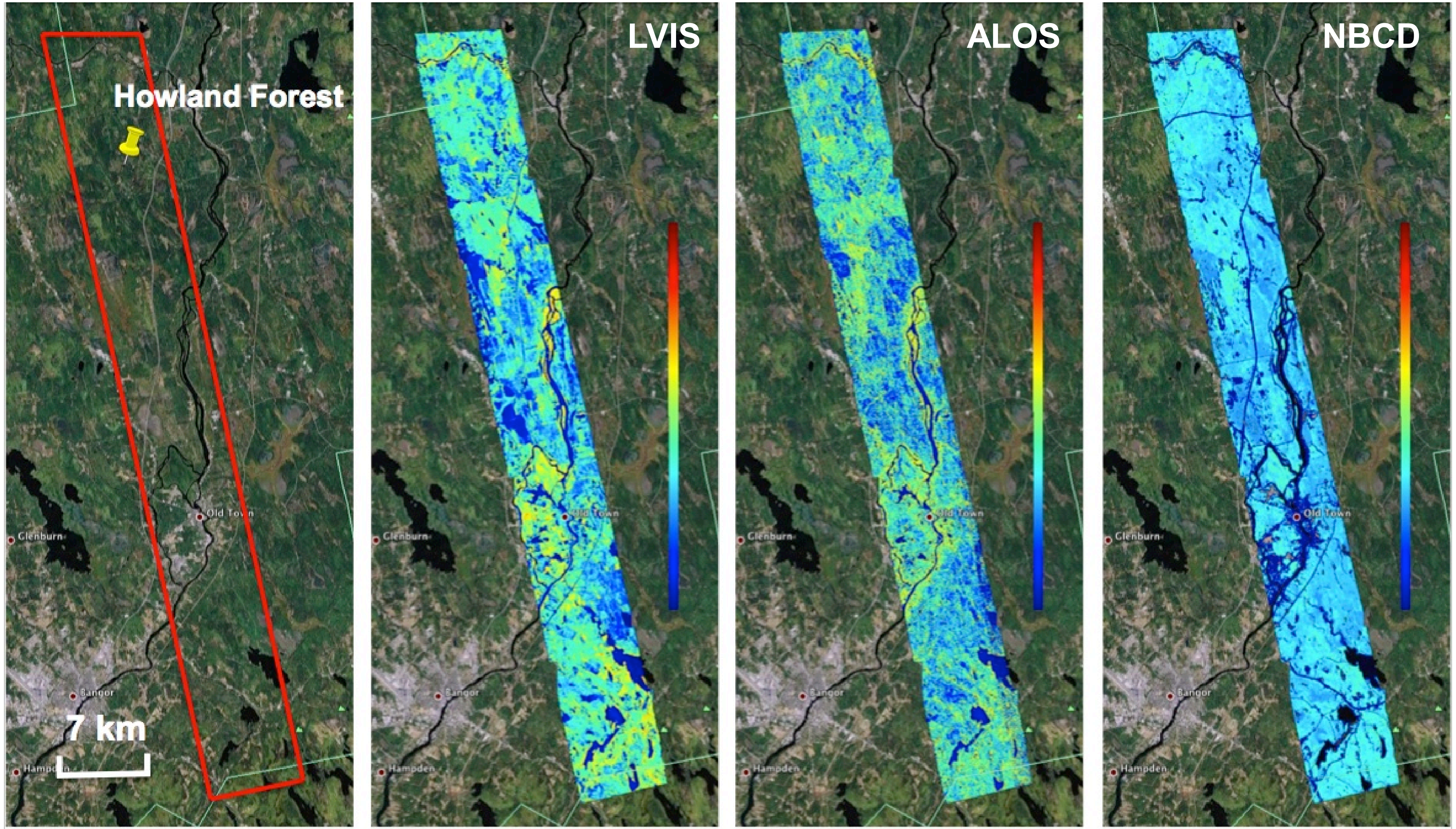
Model-Fitting Parameters


45 m
0 m
Quebec City
Montreal
New Brunswick
Howland Forest
Maine
Vermont
Bay of Fundy
50 km
© 2013 Google
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat
New Hampshire

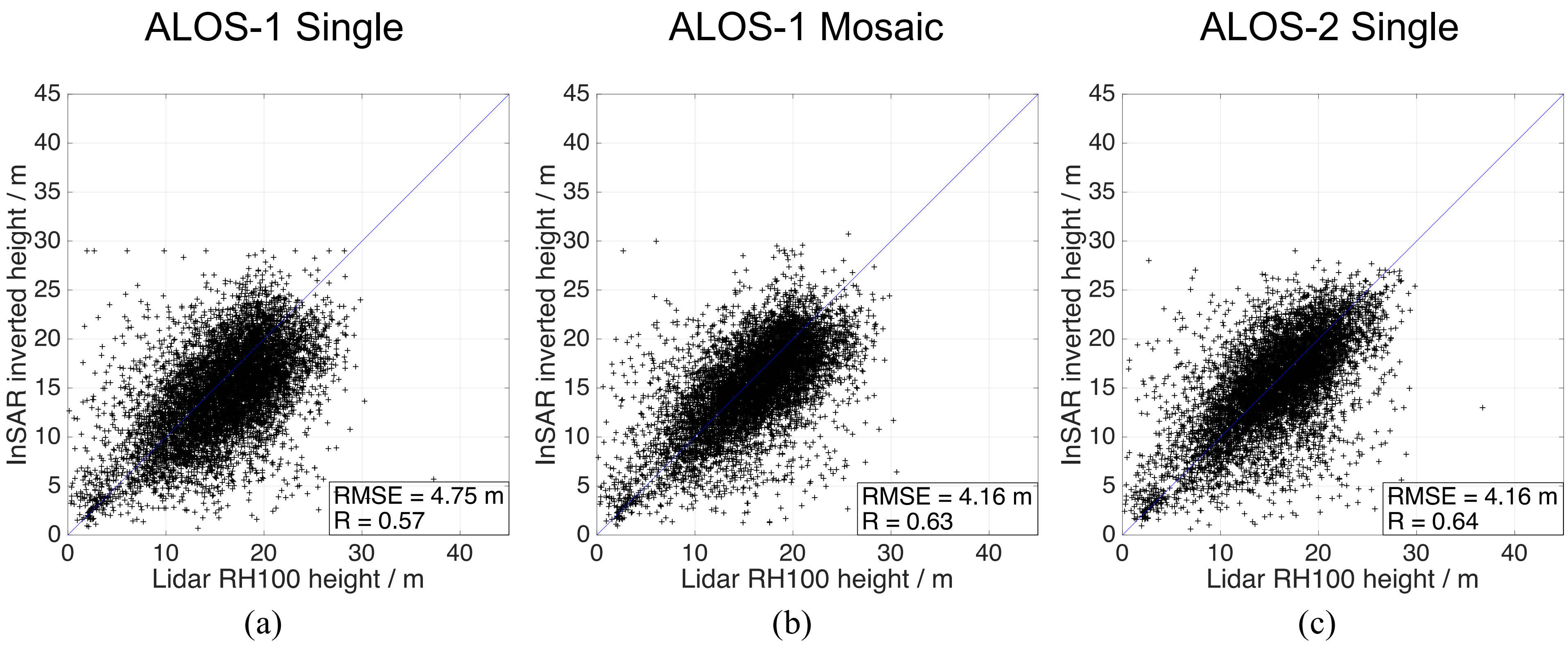
Comparison to Other State-Wide Metrics






Howland Forest
Old Town
Glenburn
Bangor
7 km
LVIS
ALOS
NBCD

ALOS-1 and ALOS-2 Scatterplots with Lidar RH100

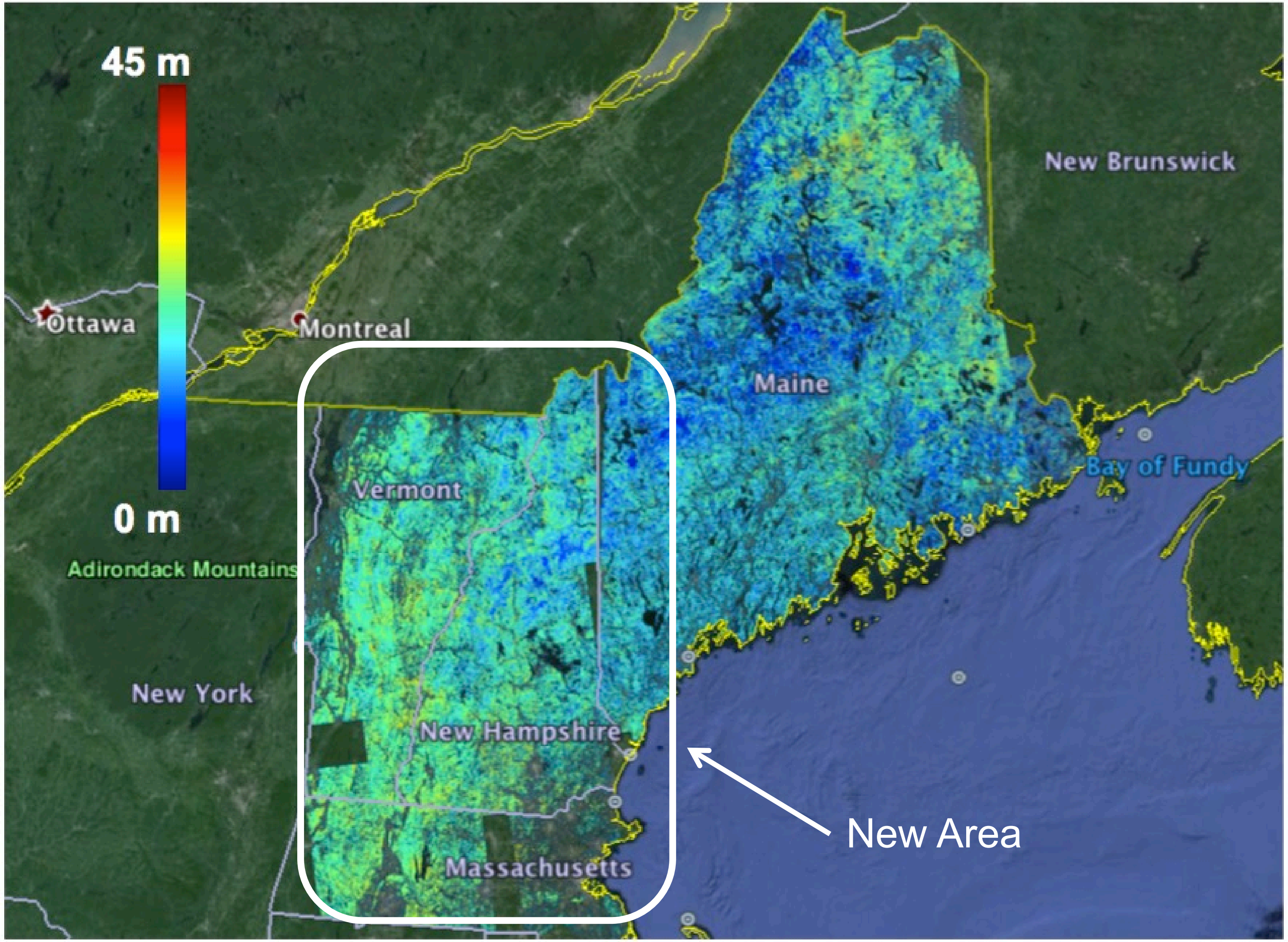


RMSE < 4 m at 6 ha resolution

To improve accuracy:

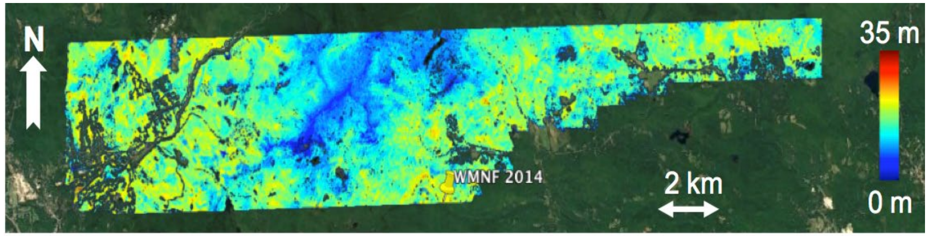
- Multiple-scene mosaicking
- Shorter temporal baseline

Application of Mosaicking

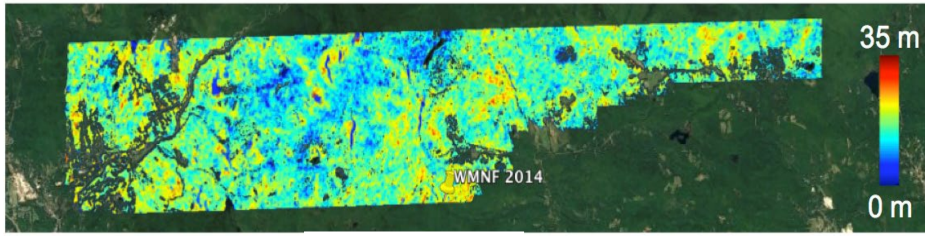


Work with AGS & Mark Ducey

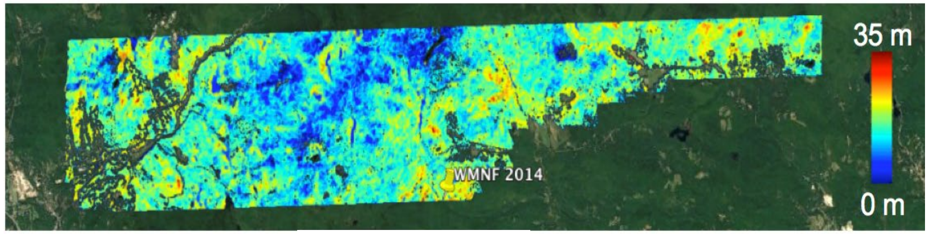
- RH100 lidar data over the Howland Forest and ALOS-1 correlation w/mosaicking used to propagate FSH parameters to lidar validation site, some 300 km away.
- Compare results with single-scene FSH estimation from ALOS-1 and ALOS-2.



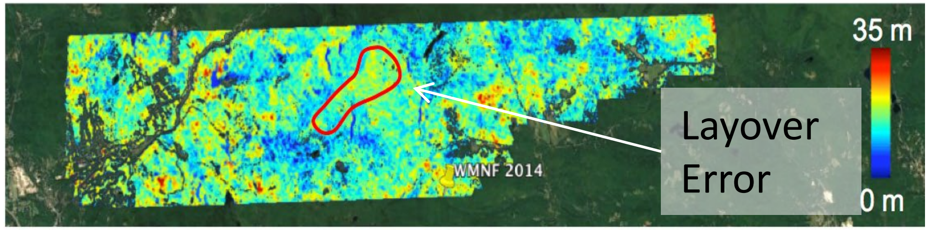
Lidar RH100



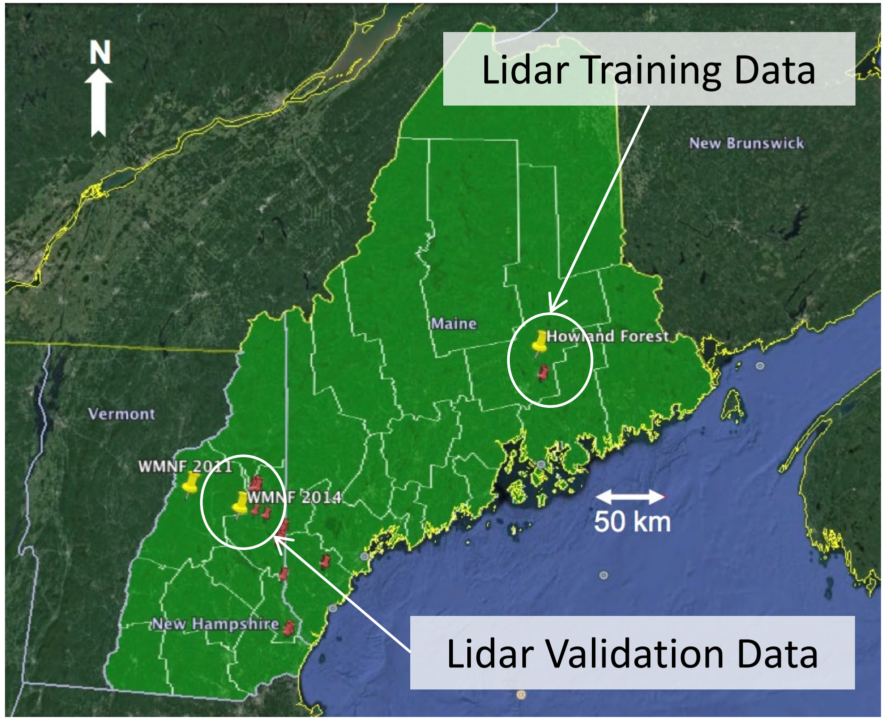
ALOS-1 single



ALOS-1 mosaic

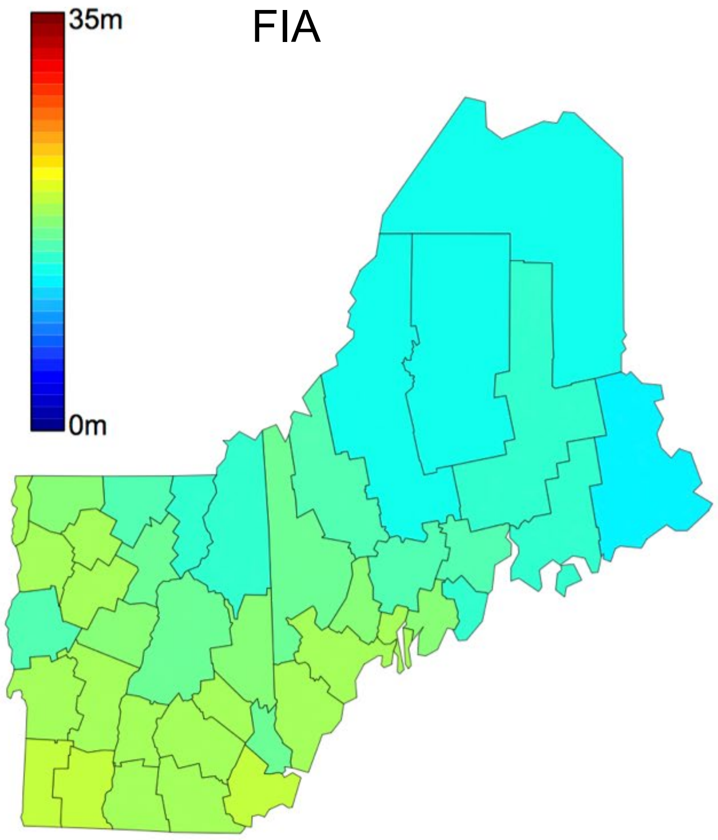


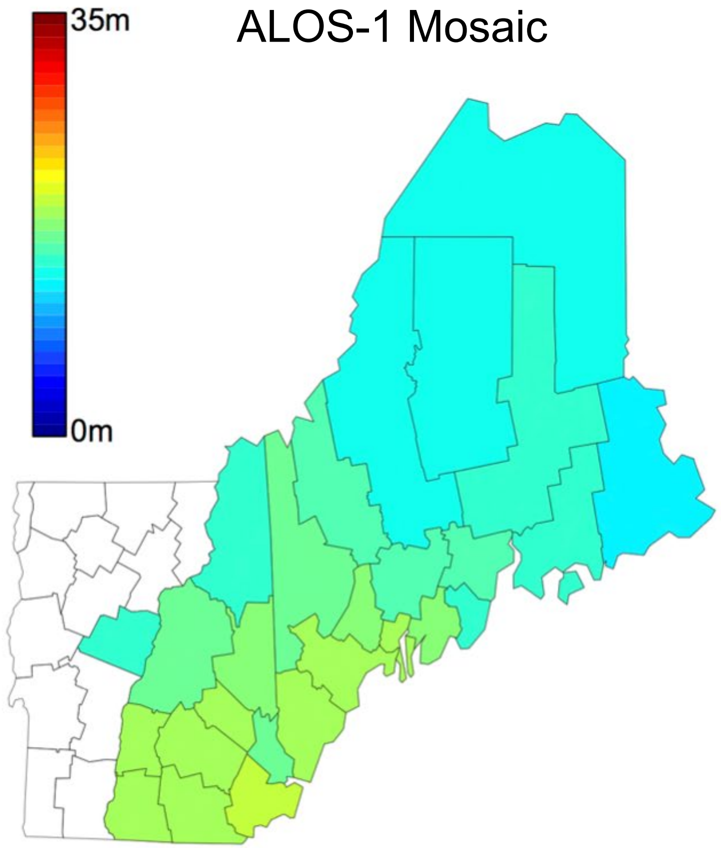
ALOS-2 single

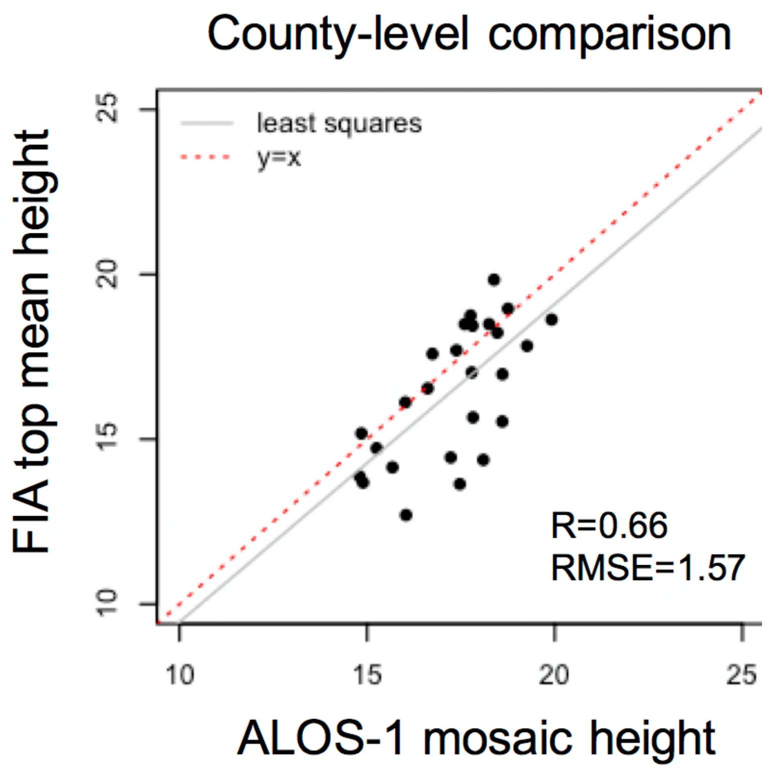


FSH at the County Level

- County-level accuracy (RMSE) is 1.6 m, comparable to FIA accuracy

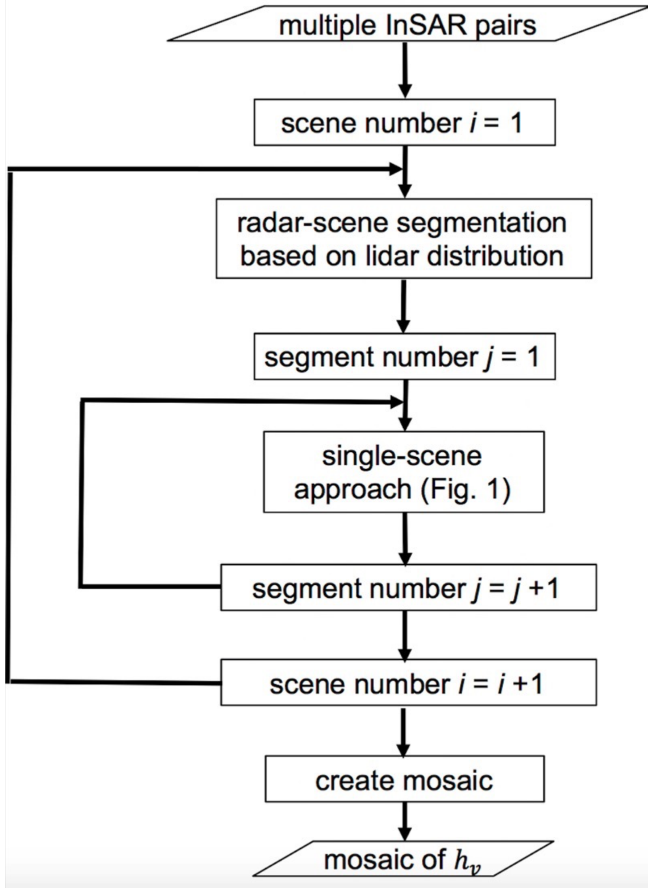






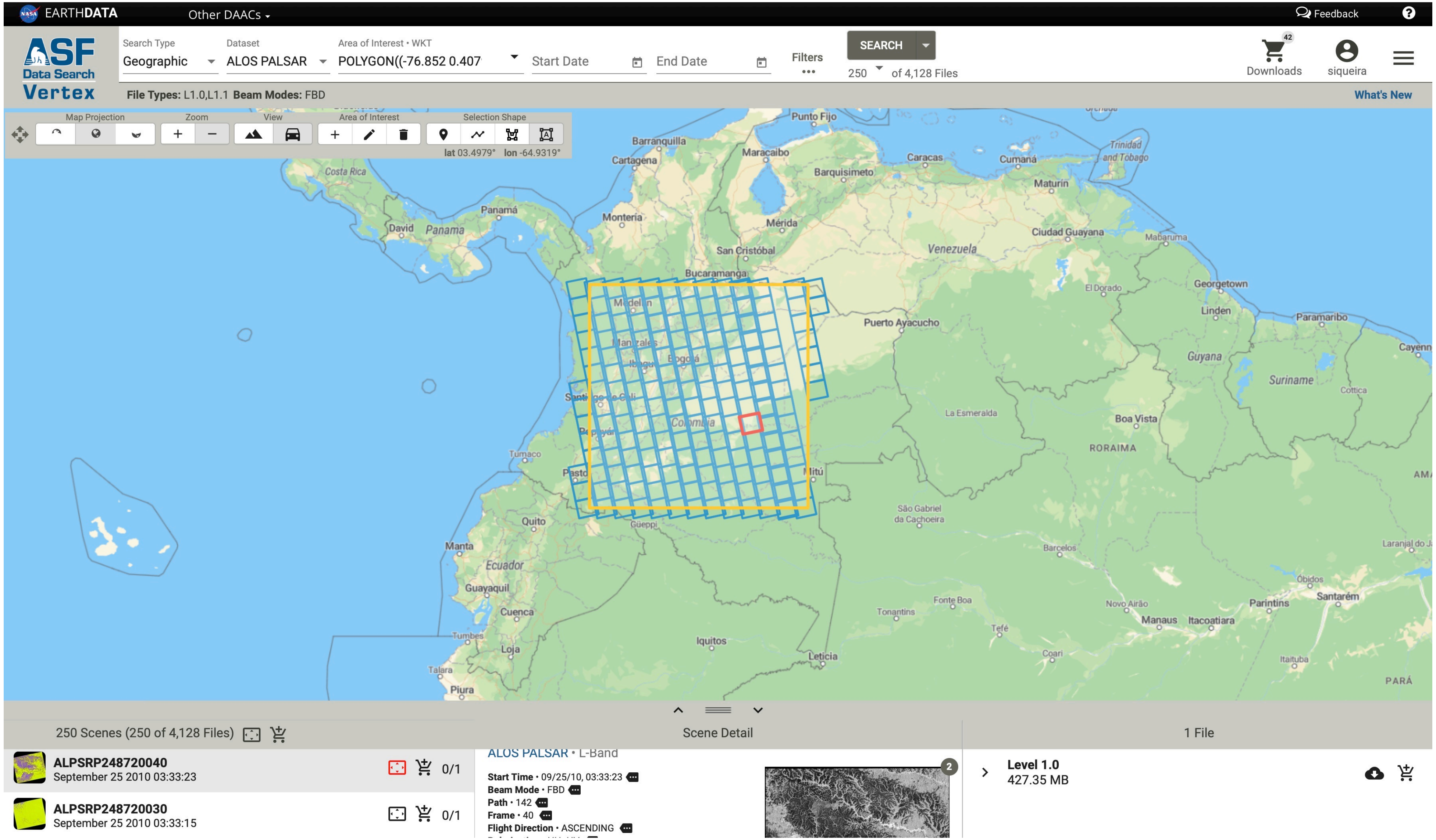
FSH Algorithm

- Algorithm is automated using Python
- Available at github/leiyangleon/FSH



- Lei, Y. and Siqueira, P., 2014. Estimation of forest height using spaceborne repeat-pass L-Band InSAR correlation magnitude over the US State of Maine. Remote Sensing, 6(11), pp.10252-10285.
- Lei, Y. and Siqueira, P., 2015. An automatic mosaicking algorithm for the generation of a large-scale forest height map using spaceborne repeat-pass InSAR correlation magnitude. Remote Sensing, 7(5), pp.5639-5659.

Finding Data



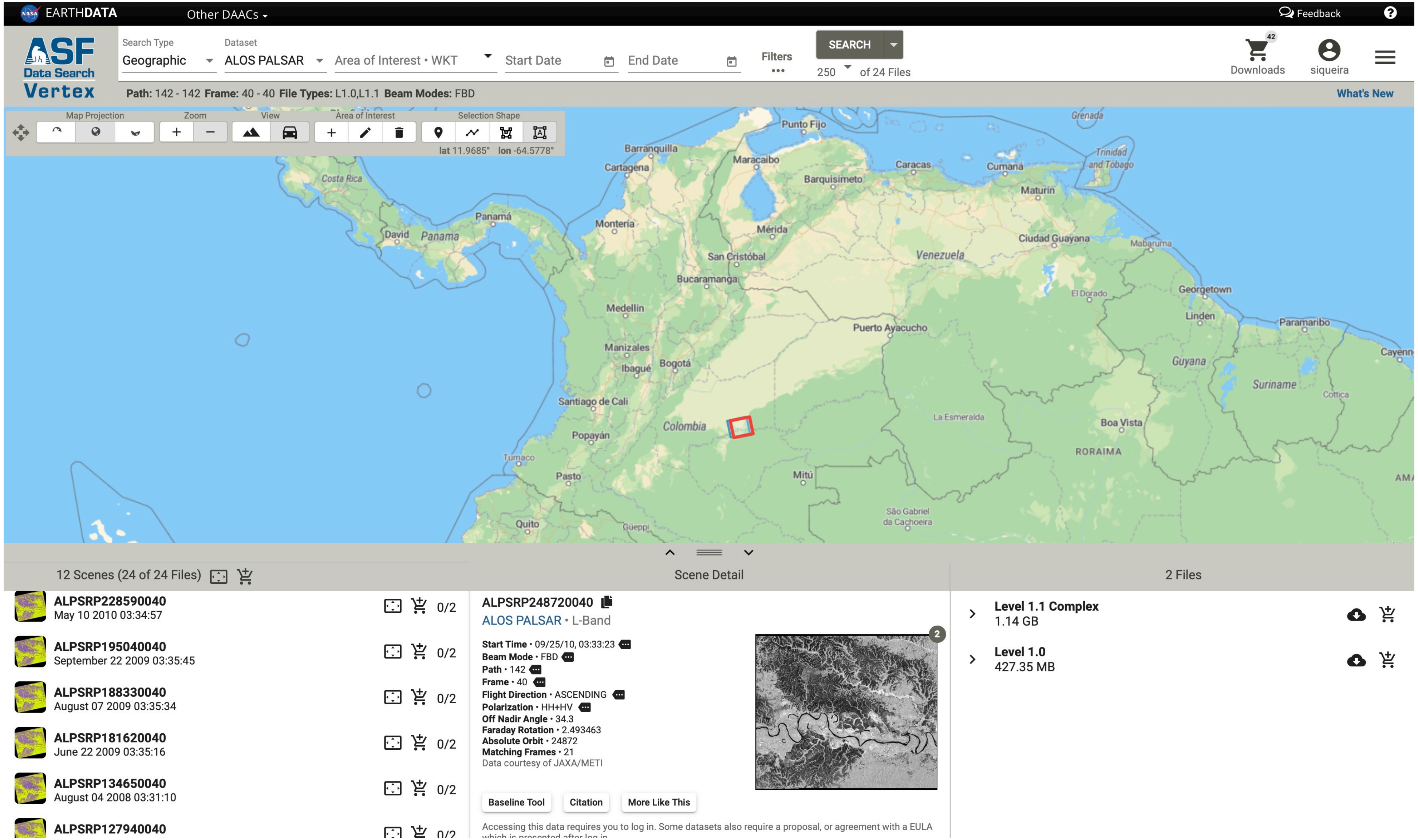
ALOS repeat-pass data can be found on the Alaska Satellite Facility's Vertex Search Engine

(vertex.daac.asf.alaska.edu)

Best scenes to use are ALOS-1 FBD (dual-polarization) that are close together in time

(although ALOS-1 lasted from 2006 – 2011 it is freely available and a good proxy for ALOS-2 and NISAR data)

Finding Data

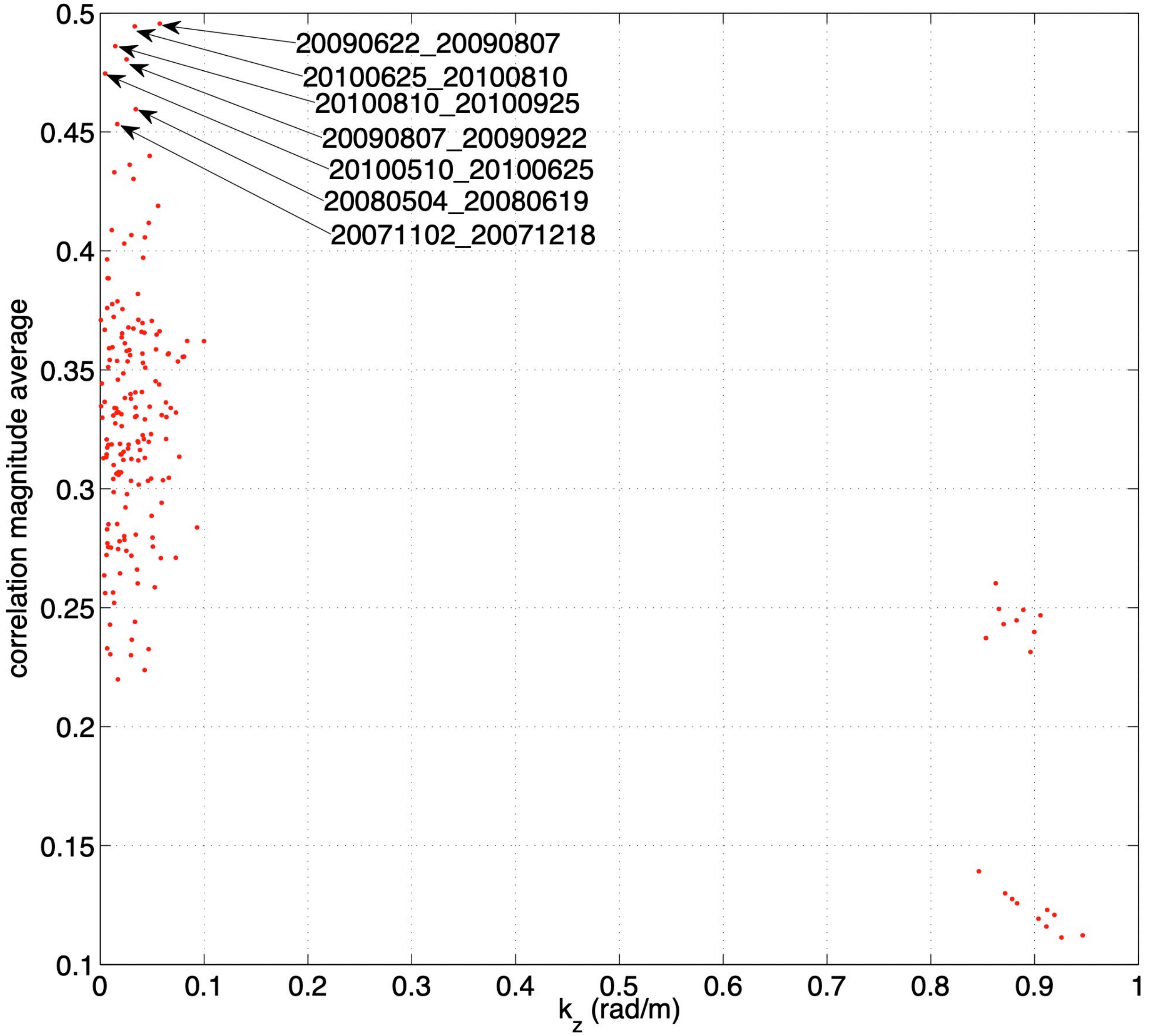


Level 1.0 or Level 1.1 data can be downloaded and further processed into interferograms using

- ISCE
- ROI_PAC
- Gamma
- SARScape
- Other

For this work, ISCE is preferred

Calculation of Scene-Averaged Coherence



Out of 12 chosen files, there are 66 possible combinations (12 pick 2) for making interferograms.

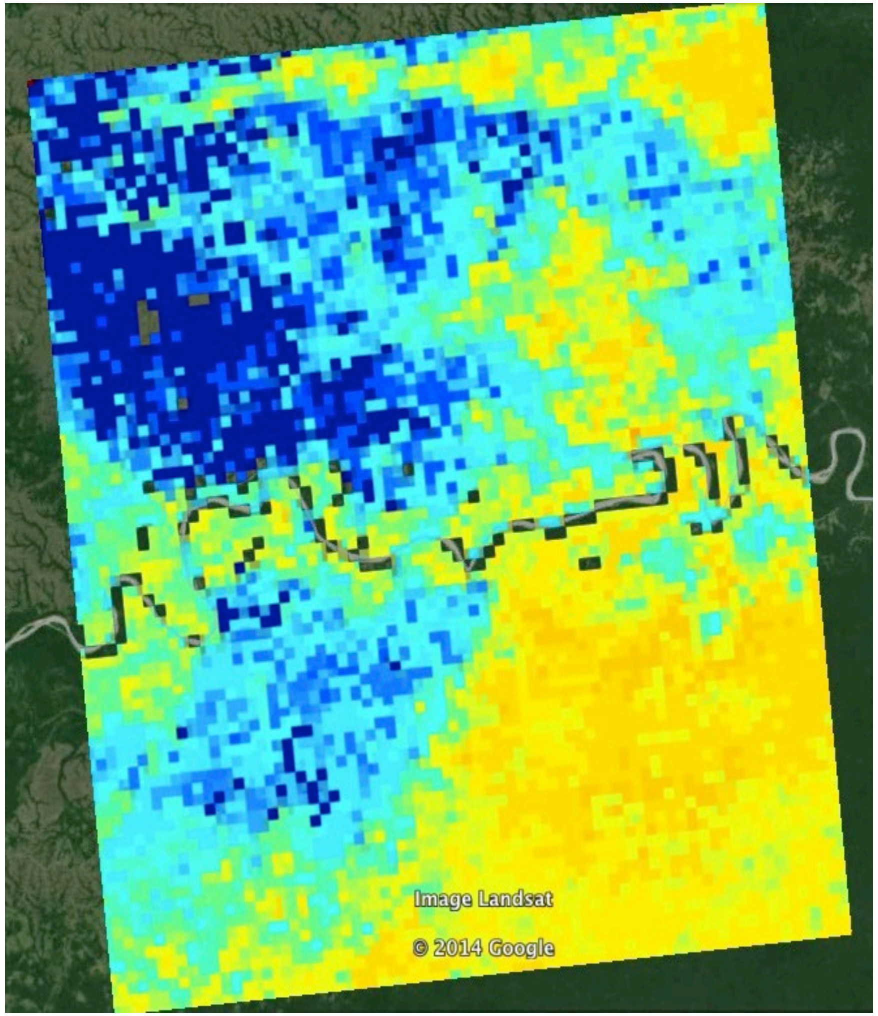
We chose those interferograms that have the largest value of correlation magnitude (coherence).

Shown here are a collection of such interferograms

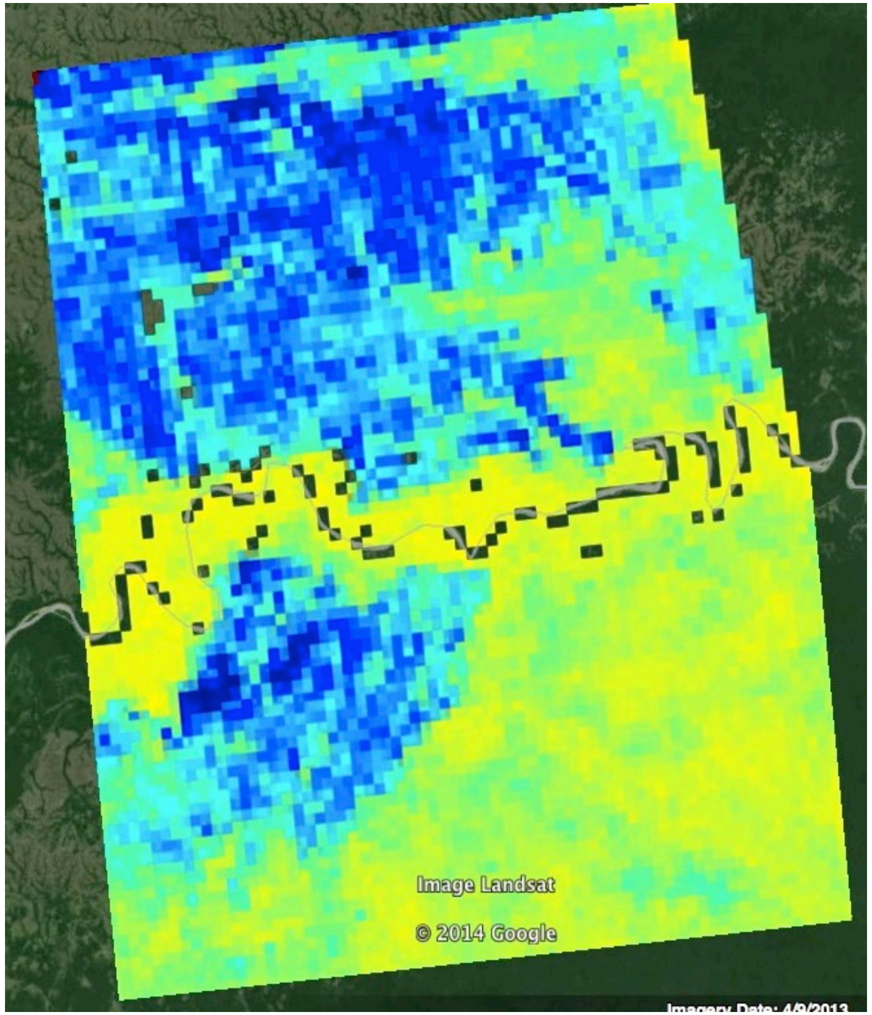
2009: June 22 and August 7
2010: June 25 and August 10
2010: August 10 and October 25
2009: August 7 and September 22
2010: May 10 and June 25
2008: May 4 and June 19
2007: November 2 and December 18

Colombia

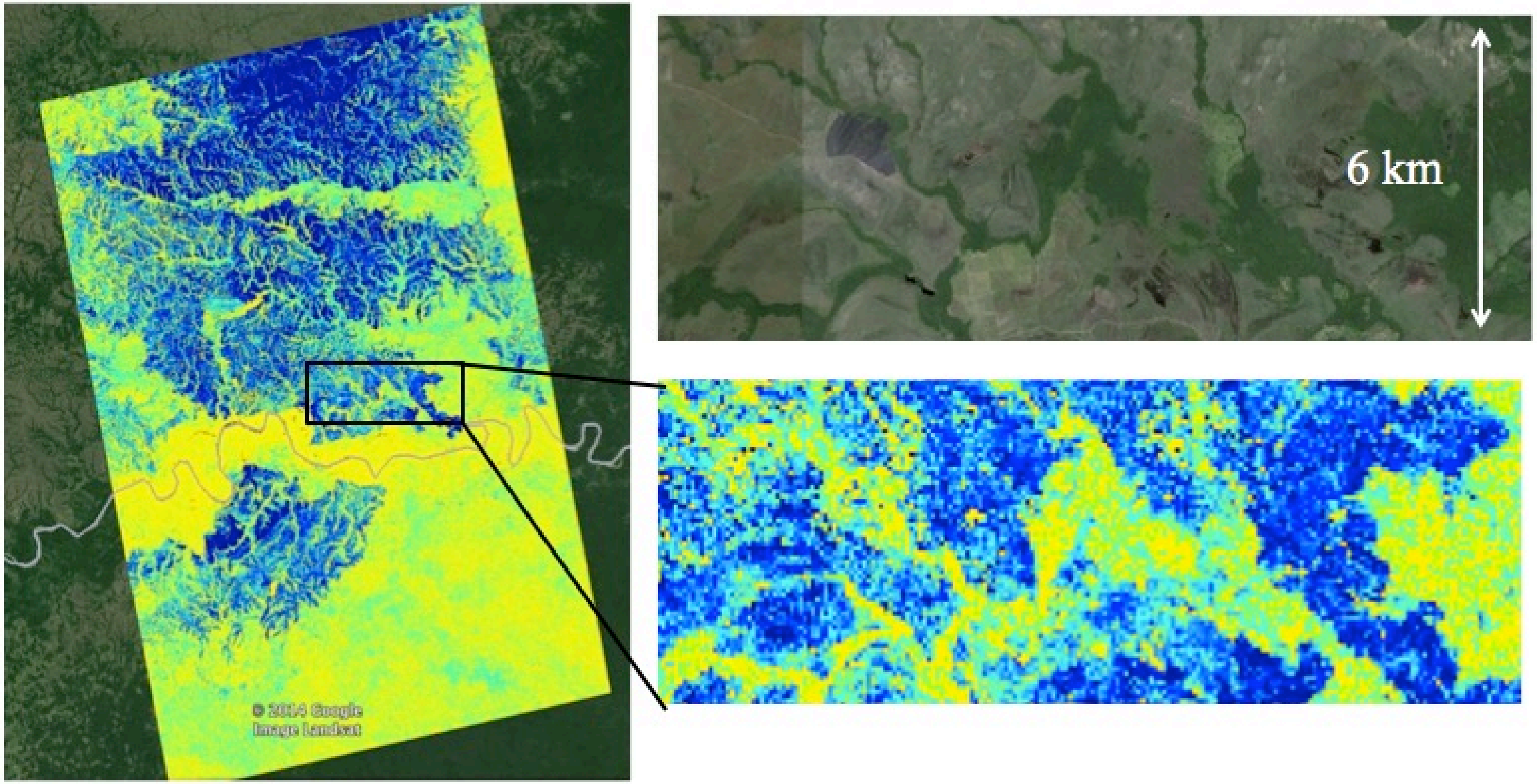
ICESAT



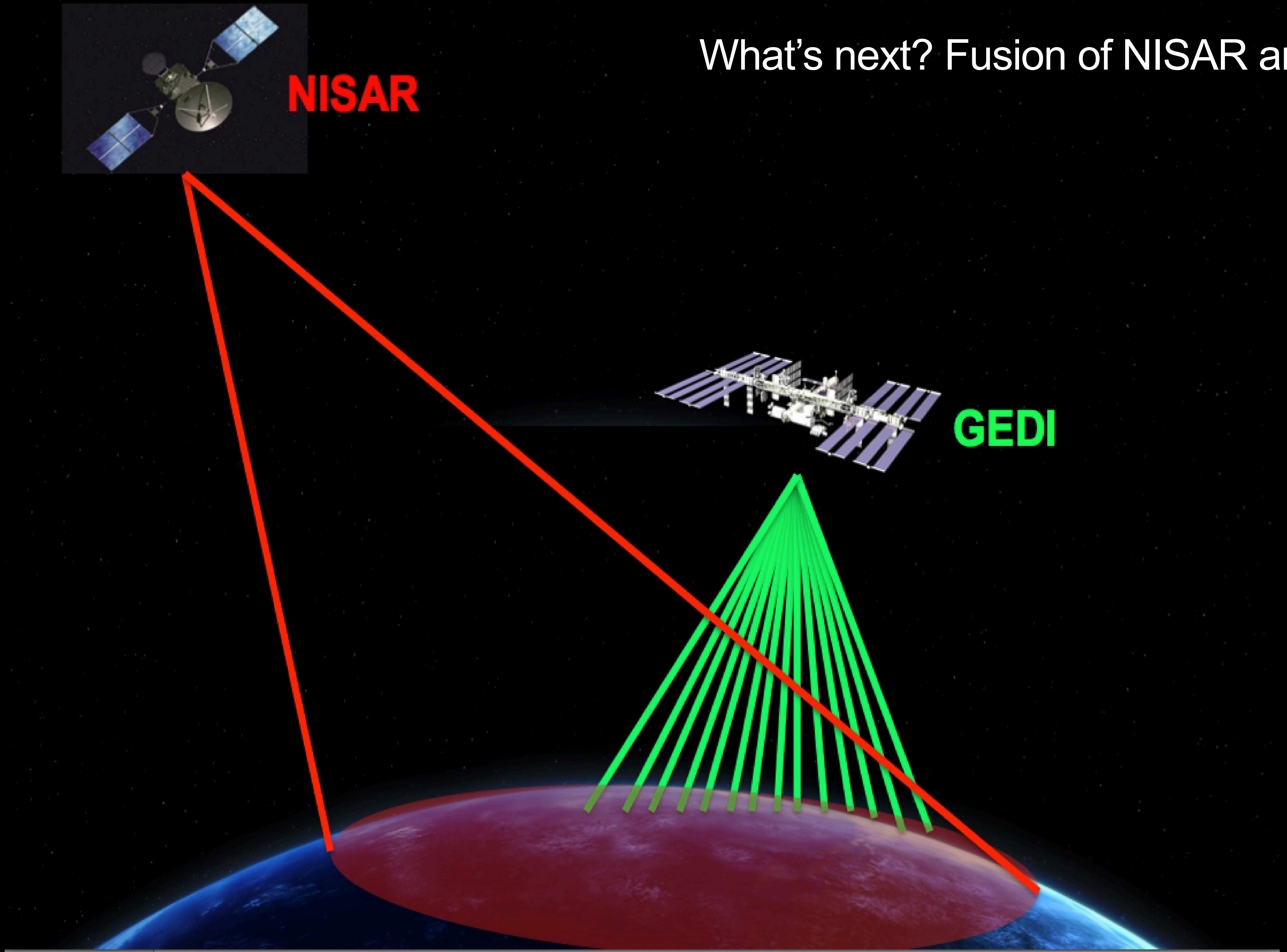
ALOS-1 Correlation



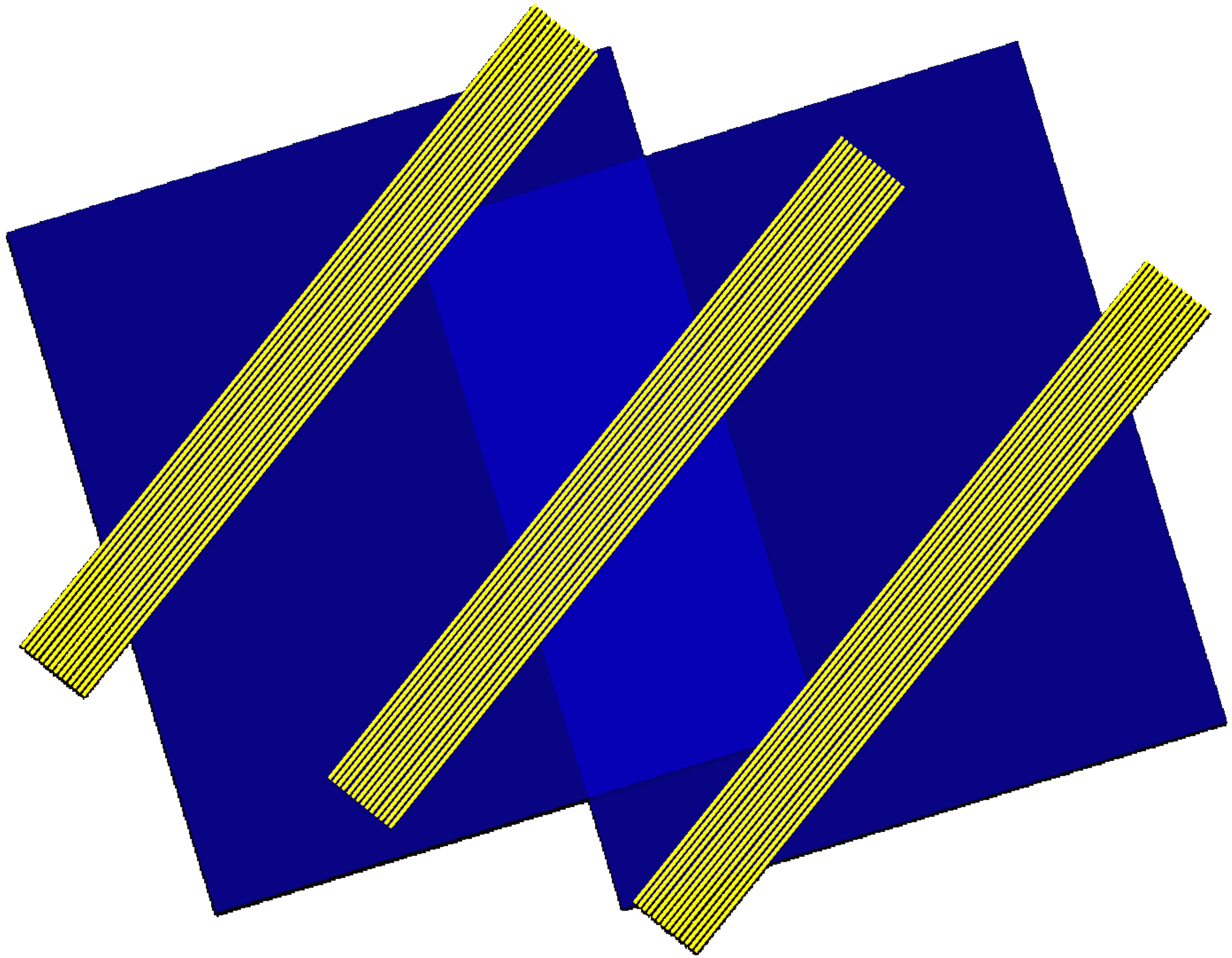
Improved Resolution over ICESAT



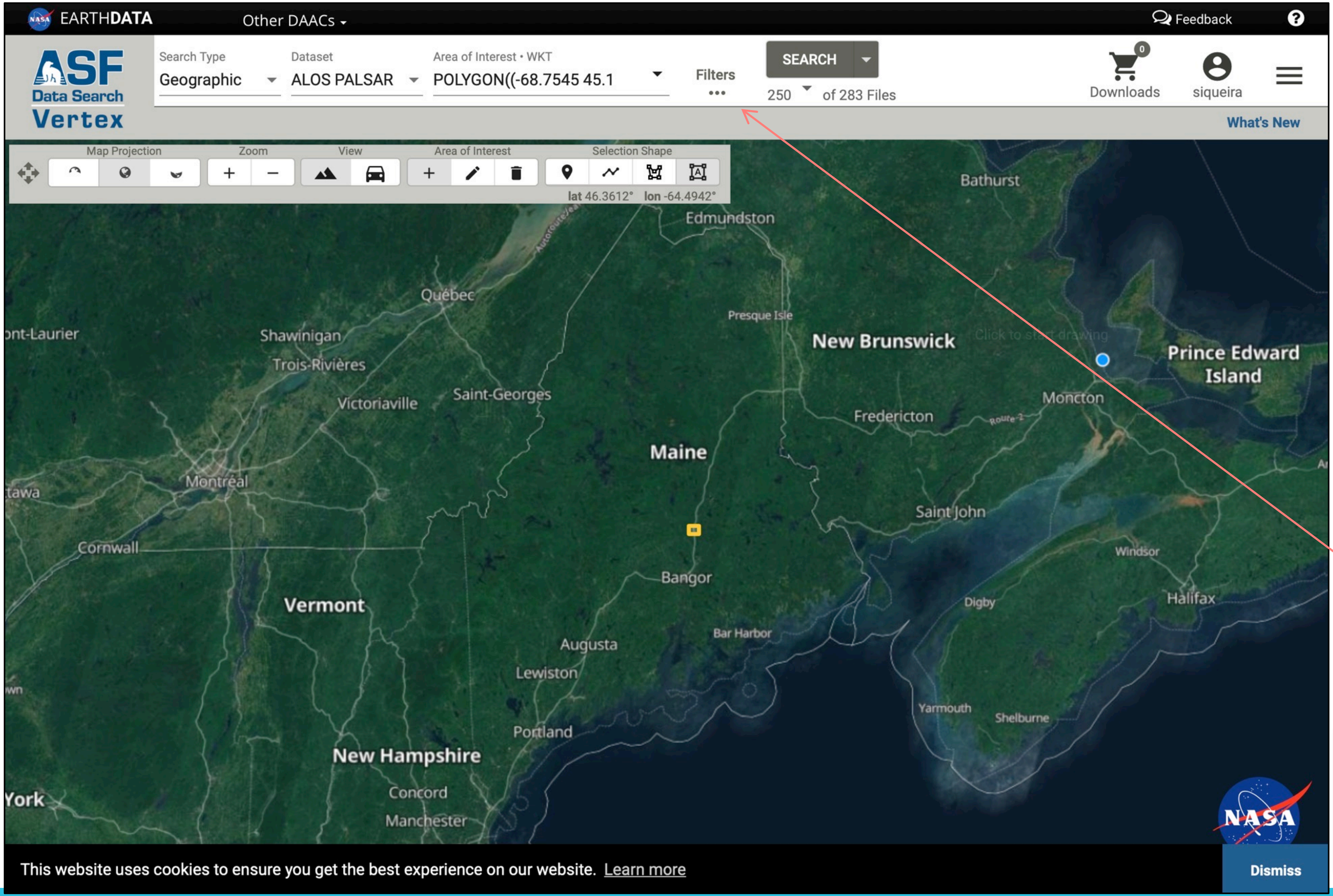
What's next? Fusion of NISAR and GEDI

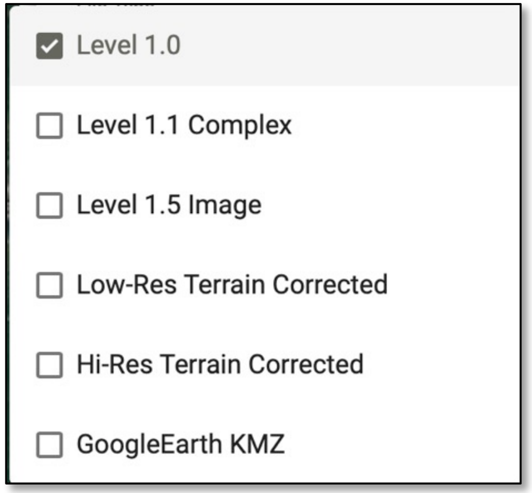


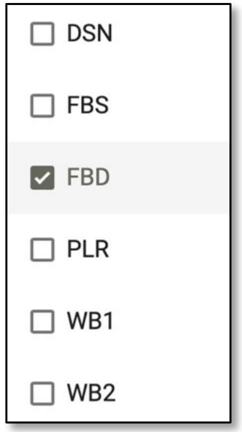
Combining of ALOS/NISAR and GEDI data



Demo
Finding Data

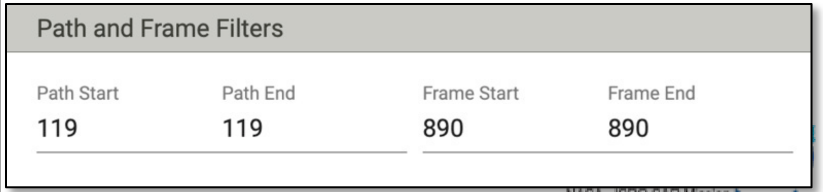


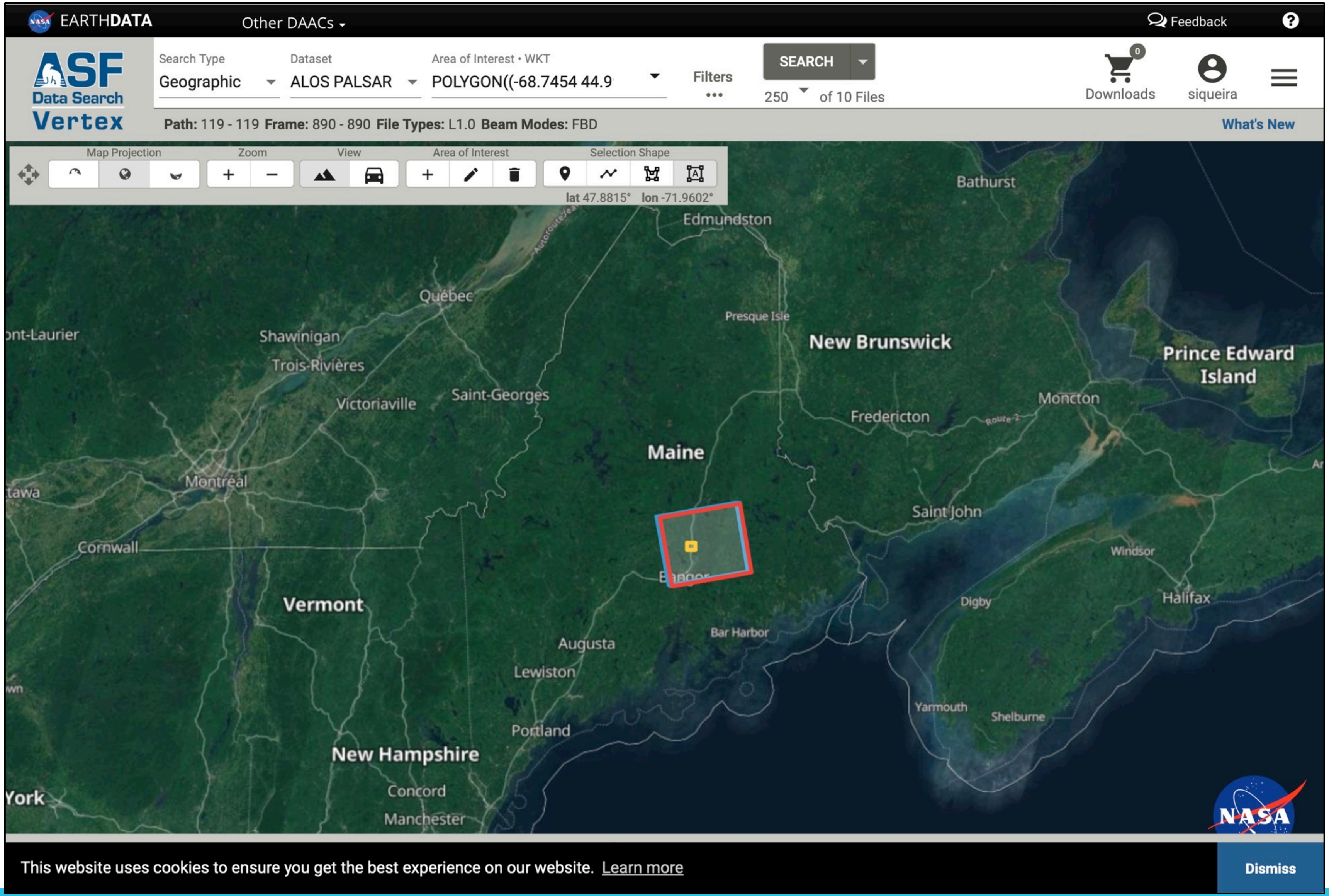




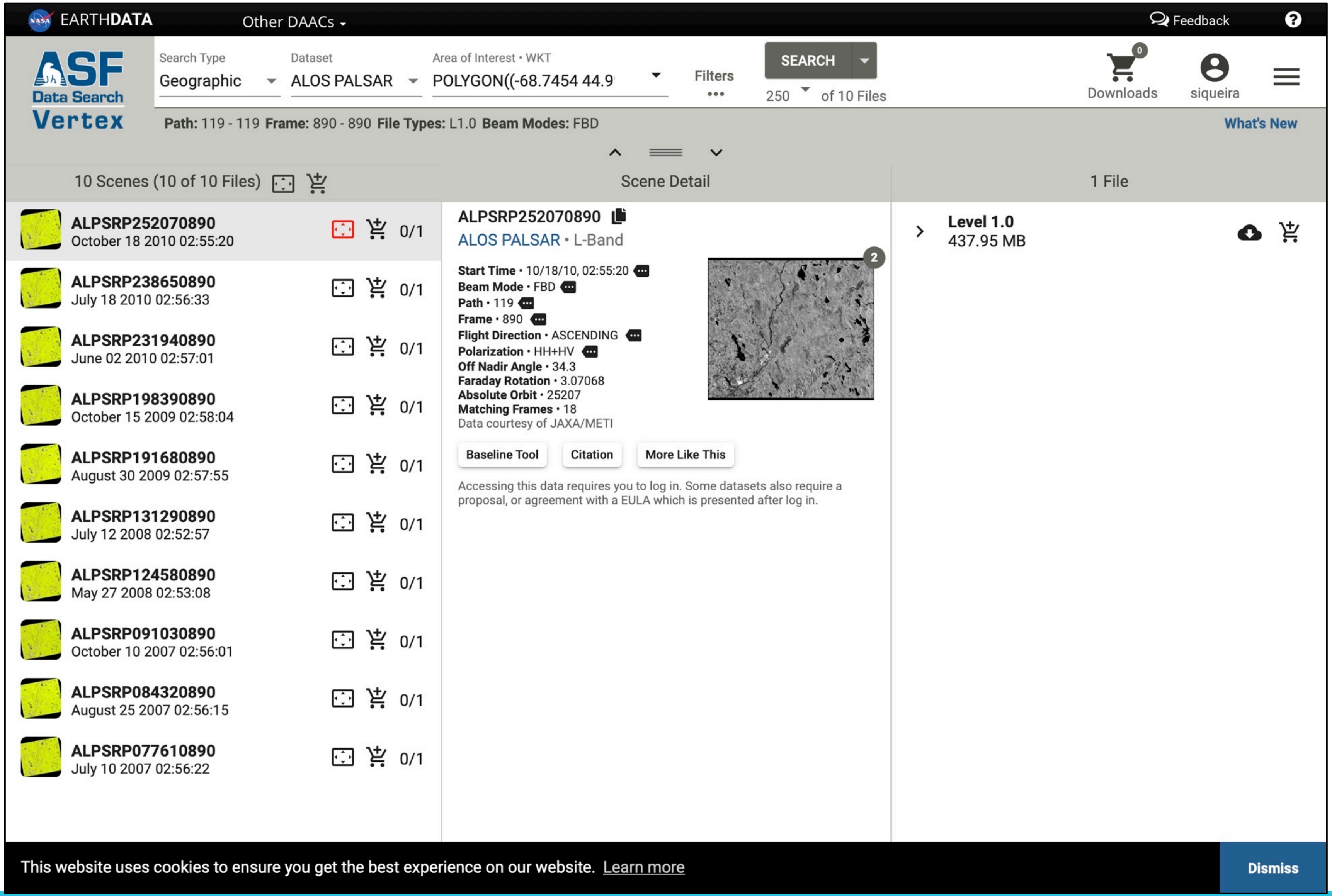
Use the "Filters selection to find data that is Level 1.0 and FBD (dual-polarization).

Additional filtering can be used to select just one scene





An outline for all of the scenes fitting these criteria can be displayed on the map



Or a set of quick-look images displayed, as well as a Shopping Cart that can be used to collect and download these files.

Note that the size of the files can be quite large (437.95 MB here).

If there are 10 of these files, then that is 4.4 GB.

Demo ISCE2

- The basic input for the FSH algorithm is the correlation magnitude derived from a repeat-pass interferogram.
- Using ISCE & ROI_PAC, this is called "`topophase.cor.geo`"
- To download and install ISCE, go to the website: https://github.com/isce-framework/isce2

ISCE2

PASSED

This is the Interferometric synthetic aperture radar Scientific Computing Environment (ISCE). Its initial development was funded by NASA's Earth Science Technology Office (ESTO) under the Advanced Information Systems Technology (AIST) 2008 and is currently being funded under the NASA-ISRO SAR (NISAR) project.

THIS IS RESEARCH CODE PROVIDED TO YOU "AS IS" WITH NO WARRANTIES OF CORRECTNESS. USE AT YOUR OWN RISK.

This software is open source under the terms of the the Apache License. Its export classification is 'EAR99 NLR', which entails some restrictions and responsibilities. Please read the accompanying LICENSE.txt and LICENSE-2.0 files.

ISCE is a framework designed for the purpose of processing Interferometric Synthetic Aperture Radar (InSAR) data. The framework aspects of it have been designed as a general software development framework. It may have additional utility in a general sense for building other types of software packages. In its InSAR aspect ISCE supports data from many space-borne satellites and one air-borne platform. We continue to increase the number of sensors supported. At this time the sensors that are supported are the following: ALOS, ALOS2, COSMO_SKYMED, ENVISAT, ERS, KOMPSAT5, RADARSAT1, RADARSAT2, RISAT1, Sentinel1, TERRASARX, and UAVSAR.

Additional materials about ISCE can be found here

https://www.unavco.org/education/professional-development/short-courses/course-materials/insar/2016-insar-isce-giant-course-materials/2016-insar-isce-giant-course-materials.html

- Once you download and install ISCE, you next have to create interferograms
- Start by editing the file **stripmapApp.xml**

```
<stripmapApp>
<component name="stripmapApp">
    <property name="sensor name">ALOS</property>
    <component name="Master">
        <property name="IMAGEFILE">
                /home/jovyan/siqueira_notebooks/ALOS_Colombia_data/ALPSRP242010040-L1.0/IMG-HV-ALPSRP242010040-H1.0__A
        </property>
        <property name="LEADERFILE">
                /home/jovyan/siqueira_notebooks/ALOS_Colombia_data/ALPSRP242010040-L1.0/LED-ALPSRP242010040-H1.0__A
        </property>
        <property name="OUTPUT">20100925</property>
    </component>
    <component name="Slave">
        <property name="IMAGEFILE">
                /home/jovyan/siqueira_notebooks/ALOS_Colombia_data/ALPSRP248720040-L1.0/IMG-HV-ALPSRP248720040-H1.0__A
        </property>
        <property name="LEADERFILE">
                /home/jovyan/siqueira_notebooks/ALOS_Colombia_data/ALPSRP248720040-L1.0/LED-ALPSRP248720040-H1.0__A
        </property>
        <property name="OUTPUT">20100810</property>
    </component>
</component>
</stripmapApp>
```

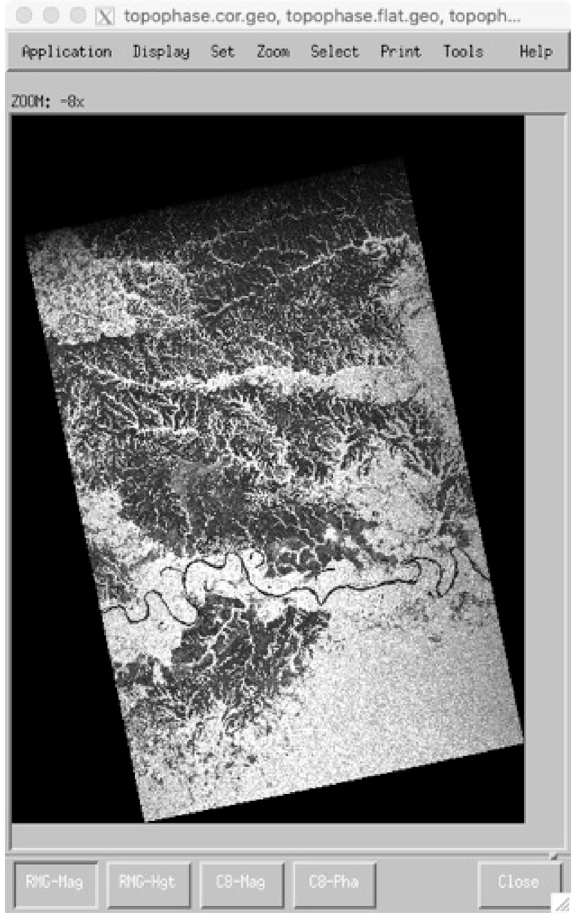
- Execute by typing the command line (or python): **stripmapApp.py stripmapApp.xml**

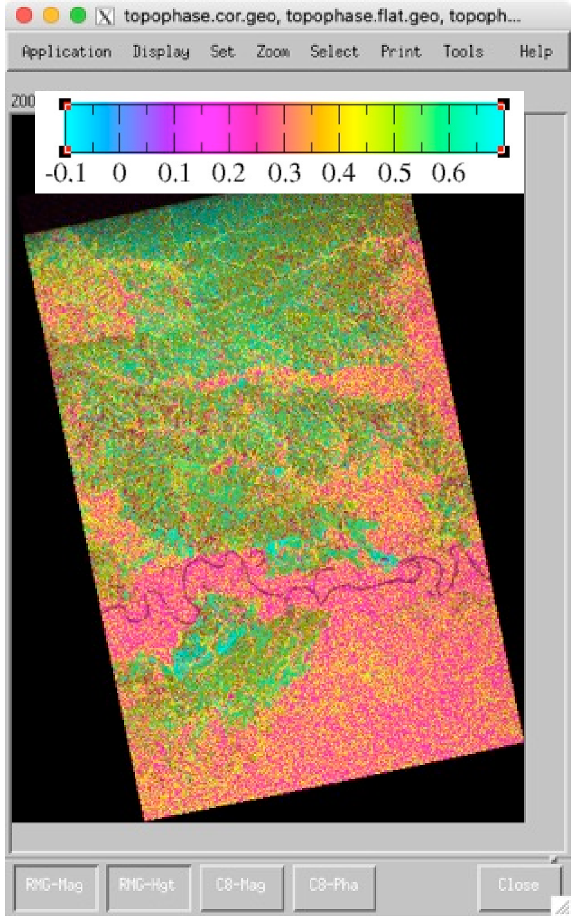
    → This can take a while to execute

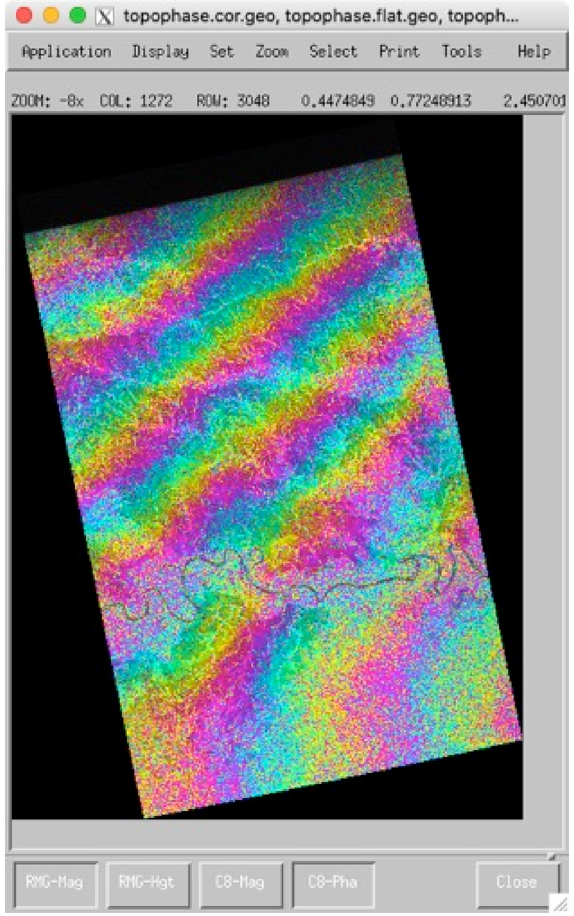
Output data from ISCE2 processing

- Use the ISCE2 tool, **mdx**, to look at files:

```
mdx -s 3026 topophase.cor.geo -rmg topophase.flat.geo -c8
```

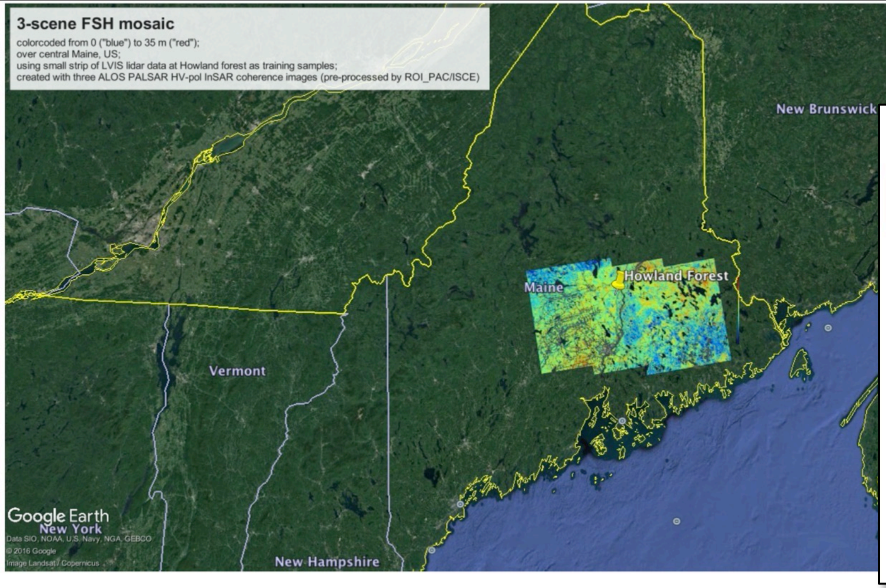






Demo
FSH on GitHub

- Or download a sub-set of these files, and the FSH scripts from GitHub: github.com/leiyangleon/FSH



Branch: dev ▾ | New pull request | Create new file | Upload files | Find file | Clone or download ▾

leiyangleon Update update.md — Latest commit 4cac585 15 hours ago

ISCE_processing_scripts	Add files via upload	2 months ago
scripts	Update mean_wo_nan.py	17 hours ago
scripts_Py3	Update mean_wo_nan.py	16 hours ago
test_example_ISCE_insarApp	Update NOTES_ISCE_insarApp.txt	2 months ago
test_example_ISCE_stripmapApp	Update NOTES_ISCE_stripmapApp.txt	2 months ago
test_example_ROIPAC	Update NOTES_ROIPAC.txt	2 months ago

Forest Stand Height (FSH) Python Scripts

- Windows (Anaconda Prompt)
- Linux
- OSX

This software performs the automated forest height inversion and mosaicking from spaceborne repeat-pass L-band HV-pol InSAR correlation magnitude data (e.g. JAXA's ALOS-1/2, and the future NASA-ISRO's NISAR) that have been pre-processed by JPL's ROI_PAC and/or ISCE programs.

Produced by the University of Massachusetts Microwave Remote Sensing Laboratory.

Yang Lei, (ylei@caltech.edu, leiyangfrancis@gmail.com), Paul Siqueira (siqueira@umass.edu).

Here you will find the folders: • `scripts`, • **scripts_Py3** and • `test_example_ISCE_stripmapApp`

- Within the data directory, test_example_ISCE_stripmapApp, type the following command (also given in the GitHub page)

```
python3 /Users/siqueira/Downloads/FSH-Master/scripts_Py3/forest_stand_height.py \
        3 2 2 5 "linkfile.txt" \
        "flagfile.txt" \
        "Howland_LVIS_NaN.tif" \
        "Maine_NLCD2011_nonwildland.tif" \
        "/Users/siqueira/Downloads/test_example_ISCE_stripmapApp/" \
        "gif json kml mat tif" --flag_proc=1
```

(or you can edit a file, `test_script.sh`, and execute it as needed)

There are several files here that you can look at

- `Linkfile.txt` (a simple file indicating which scenes are linked to one another)
- `Flagfile.txt` (a text file that provides index numbers, scene names and directory names
- `Howland_LVIS_NAN.tif` (geotiff of measured forest heights from lidar, ground validation, GEDI, or other)
- `Main_NLCD2011_nonwildland.tif` (a simple classification mask to remove water bodies and cities)

Linkfile.txt

```
2 1
2 3
```

Flagfile.txt

```
001 890_120_20070727_HV_20070911_HV 070727 070911 890 120 HV
002 890_119_20070710_HV_20071010_HV 070710 071010 890 119 HV
003 890_118_20070808_HV_20070923_HV 070808 070923 890 118 HV
```

```
[boreal 233 ] test_example_ISCE_stripmapApp : test_script.sh

Namespace(N_pairwise=20, N_self=10, Nd_pairwise=20, Nd_self=10, bin_size=100, edges=2, …

19:36:00
auto_tree_height_many finished at 19:36:09
1 edge file(s) created at 19:42:07
2 edge file(s) created at 19:48:44
intermediate() complete - overlap areas calculated at 19:51:23

        .... some intermediate updates ....

auto_mosaicking_new finished at 19:53:13
write_deltaSC completed at 19:53:13
all tree height map files written at 20:02:19
```

Demo
FSH output files

- File outputs in many standard formats

    kml   geotiff   json   matlab   gif

- Files can be found in data directories

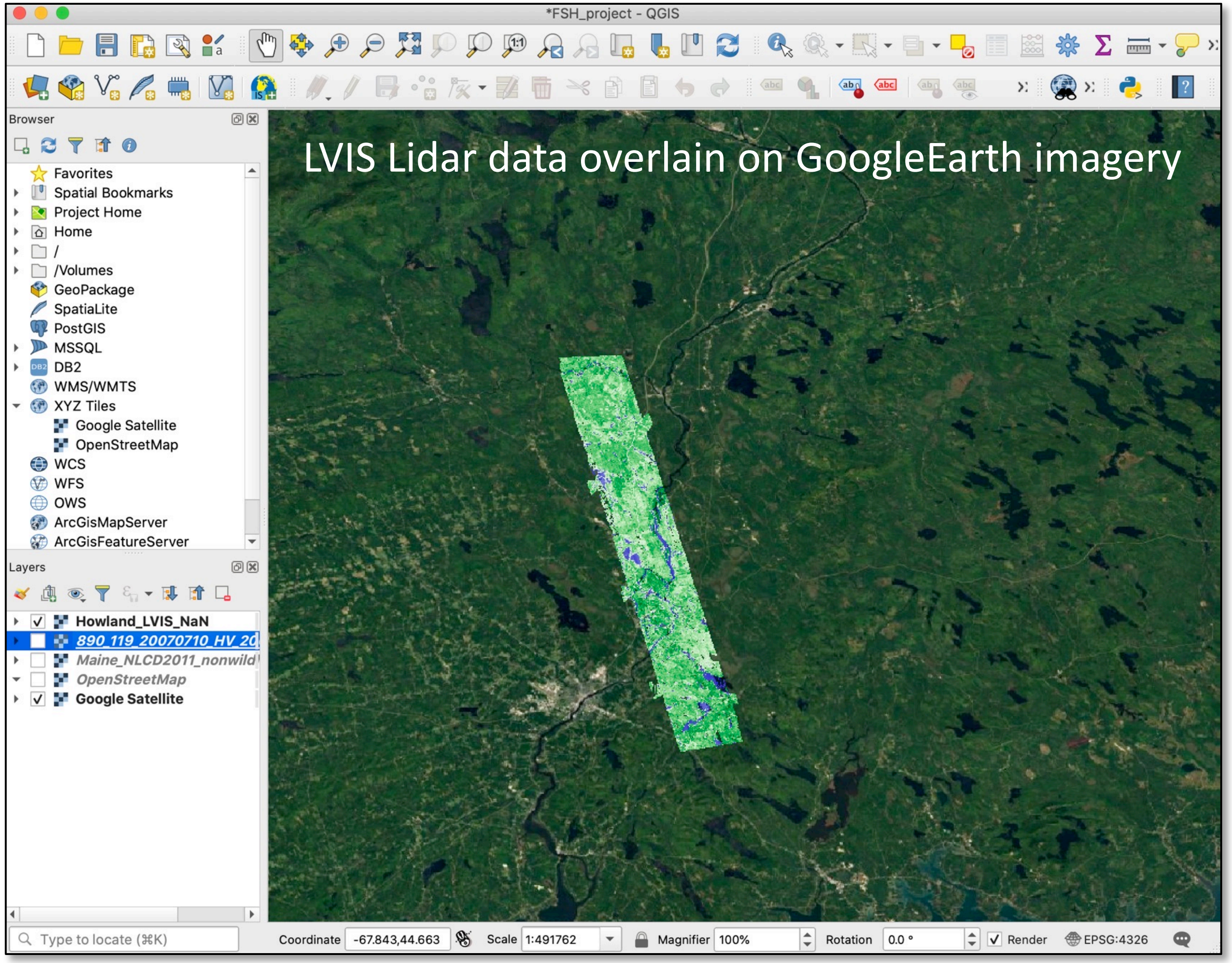
```
[boreal 242 ] test_example_ISCE_stripmapApp : ls f890_o119
890_119_20070710_HV_20071010_HV_fsh.json       890_119_20070710_HV_20071010_HV_fsh_255.kml
890_119_20070710_HV_20071010_HV_fsh.mat        890_119_20070710_HV_20071010_HV_fsh_255.tif     int_070710_071010
890_119_20070710_HV_20071010_HV_fsh.tif        890_119_20070710_HV_20071010_HV_geo.txt
890_119_20070710_HV_20071010_HV_fsh_255.gif    890_119_20070710_HV_20071010_HV_orig.mat

[boreal 243 ] test_example_ISCE_stripmapApp : more f890_o119/890_119_20070710_HV_20071010_HV_geo.txt
width: 4124
nlines: 4106
corner_lat: 45.739722
corner_lon: -69.167500
post_lat: -0.000278
post_lon: 0.000278
```

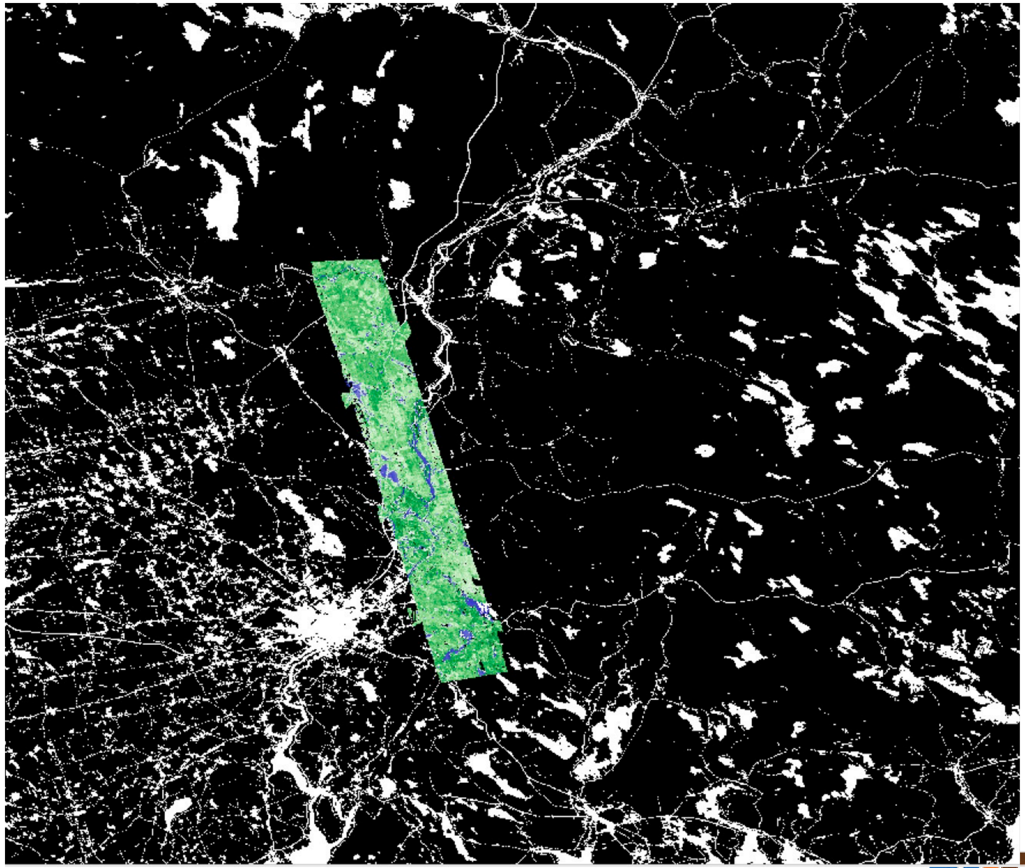
- Display results and input files in QGIS

Demo
QGIS files

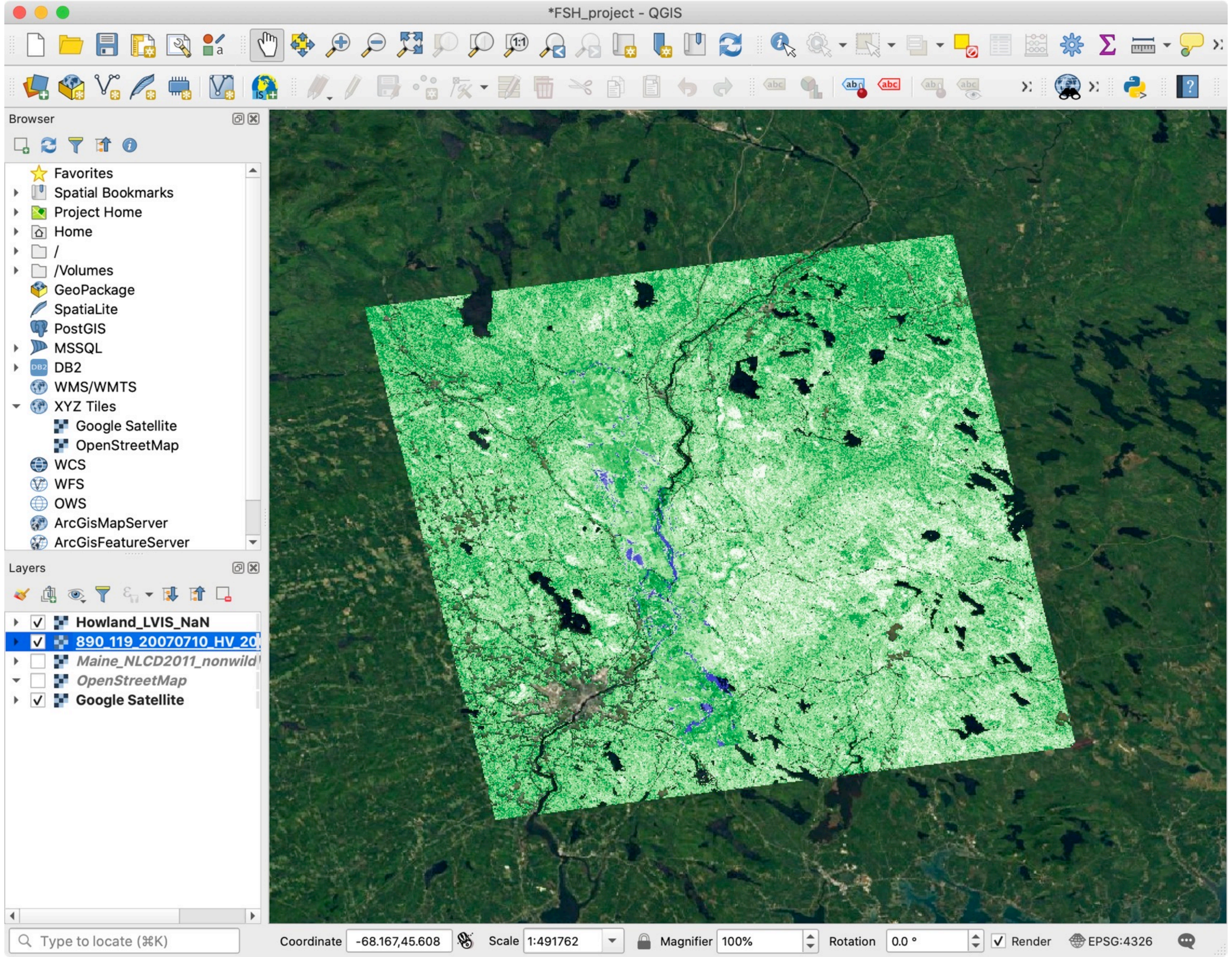
- An illustration of some of the intermediate files shown on QGIS

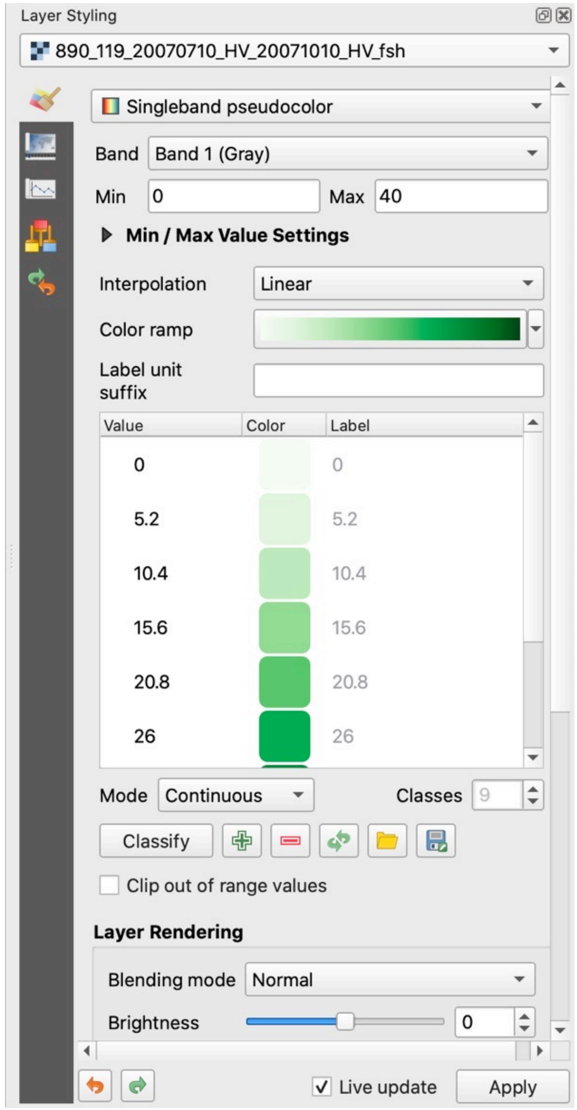


LVIS Lidar data overlain on NLCD-derived forest mask



Demo
QGIS files





Papers

Generation of large-scale moderate-resolution forest height mosaic with spaceborne repeat-pass SAR interferometry and lidar

Yang Lei, Paul Siqueira *Member, IEEE,* Nathan Torbick, Mark Ducey, Diya Chowdhury, and William Salas

2424 IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 56, NO. 4, APRIL 2018

Detection of Forest Disturbance With Spaceborne Repeat-Pass SAR Interferometry

Yang Lei, Richard Lucas, *Member, IEEE,* Paul Siqueira, *Member, IEEE,*
Michael Schmidt, and Robert Treuhaft

Remote Sens. **2014**, *6*, 10252-10285; doi:10.3390/rs61110252
OPEN ACCESS
remote sensing
ISSN 2072-4292
www.mdpi.com/journal/remotesensing

Article

Estimation of Forest Height Using Spaceborne Repeat-Pass L-Band InSAR Correlation Magnitude over the US State of Maine

Yang Lei and Paul Siqueira *

WAVES IN RANDOM AND COMPLEX MEDIA, 2017
VOL. 27, NO. 1, 129–152
http://dx.doi.org/10.1080/17455030.2016.1209594
Taylor & Francis
Taylor & Francis Group

A physical scattering model of repeat-pass InSAR correlation for vegetation

Yang Lei[a], Paul Siqueira[a] and Robert Treuhaft[b]

Remote Sens. **2015**, *7*, 5639-5659; doi:10.3390/rs70505639
OPEN ACCESS
remote sensing
ISSN 2072-4292
www.mdpi.com/journal/remotesensing

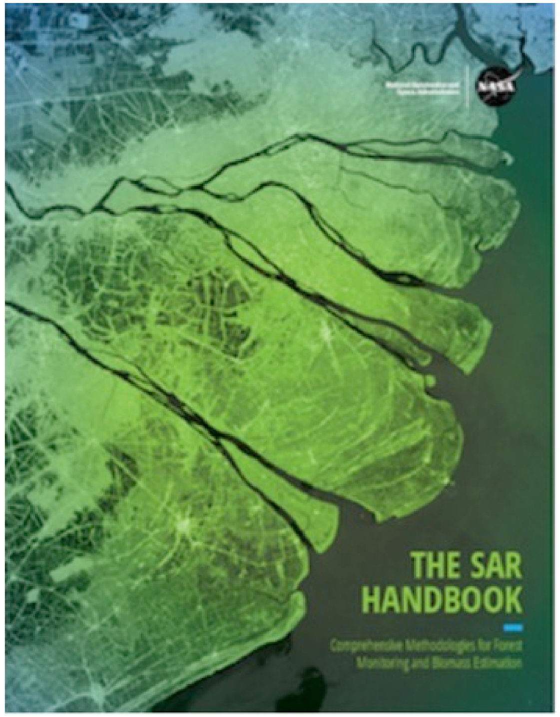
Article

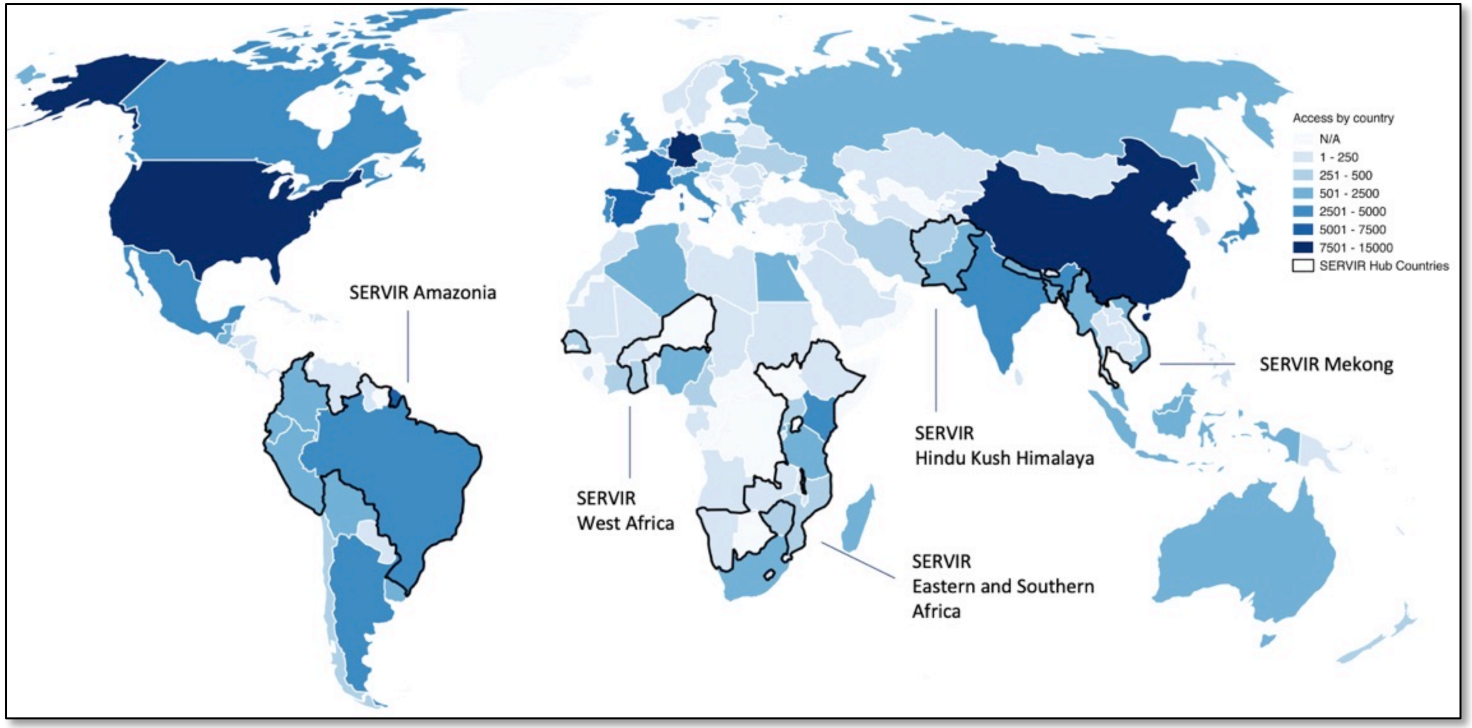
An Automatic Mosaicking Algorithm for the Generation of a Large-Scale Forest Height Map Using Spaceborne Repeat-Pass InSAR Correlation Magnitude

Yang Lei and Paul Siqueira *

The SAR Handbook

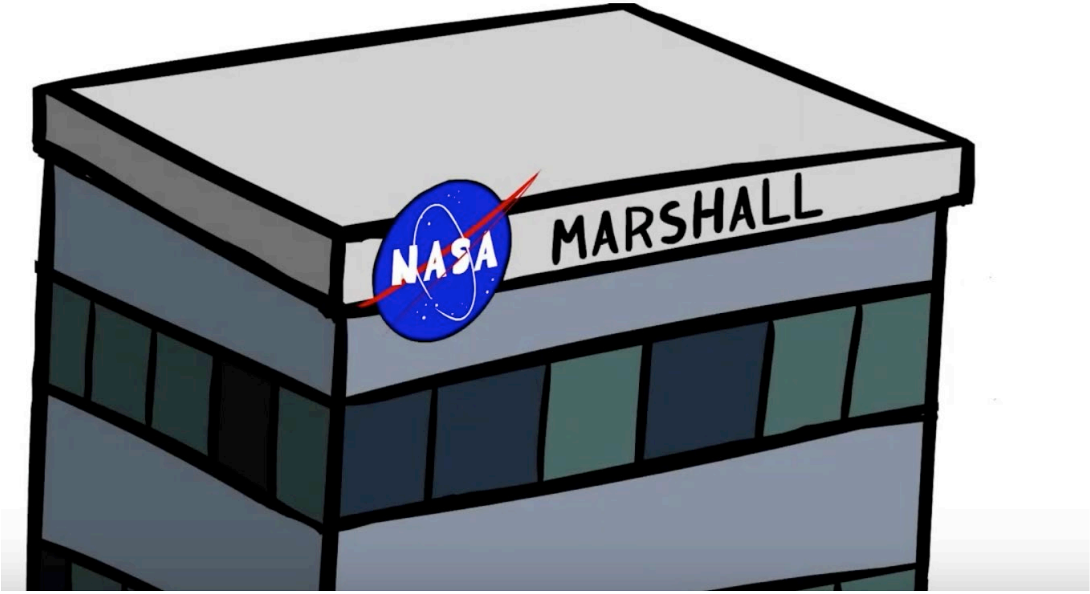
https://servirglobal.net/Global/Articles/Article/2674/sar-handbook-comprehensive-methodologies-for-forest-monitoring-and-biomass-estimation

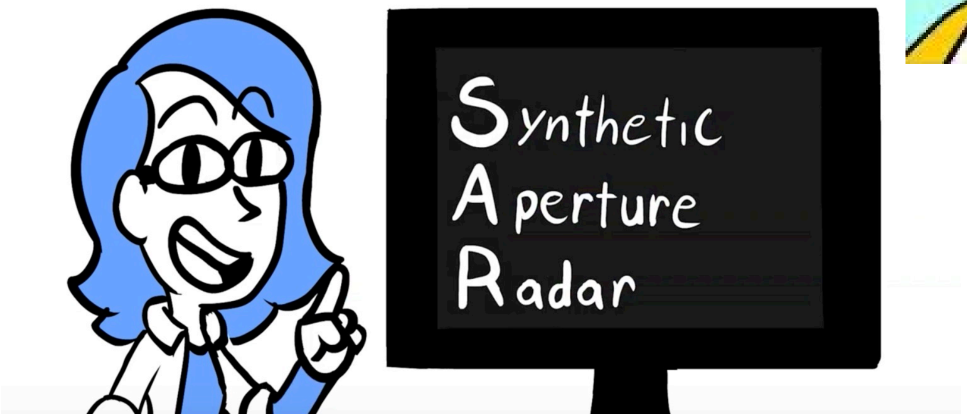




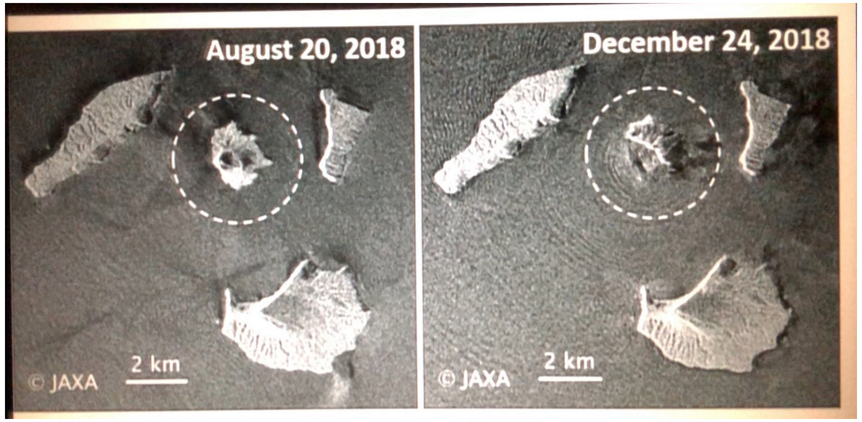
Top countries by Handbook materials accessed:	
1. U.S.A.	14,280
2. Germany	9,615
3. China	8,543
4. Spain	6,142
5. France	5,175

- You know you have arrived when you have a youtube video





Screenshots from JAL



NASA - ISRO SAR Mission

Summary

- We talked about different levels of SAR data usage
- FSH requires Interferometric SAR, which can be challenging
- FSH works best with L-band HV-data collected with small spatial baseline
- Data can be found on NASA's Alaska Satellite Facility's DAAC
- Results shown for the US State of Maine
  - Height estimation RMSE < 4 m over 3-6 ha stands (~250 m)
  - Large-scale mosaic (11.6 million ha) created using small piece of LiDAR training samples (44,000 ha)
- Estimation error further reduced by 1) mosaicking, 2) small repeat cycle, and 3) using a large amount of LiDAR samples.
- Need to be aware of weather effects on interferometric decorrelation signature
- ISCE2 & FSH software, along with FSH demo data can be downloaded from GitHub
- We went through a "demo" for how to process data into estimates of Forest Stand Height

Questions

- Please enter your questions into the chat box
- We will post the questions and answers to the training website following the conclusion of the course

Obrigado & Felicidades!