NEXT-GENERATION WETLAND MAPPING AND MONITORING WITH NISAR

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NAWM Wetland Mapping
Consoritum Webinars
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Presentation Outline

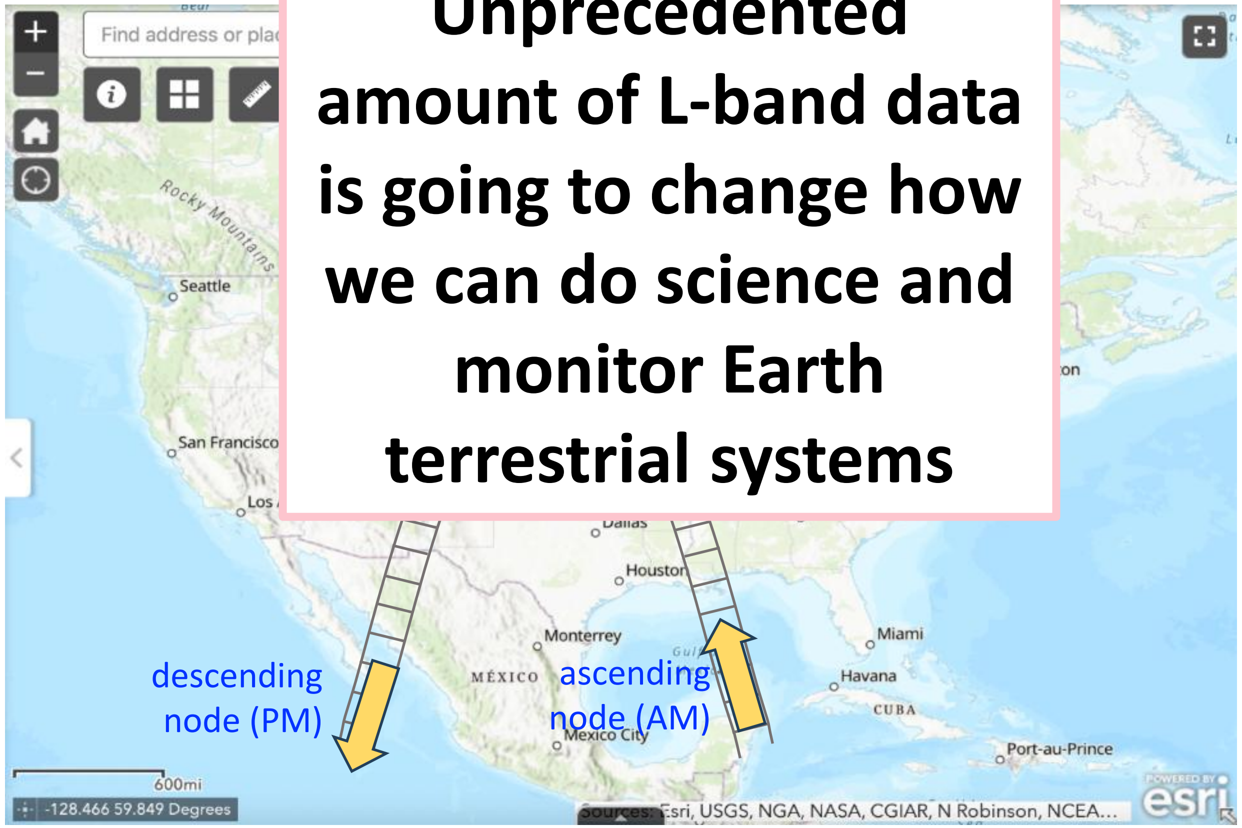
- NISAR specs and data collection plan
- Fundamentals: SAR scattering from wetlands
  - Double bounce scattering from flooded vegetation
  - L-band vs. C-band (Sentinel-1)
- What do first NISAR images look like? What processing still is in the works? – RFI, calibration
- Recent research in prep for NISAR using Airborne NASA-ISRO ASAR
  - Great Lakes wetlands focus
  - Review of selected results
- NISAR take home messages, tools and training

NISAR
A New Mission for Ecosystems Science

NISAR Launch

- NISAR is a joint NASA-ISRO (Indian Space Research Organization) Two-frequency (L- and S-band) Synthetic Aperture Radar (SAR) mission that was launched into space on July 30, 2025

Unprecedented amount of L-band data is going to change how we can do science and monitor Earth terrestrial systems



- L-Band SAR (24 cm wavelength) will cover all land surfaces, globally, two times (ascending and descending) every 12 days
- resolution of 10 m/20 m over a 240 km swath at ~6 am/6 pm local time
- Data are freely available through the Alaska Satellite Facility (www.asf.edu) and Earthdata access

Siqueira – NISAR Ecosystems Lead

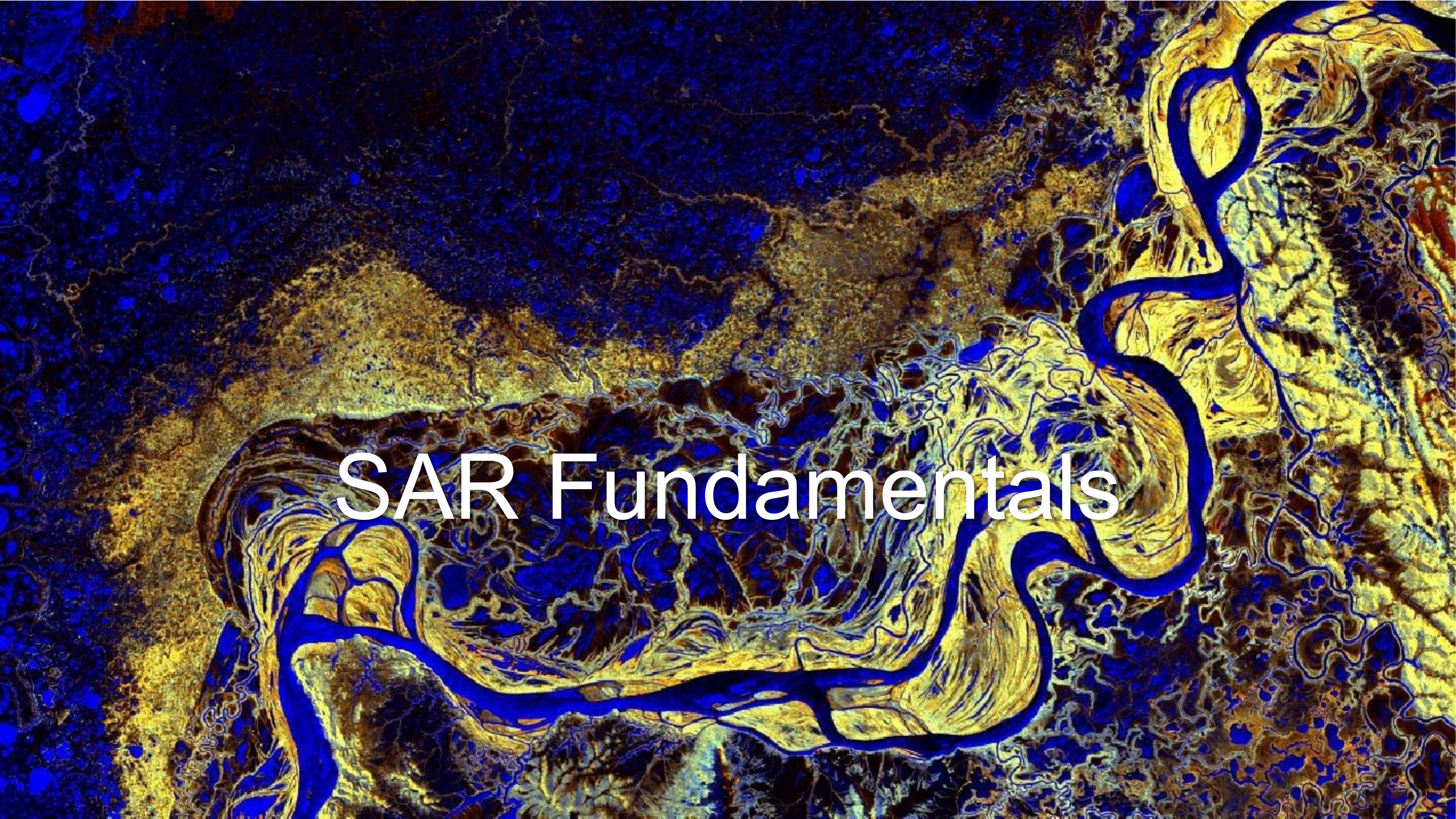
NISAR Status

NISAR Launch 7/30/2025
Satish Dhawan Space Centre, India

- Launched July 30, 2025
- Began acquiring global Reference Observation Plan in November 2025
- Currently in the science validation phase (ends Summer 2026)
- Feb. 2026 - 1st major release of L-band data from ~Nov. 2025 – Jan. 2026
  - Uncalibrated products are being produced & ~100,000 have been released through NASA Earthdata and the Alaska Satellite Facility DAAC
- Current plans for future & regular L-band SAR calibrated product release:
  - Calibrated data products release starting around July 2026
    - Forward processing at first – products from newly acquired data generated and delivered within ~72 hours
    - Catch-up processing of Nov. 2025 – July 2026 data will be done in parallel, with goal of completing by December 2026

NISAR

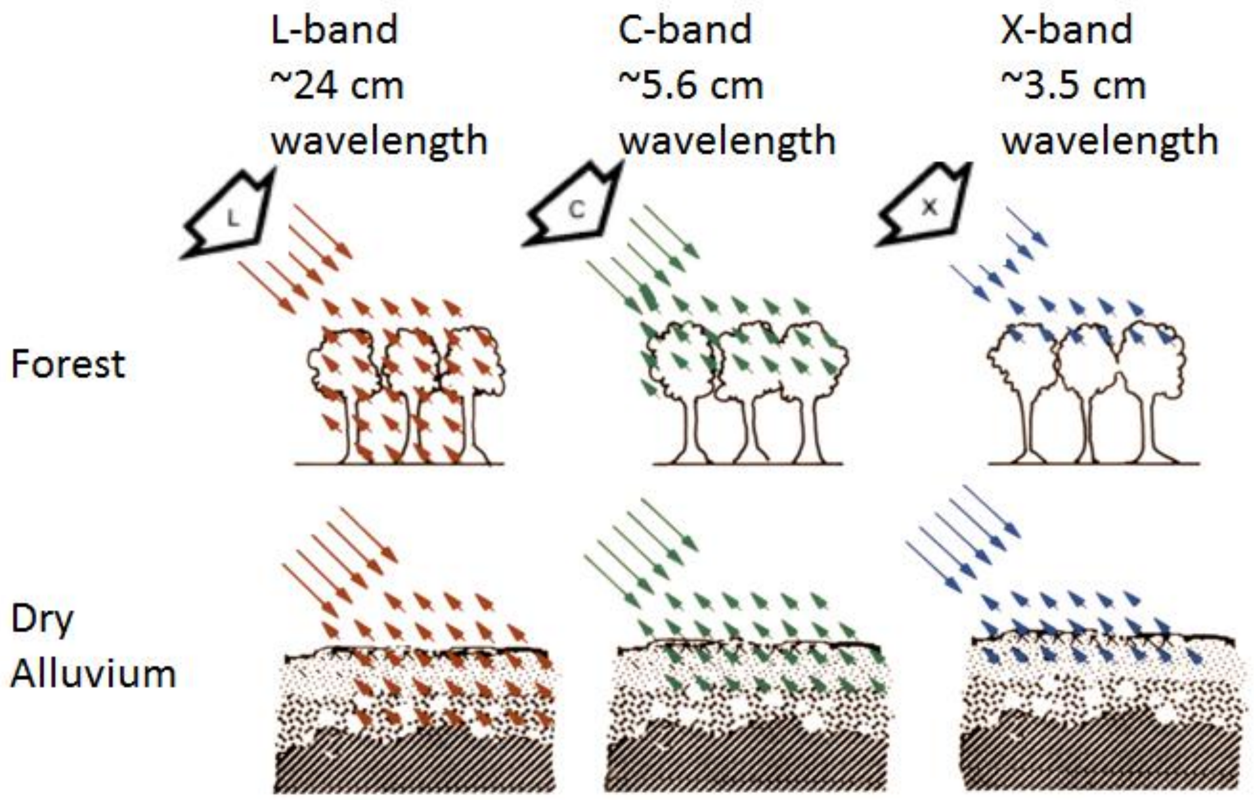
SAR Fundamentals



Synthetic Aperture Radar (SAR) Sensors

- Active systems transmit energy at specific wavelengths and polarizations toward target (Earth) record energy backscattered from image elements

- Strength of return signal and type of scattering is a function of:
  - *System Parameters*:
    - SAR wavelength (frequency) and polarization
    - Imaging geometry
  - *Features of Image Elements*:
    - Dielectric constant (moisture status of natural surfaces)
    - Surface roughness
    - Structure and geometry of image features

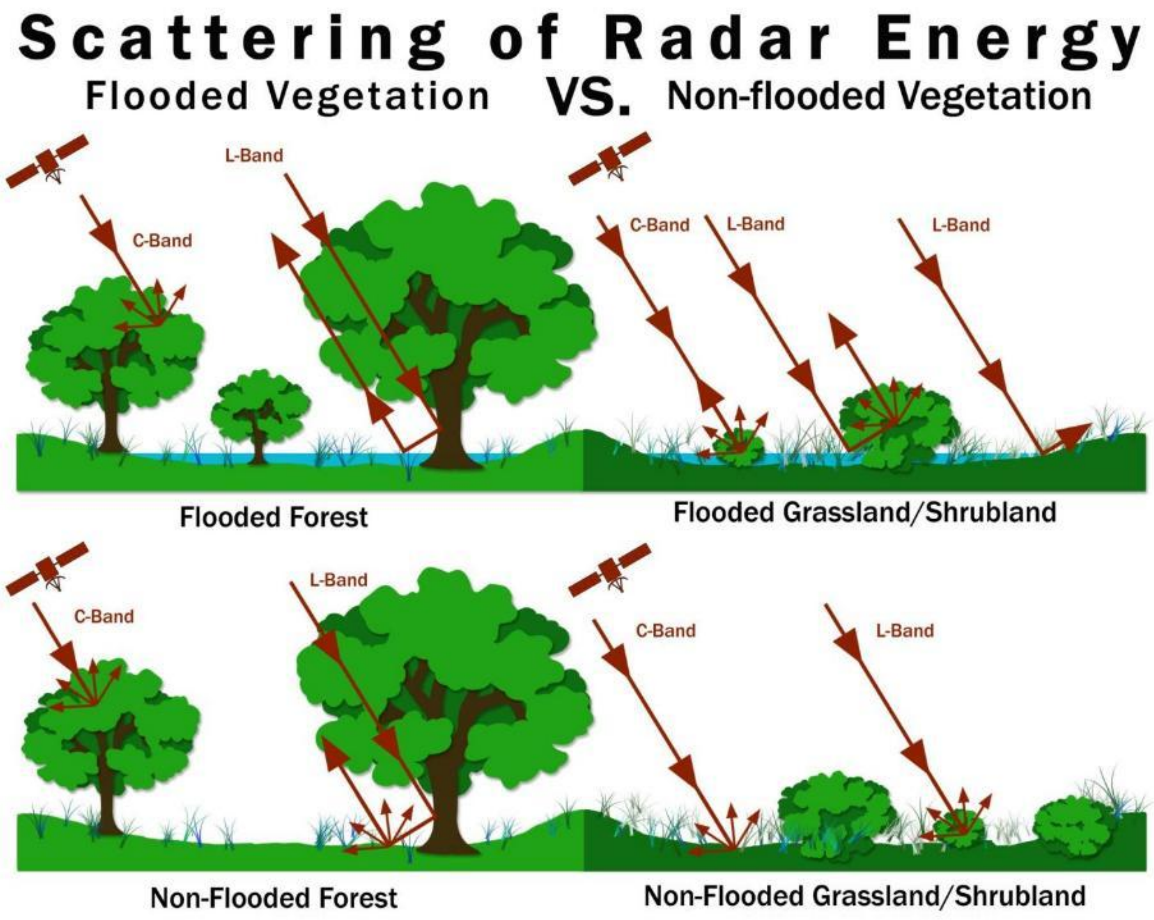


Synthetic Aperture Radar (SAR) L-band vs. C-band

• L Band

Sources include Seasat, JERS-1, PALSAR, PALSAR-2, PALSAR-4, SAOCOM, NISAR

- Longer wavelength (~24 cm), able to penetrate forest canopy to detect presence of standing wate
- Larger dynamic range – detects inundation in a range of vegetation biomass
- Maintains coherence in vegetated areas
- More susceptible to ionospheric phase delays

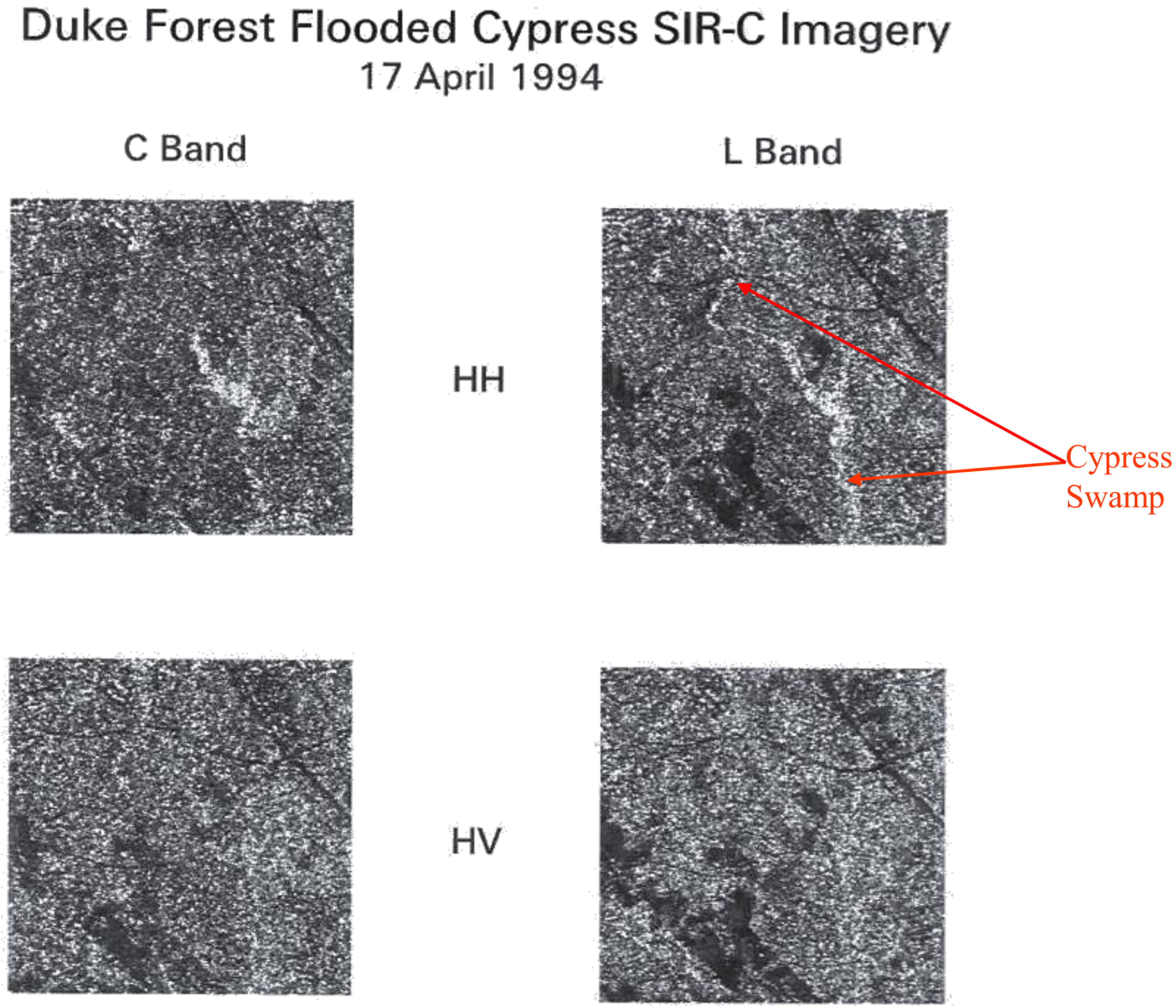


• C Band

Sources include ERS1, ERS2, Sentinel-1, RADARSAT-2, Envisat

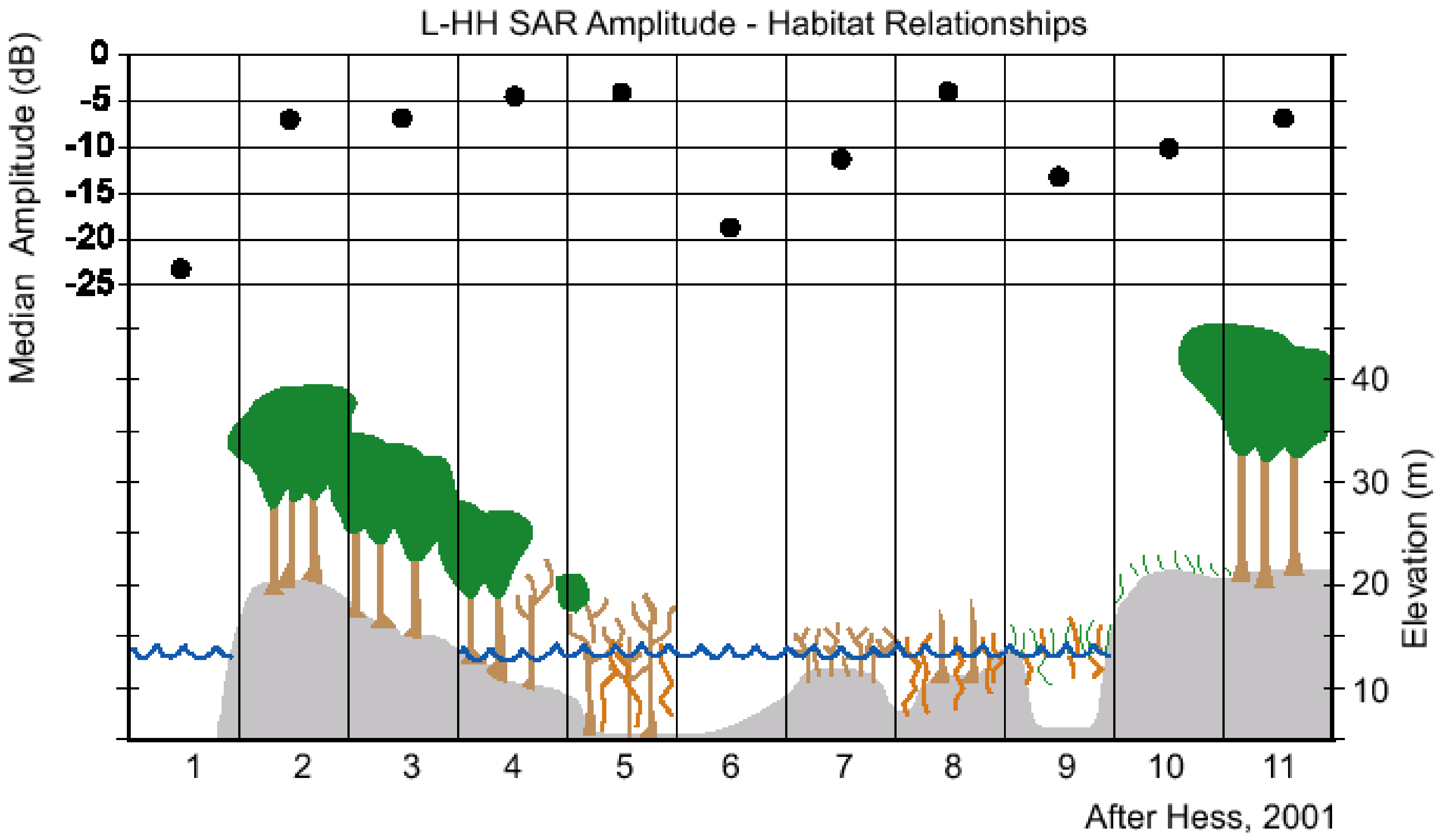
- Much shorter wavelength (~5.6cm), better at detecting moisture in open areas
- Lower penetration in dense vegetation and particularly woody vegetation (i.e. shrub and treed swamps)
- Decorrelates in vegetated areas

Flood detection beneath a forested canopy



- L-band HH-pol provides the best delineation of the flooded cypress swamp
- With L-band double bounce scattering occurs from the smooth water surface to the tree trunks and back to the sensor

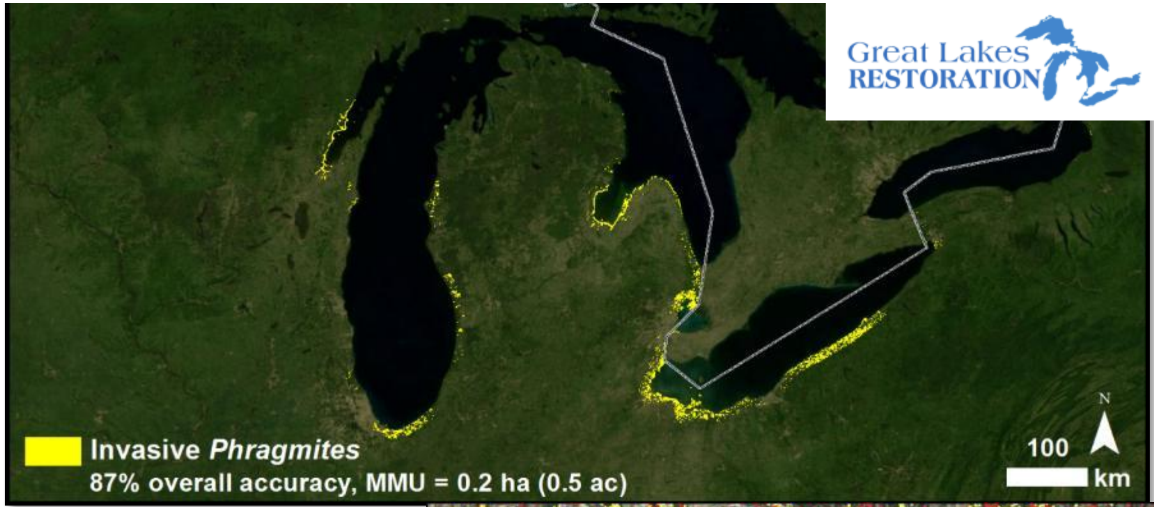
Theoretical L-band Scattering in forest, herbaceous and open areas



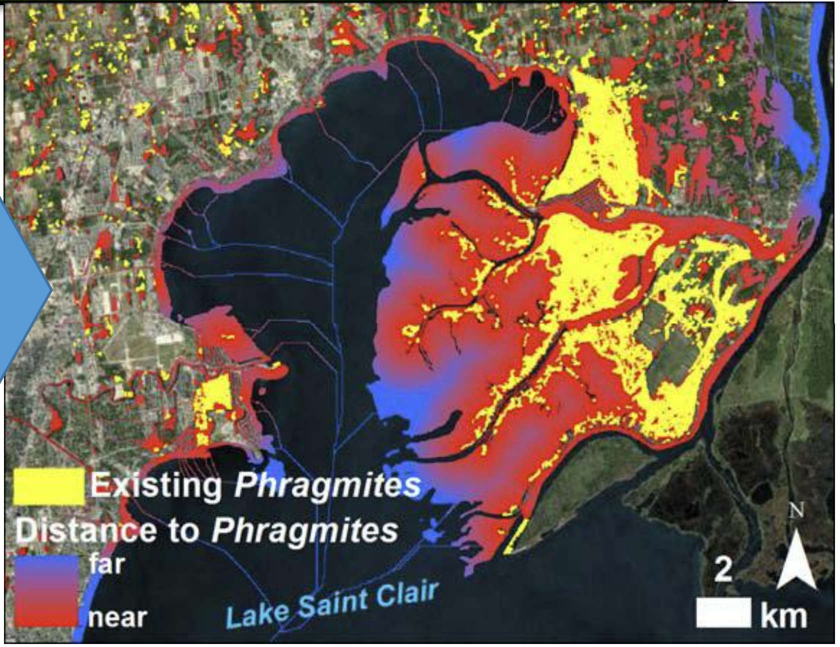
L-band PALSAR-Derived Map of Large Dense Stands of Invasive *Phragmites australis* produced for Decision Support

Multi-season L-band data alone was found very effective for mapping this invasive wetland plant due to:

- High biomass
- Standing water
- 3 seasons of variation

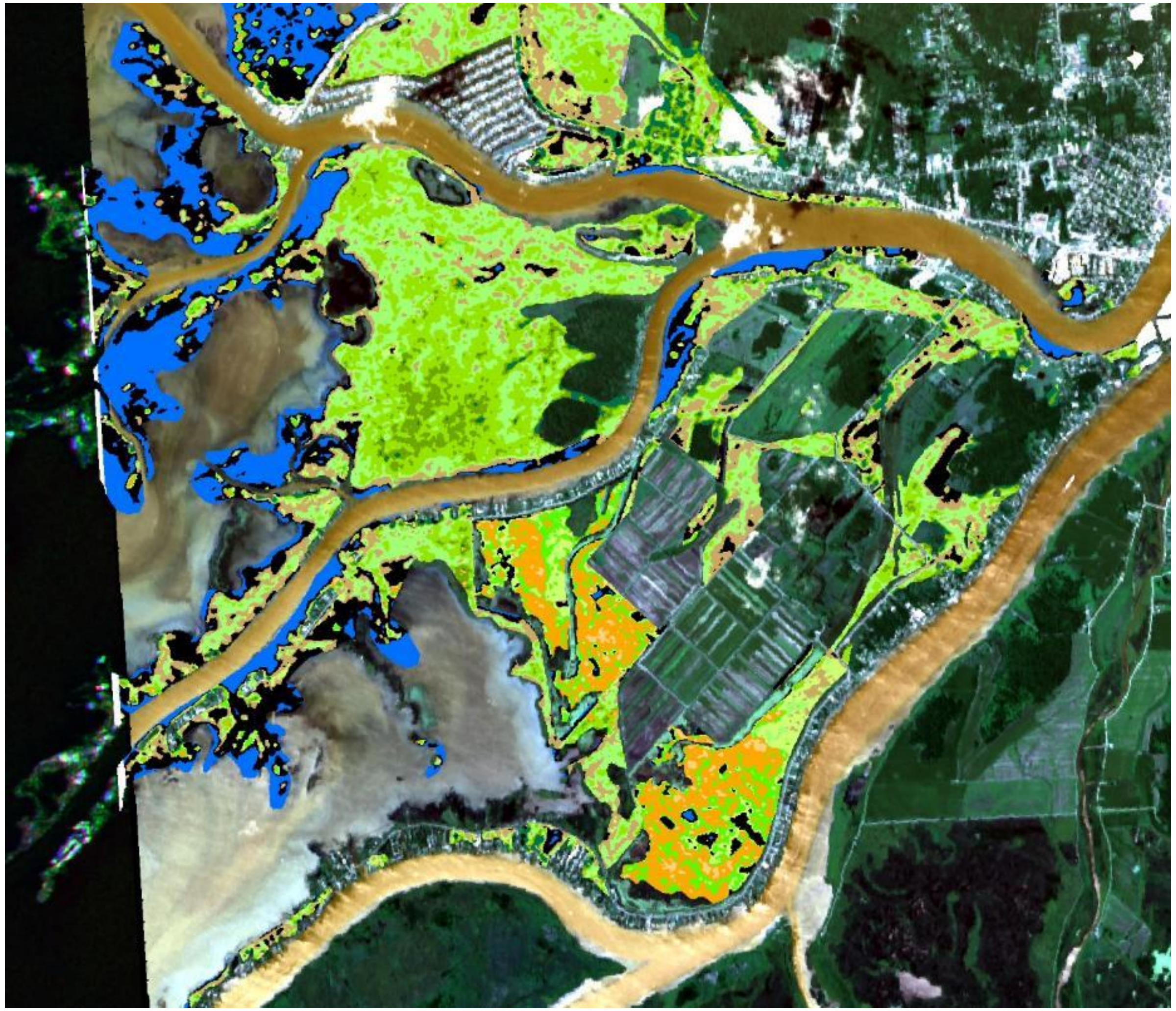


USGS and USFWS funded the mapping of Invasive *Phragmites australis* to aid in a decision support tool that predicts spread of the invasive plant



Bourgeau-Chavez et al. (2012) Journal of Great Lakes Research

Lake St. Clair PALSAR
Mapping Invasive *Phragmites*



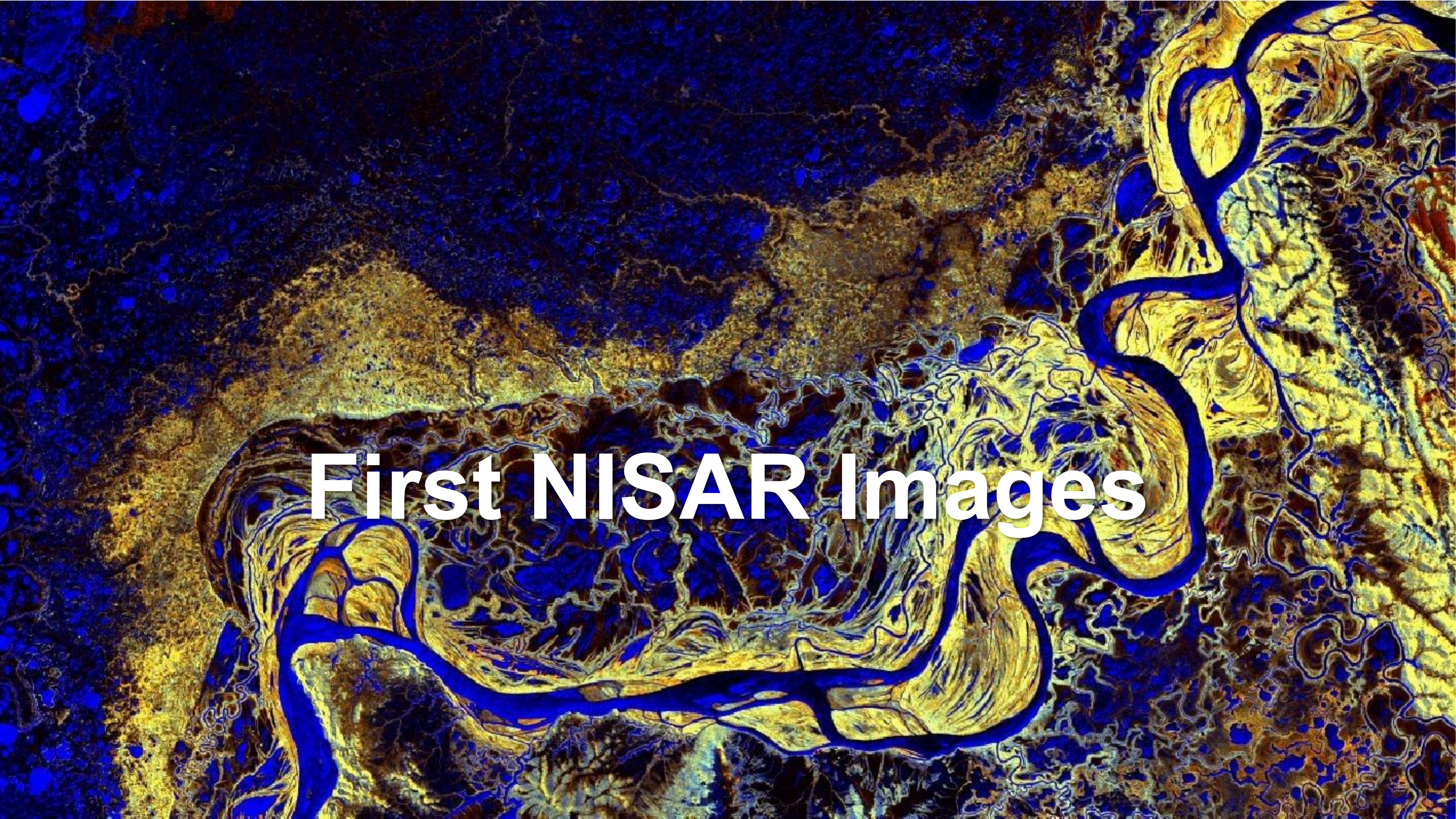
1. PALSAR HH
   - July 2006
   - October 2008
   - May 2008

2. PALSAR HV

   **Sensitive to biomass
   - October 2008
   - April 2008
   - May 2008

3. Wetland Map

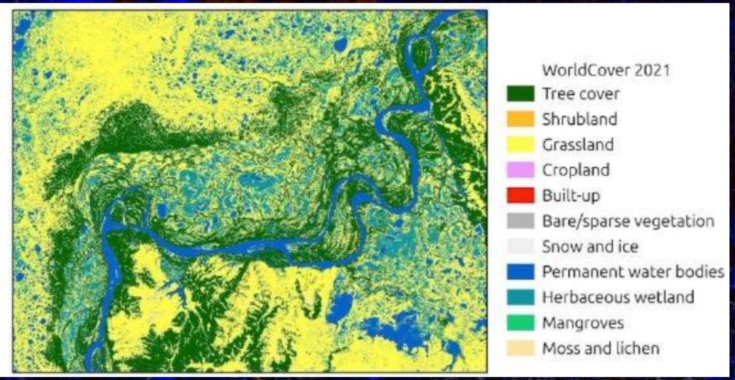
First NISAR Images

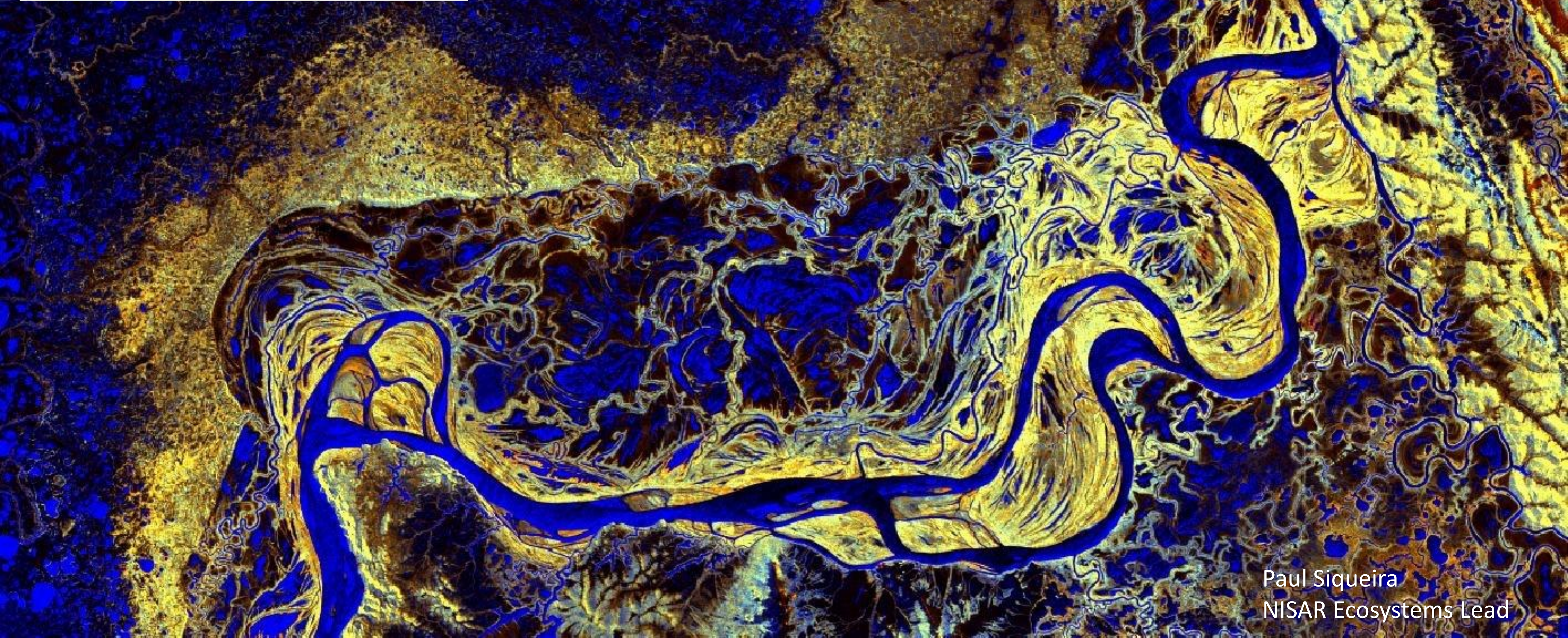


NISAR Image Yukon Delta

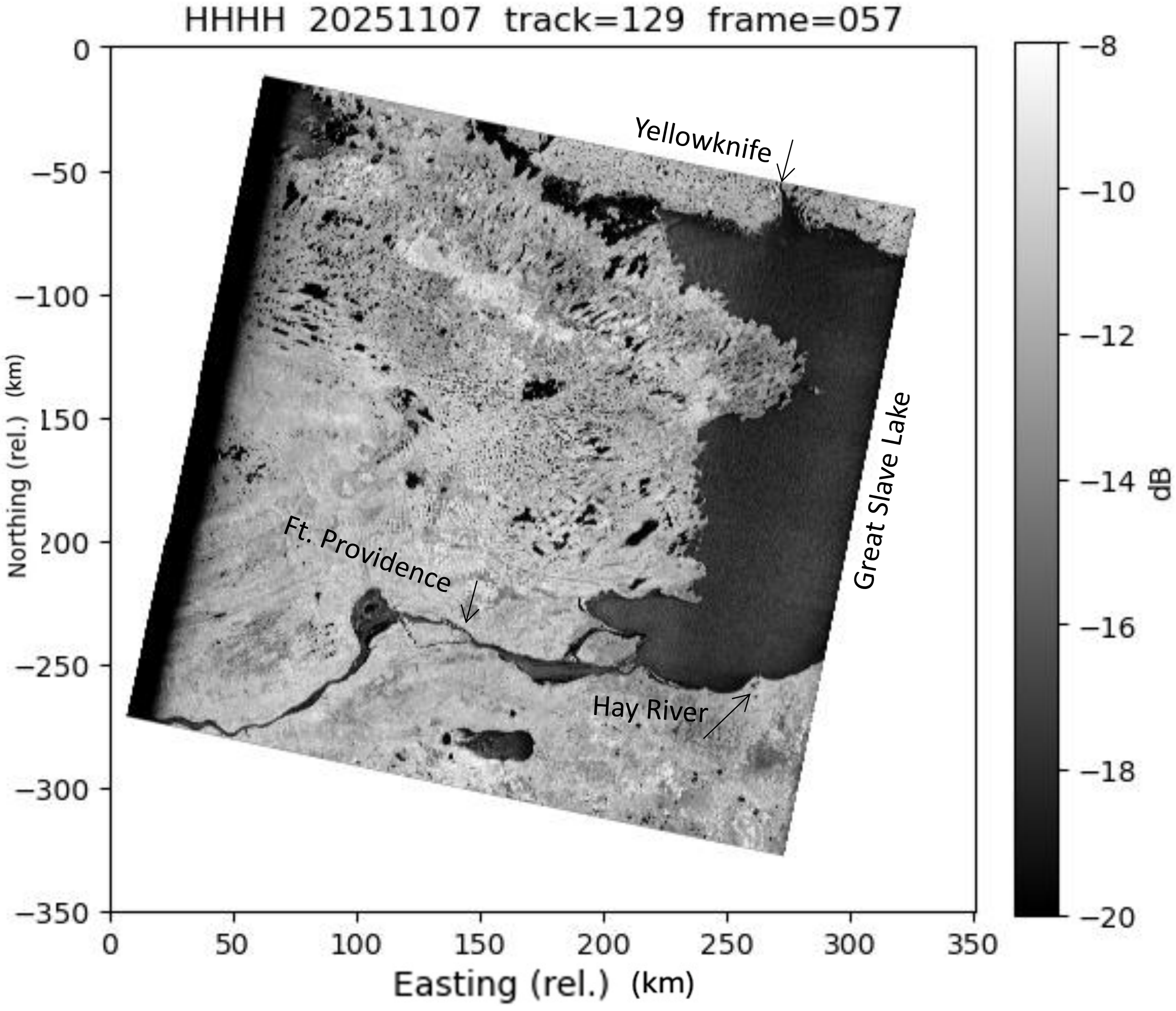
Color scheme chosen to highlight inundated areas and other features in the landscape

HH, HV, HV/HH

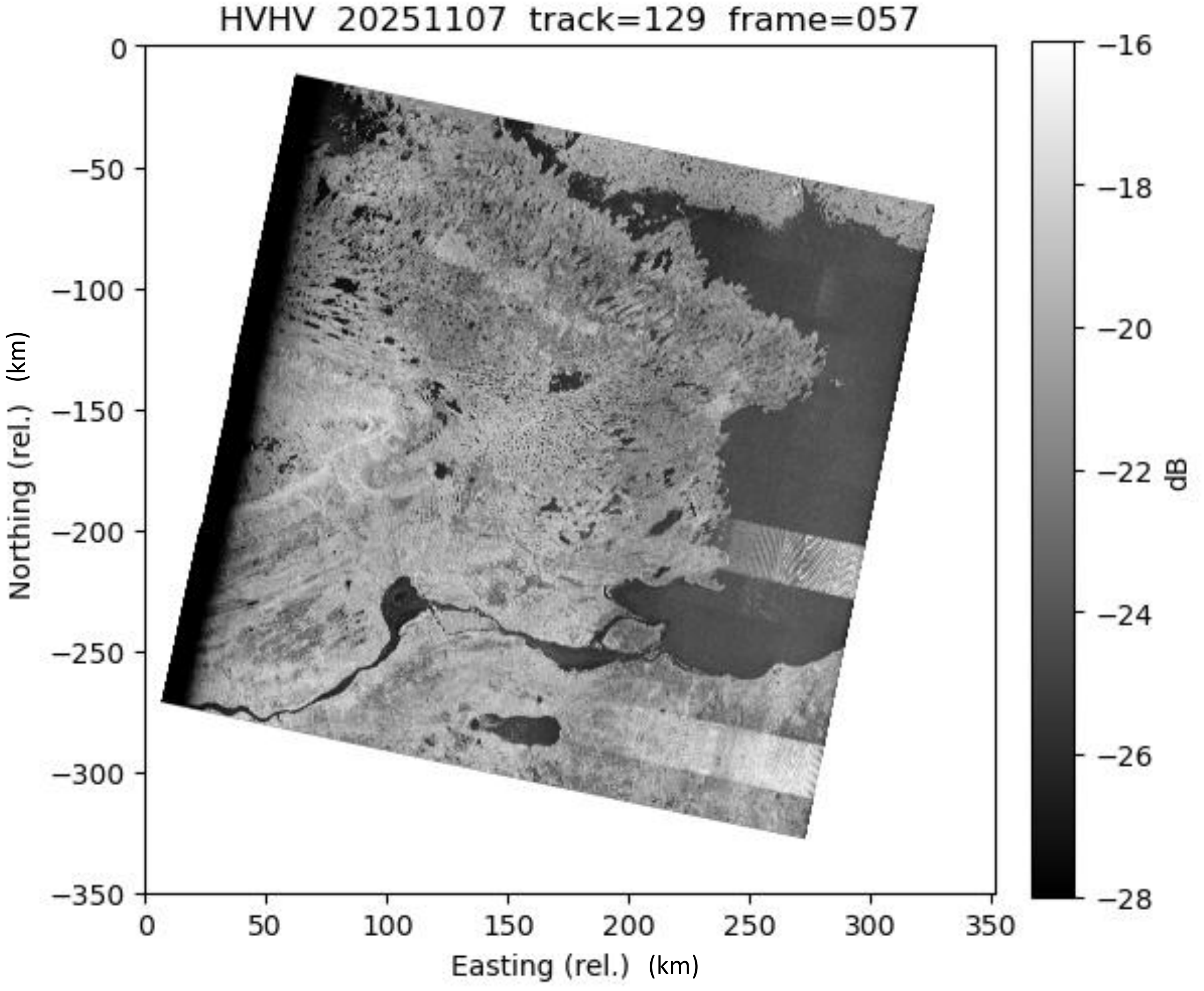




Paul Siqueira
NISAR Ecosystems Lead



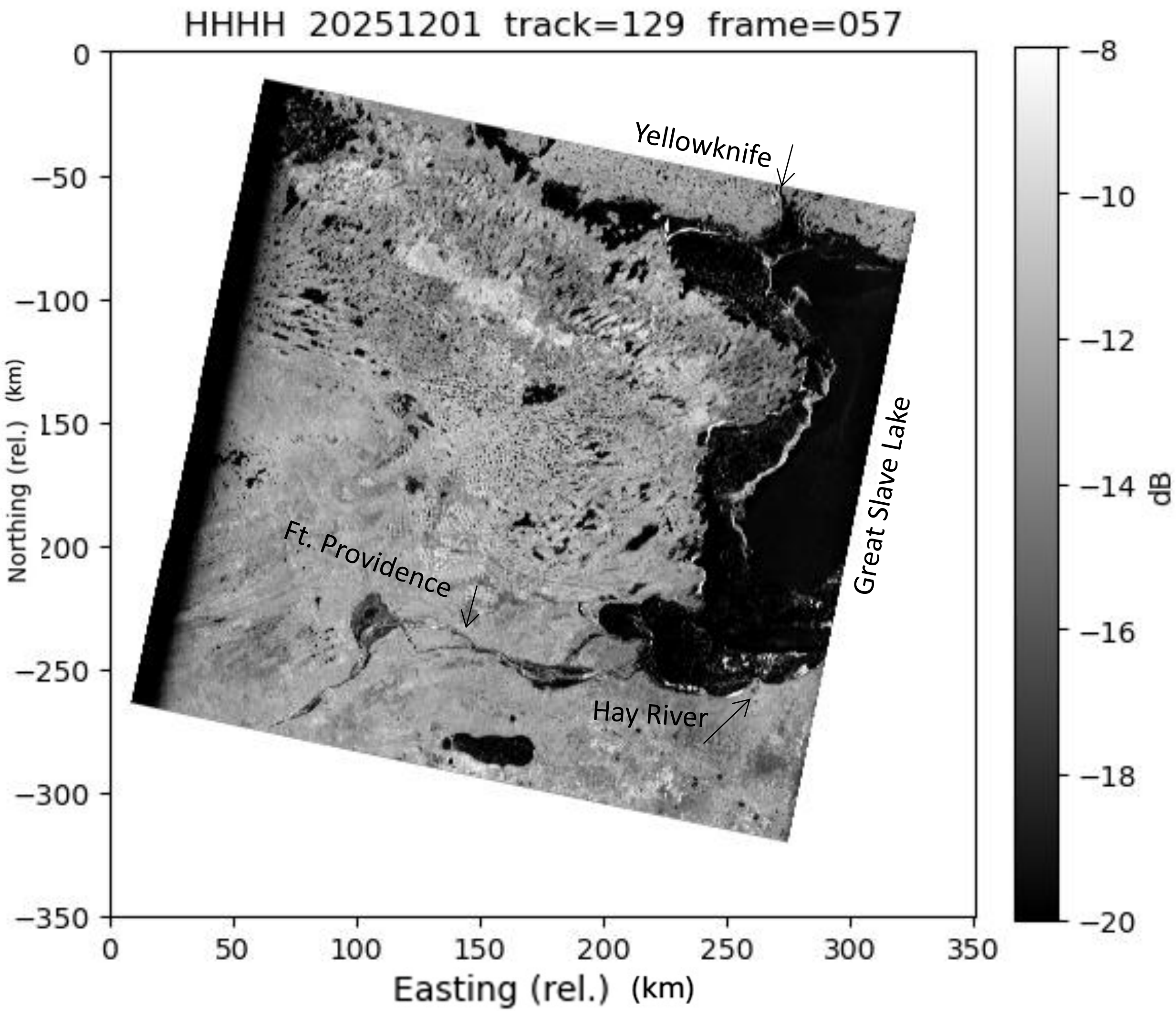
Co-Pol



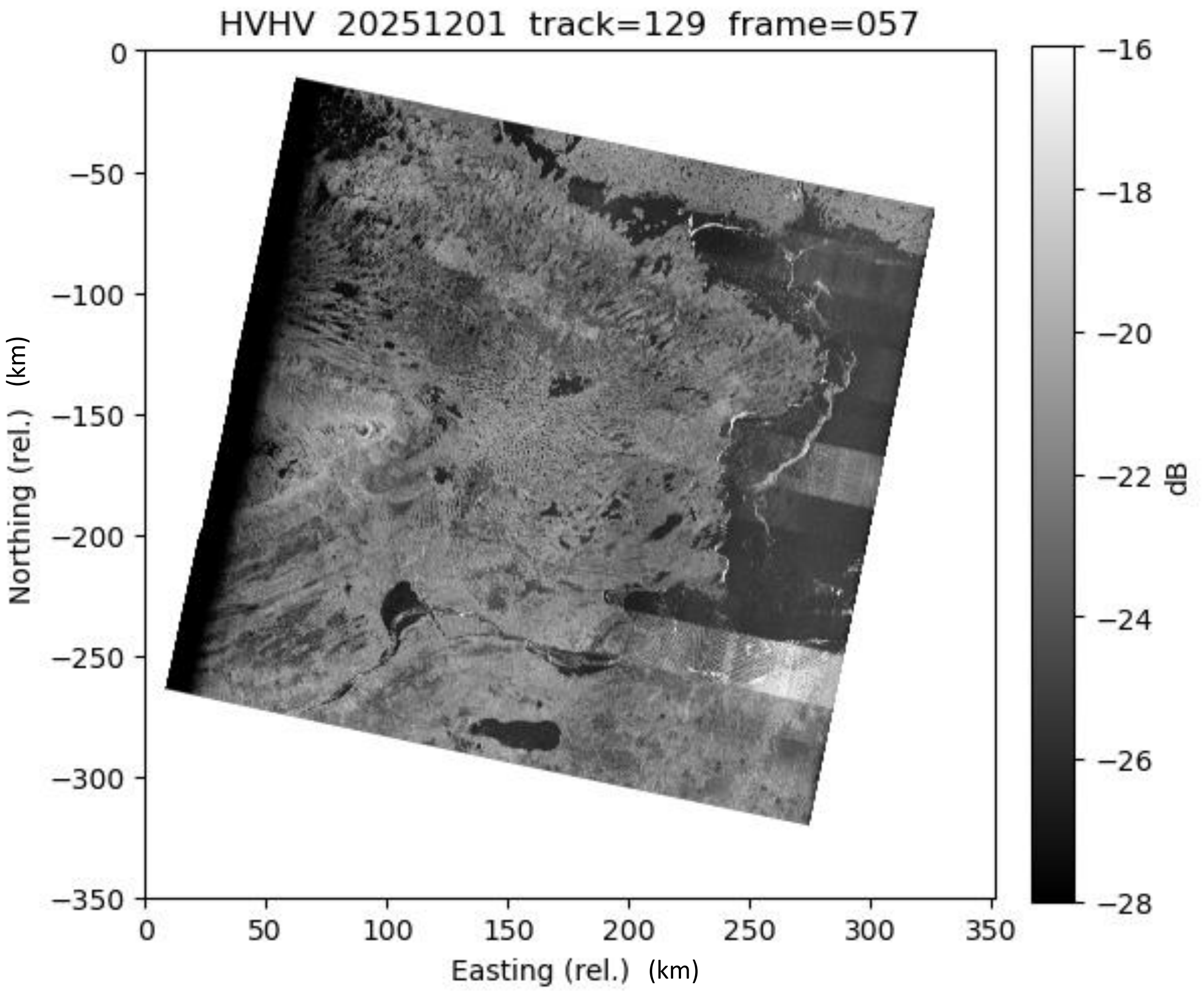
Cross-Pol

You can see the ice forming in the Great Slave Lake during the Months of December - January

Cross-polarized returns have the same dynamic range as co-pol, but are reduced in magnitude by 8 dB. For this reason, artifacts such as Radio Frequency Interference are much more prominent in the imagery.



Co-Pol



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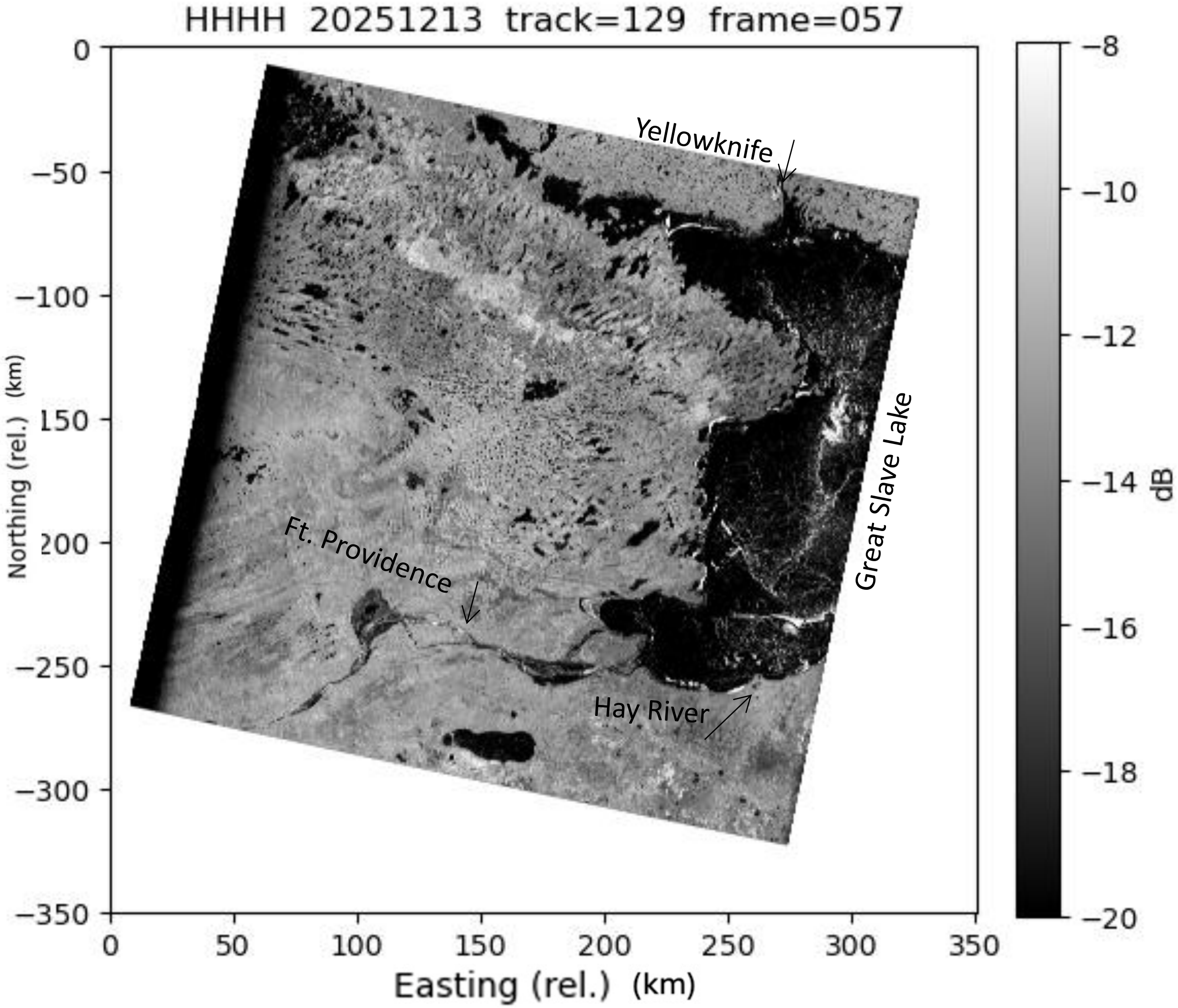
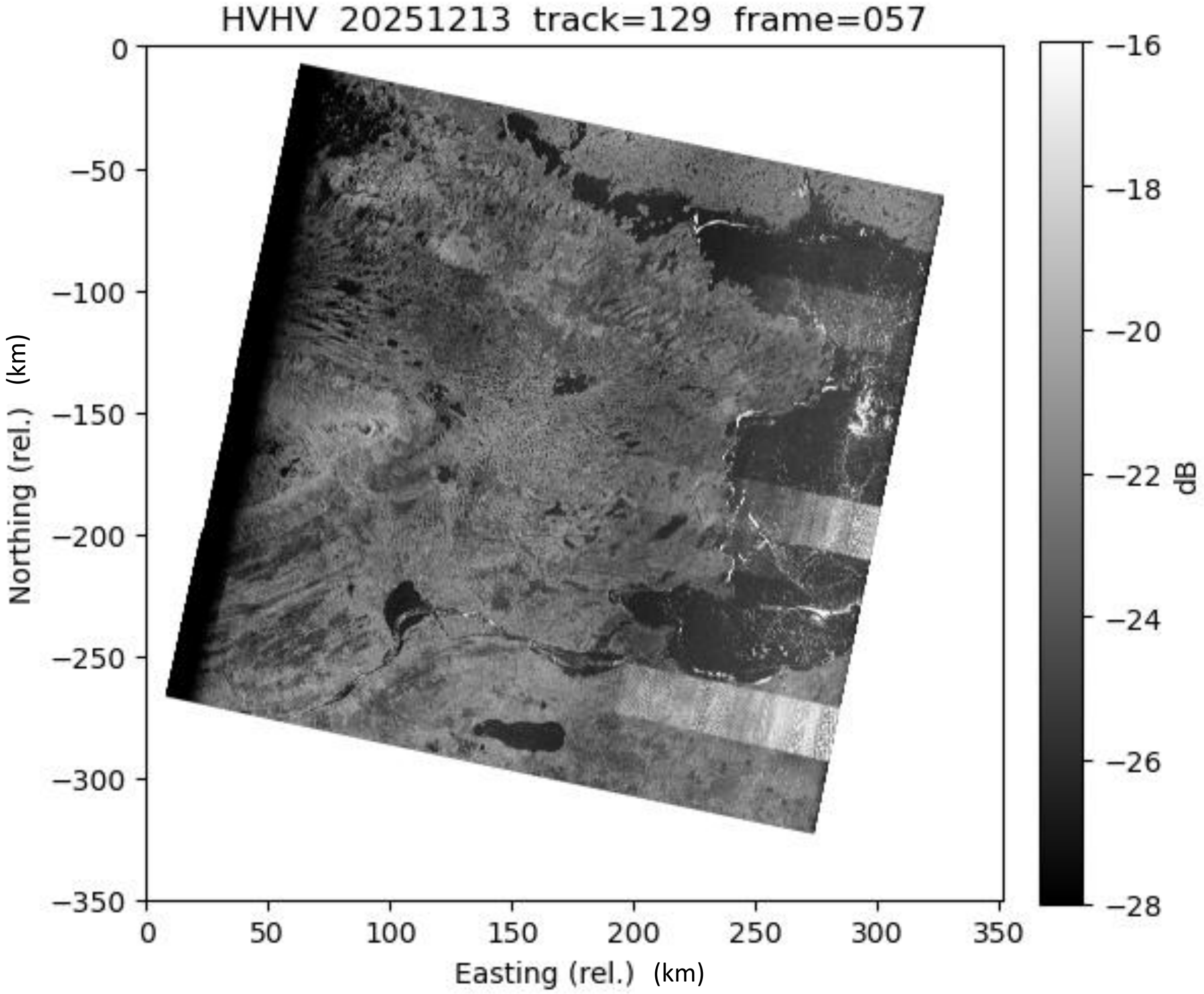


Co-Pol



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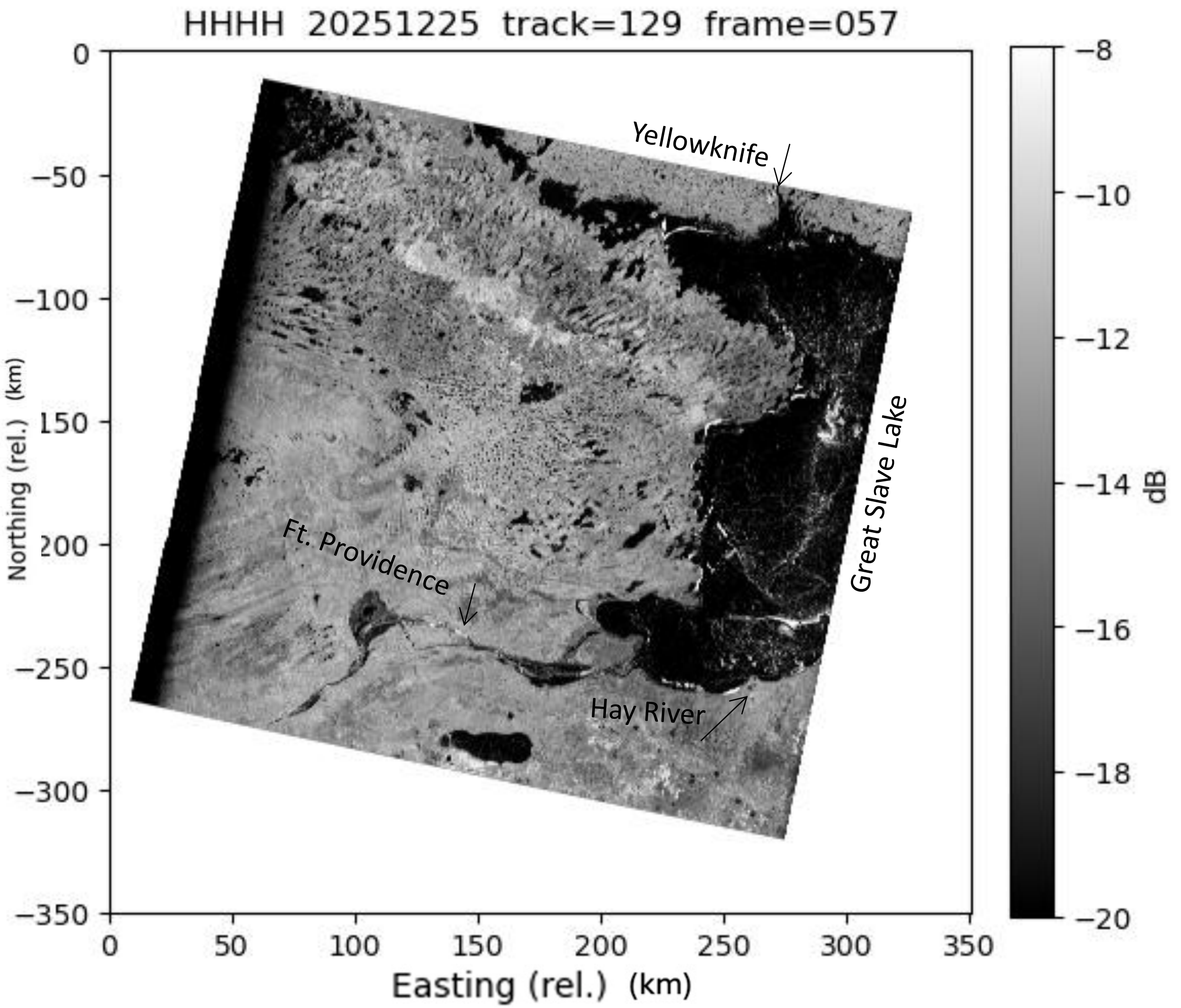
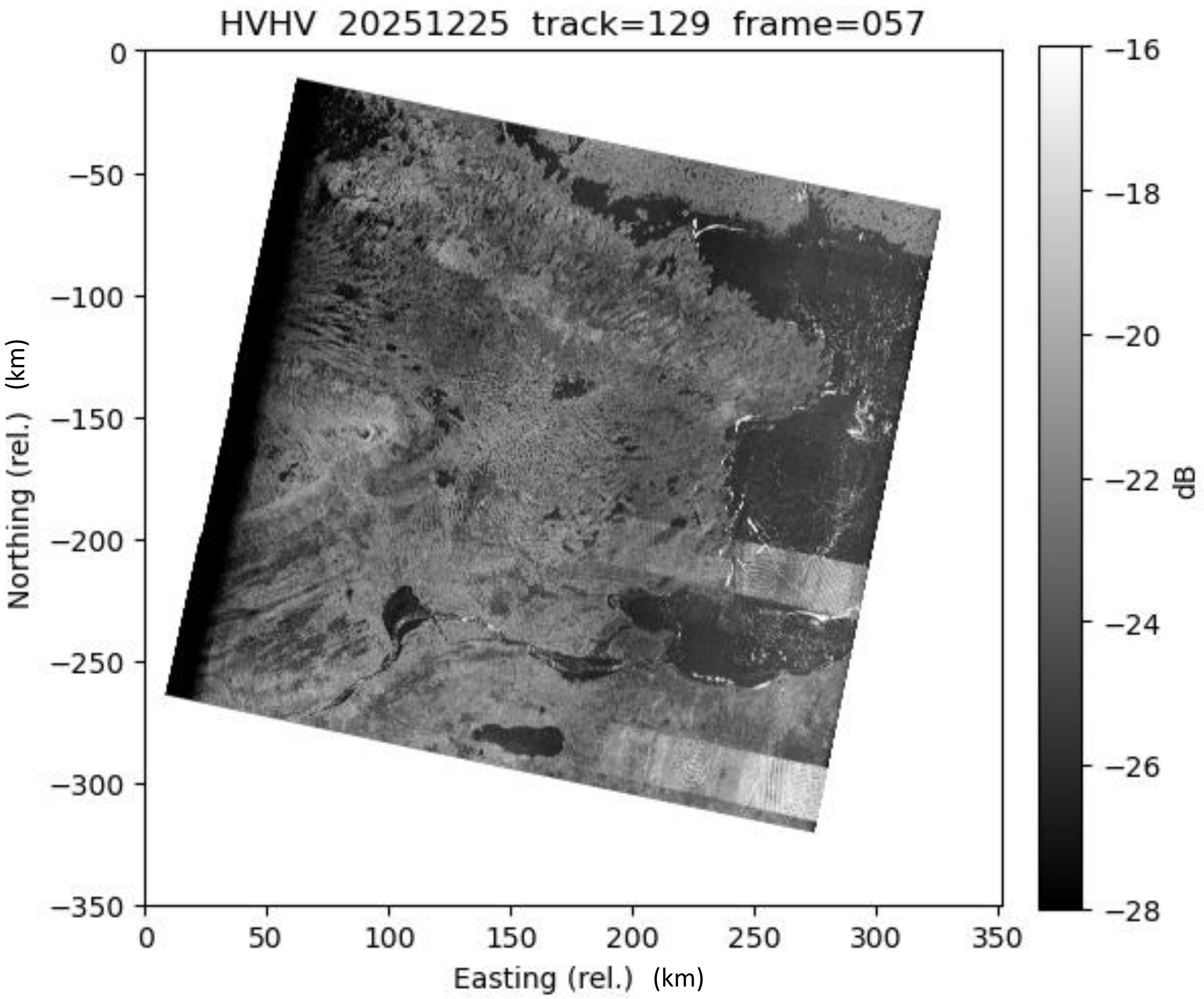


Co-Pol



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Siqueira – NISAR Ecosystems Lead

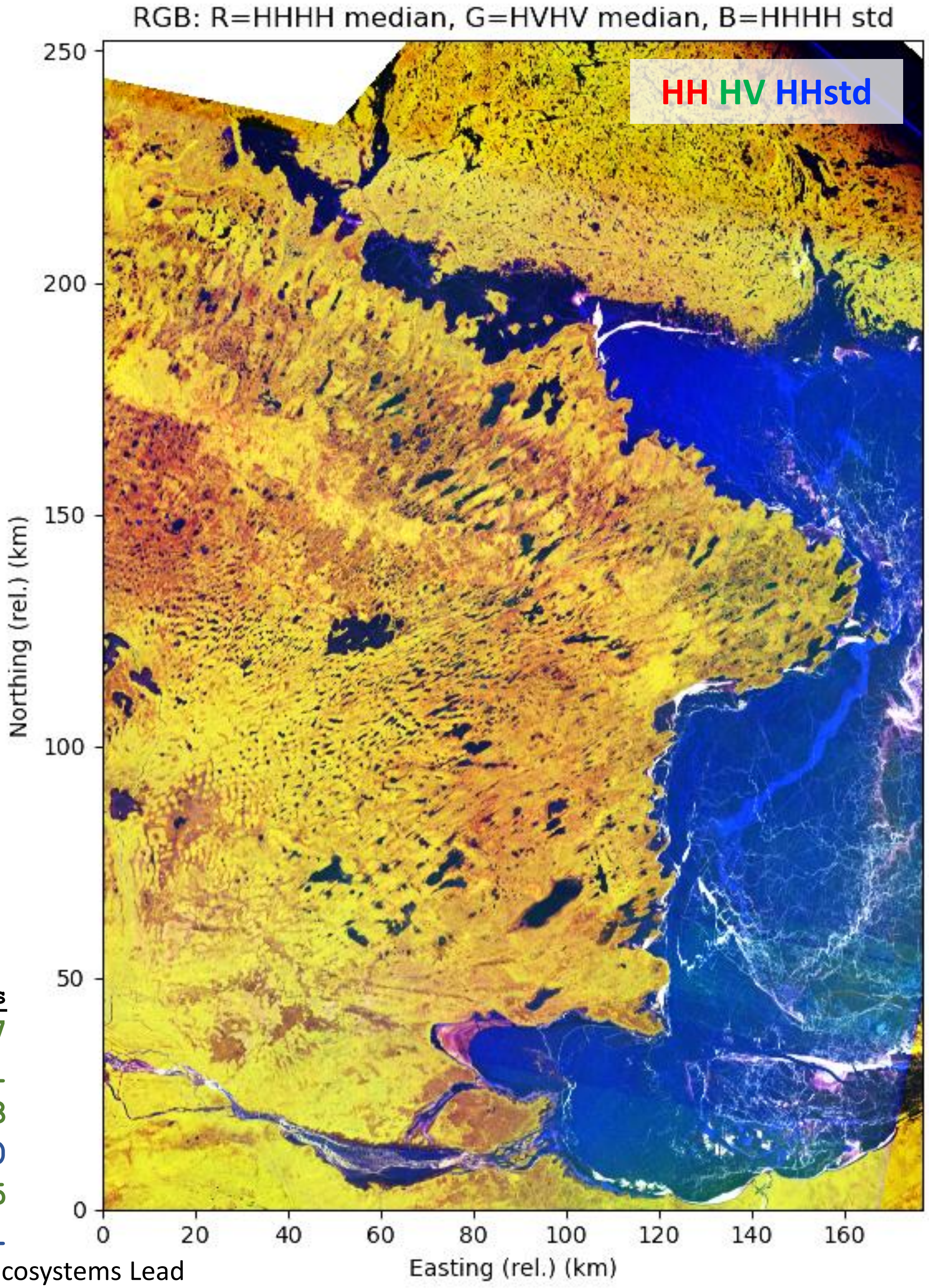
System is stable, calibration, RFI removal underway

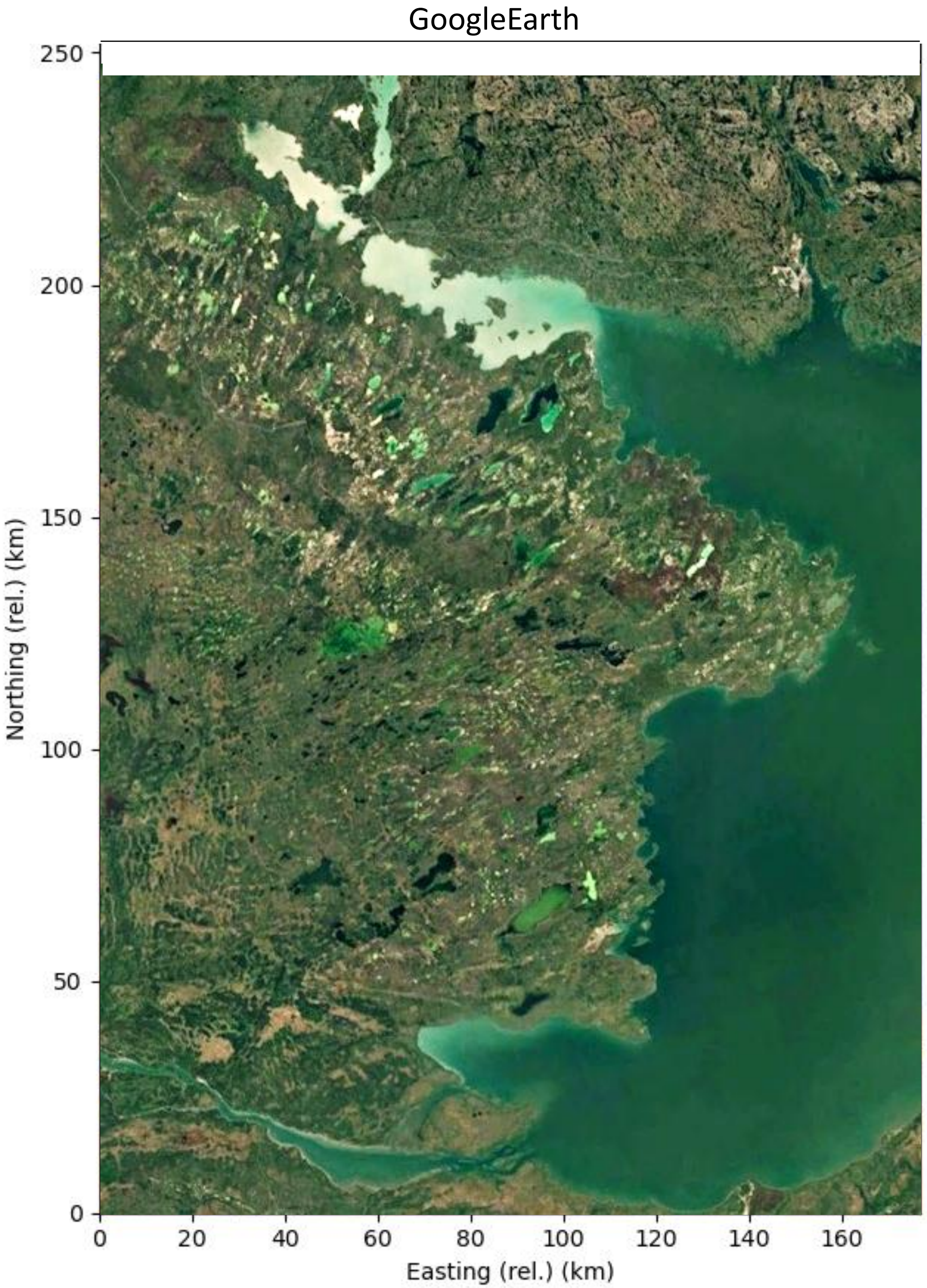
Combining time-series over six dates is used to highlight regions of different landcover.

Bright red plus some green creates the color OCHRE, indicating strong HH, some HV and low HH variation over time.

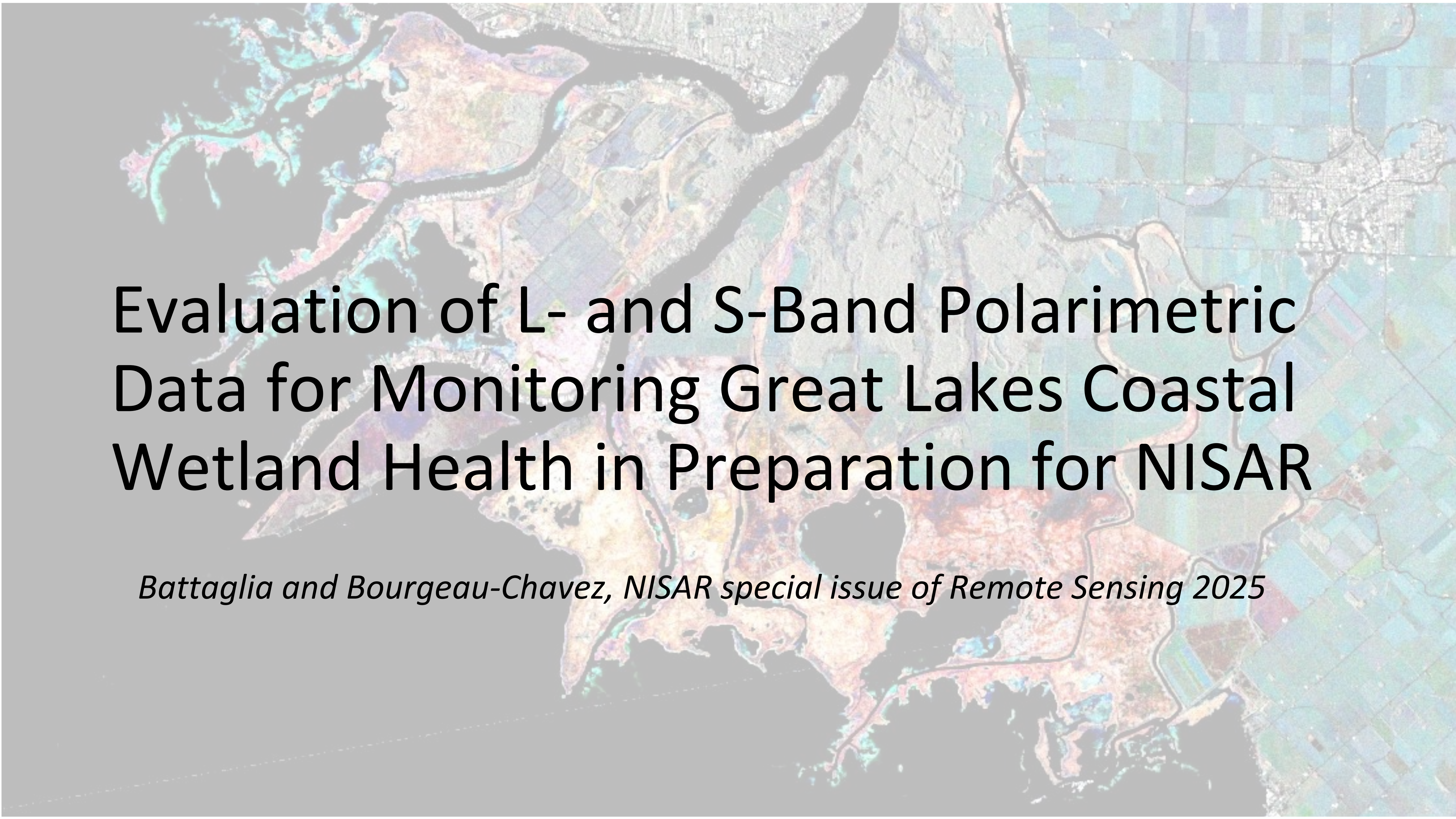
Bright BLUE comes from low HH, low HV, but strong variation over time, indicating the freezing of the Great Slave Lake

Track/Frames	Dates
129_D_057	20251107
062_A_033	20251201
	20251213
CRID X05009	20251220
	20251225
	20260101





Siqueira – NISAR Ecosystems Lead



Evaluation of L- and S-Band Polarimetric Data for Monitoring Great Lakes Coastal Wetland Health in Preparation for NISAR

Battaglia and Bourgeau-Chavez, NISAR special issue of Remote Sensing 2025

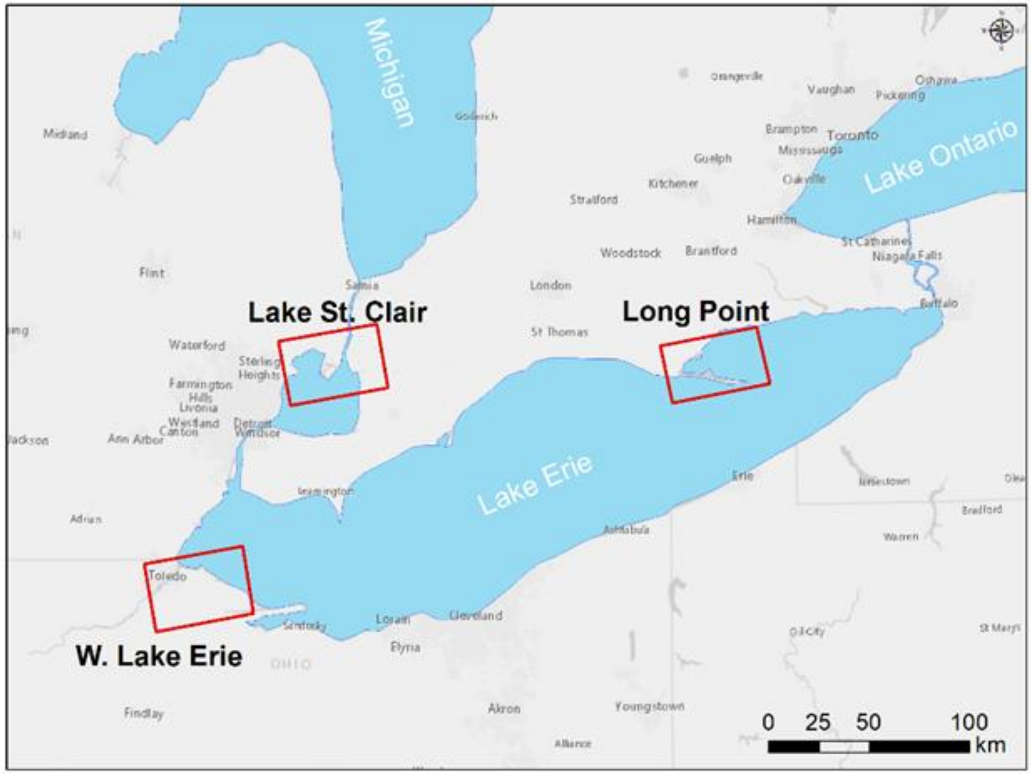
Airborne SAR Collect & Research Questions

1) Can L-band and S-band polSAR data be used to map wetland ecotypes and differentiate invasive species, such as *Phragmites australis*, with high accuracy in lieu of optical data?

2) Do physically based scattering models explain polarimetric L- and S- band SAR interactions with wetland systems or is anomalous behavior exhibited for double bounce, as was previously found for C-band (Atwood et al. 2019)?

3) What are the vegetation structure and biomass limitations of L-band vs. C- or S-band in monitoring wetland inundation?

NASA-ISRO ASAR L- and S-band data were collected over 3 Great Lakes wetland complexes on July 14, 2022



Field Locations and ASAR Footprints

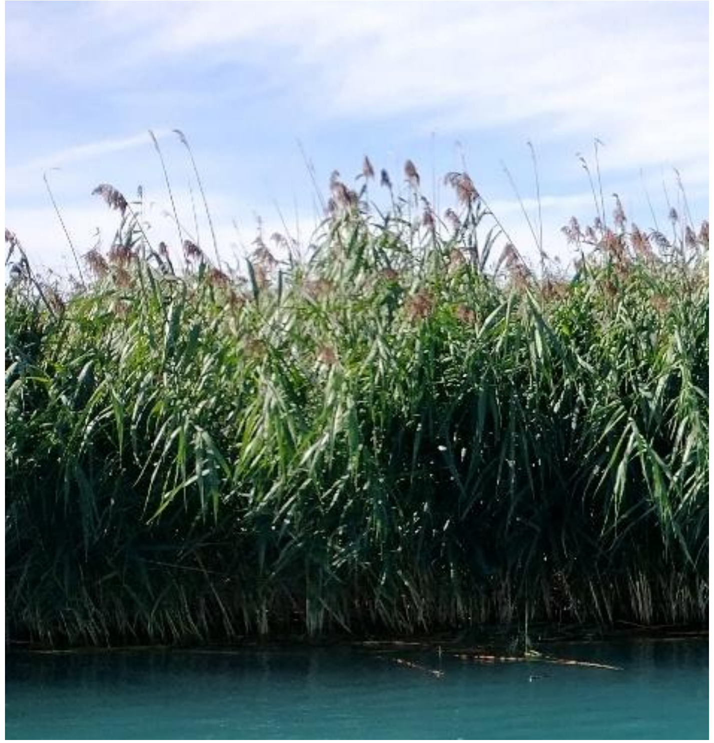
Data Collected at 42 sites in summer 2021 under a GLRI grant funded by USFWS

- Vegetation type
- Inundation status
- Stem counts
- Basal diameter
- Diameter at 1 m above water
- Water depth

Common Monotypes in the Great Lakes

Schoenoplectus

Typha



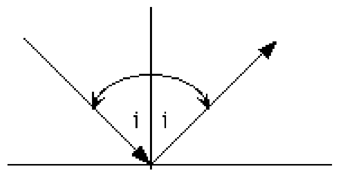
Phragmites

Lower — Biomass → Higher

Physically Based Model Polarimetric Decompositions

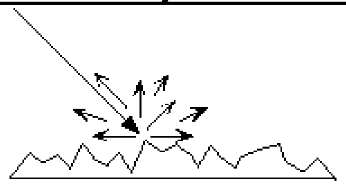
- Partition the total backscattered power into distinct physical scattering mechanisms
- 3 component model –based decomposition – van Zyl 2011 NNED
  - 3 scattering mechanisms
    - Single bounce (surface scatter)
    - Double bounce
    - Volume scatter (diffuse scattering)

Specular Reflection



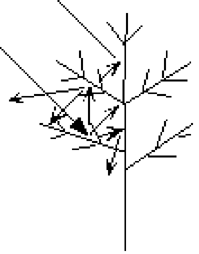
Reflection off a smooth surface
The angle of incidence, i, equals the angle of reflection.

Single Bounce/Surface Scatter



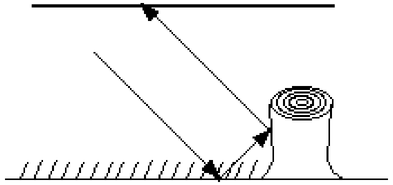
Scattering off a rough surface
The variation in surface height is on the order of the incoming signal's wavelength.

Volume Scatter



Volumetric Scattering
Example scattering in a tree

Double Bounce



Double Bounce
One possible natural occurence – reflecting off two smooth surfaces, grass and a freshly-cut tree's stump

Polarimetric Decomposition Images

-Van Zyl 2011 NNED Decomposition

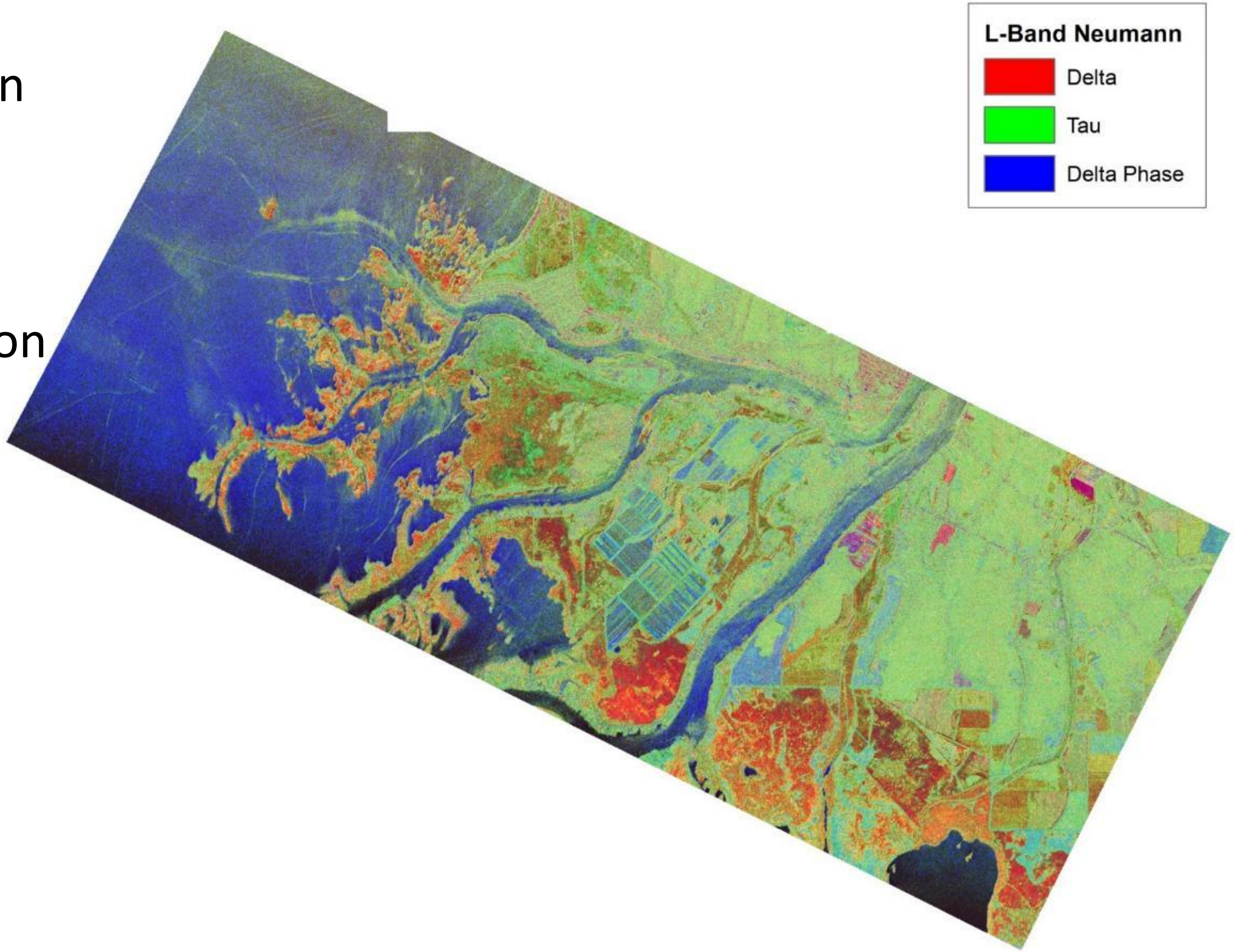
- Double-bounce scattering
- Volume scattering
- Surface scattering

-1997 Cloude-Pottier Decomposition

- Entropy -H
- Anisotropy - A
- Alpha Angle- α

-2009 Neumann Decomposition

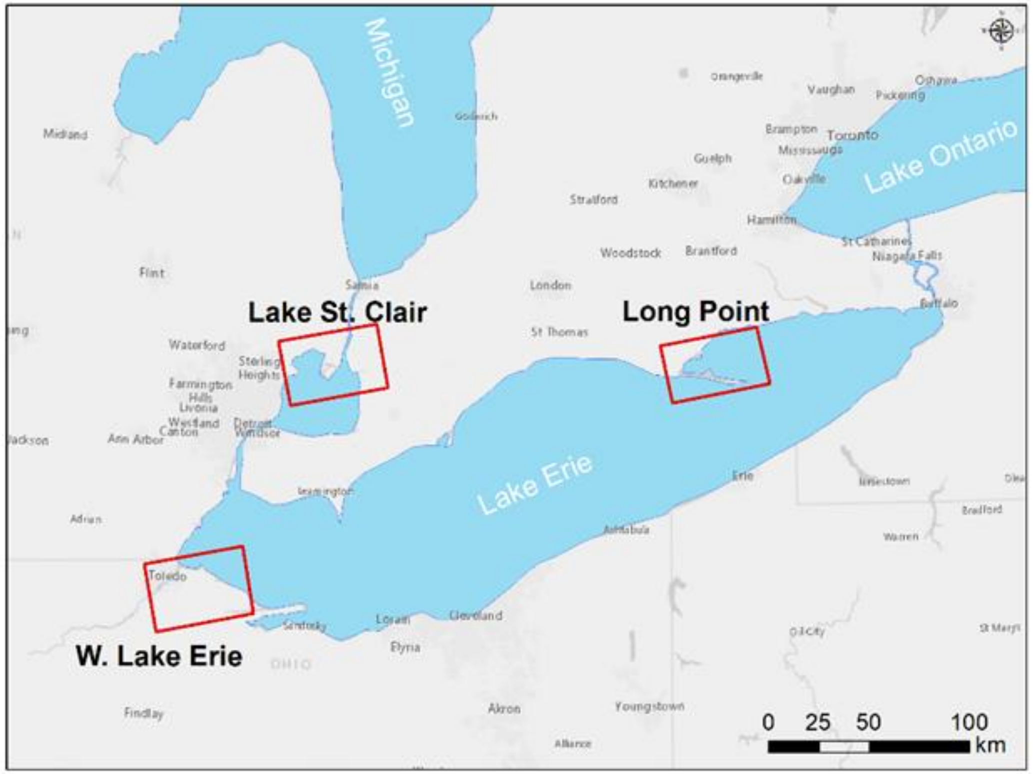
- Delta
- Tau
- Delta Phase



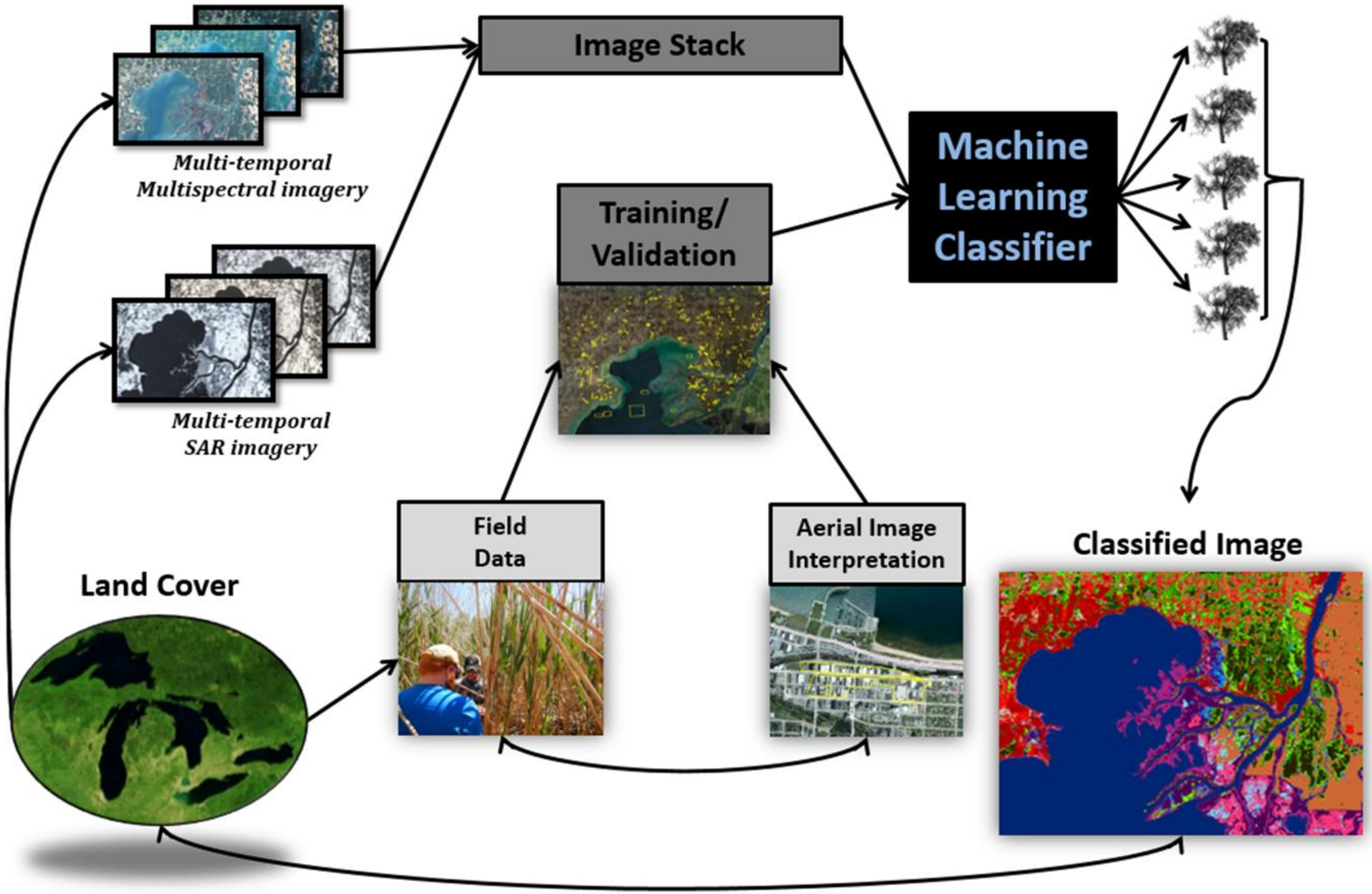
Research Question #1

1) Can L-band and S-band polSAR data be used to map wetland ecotypes and differentiate invasive species, such as *Phragmites australis*, with high accuracy in lieu of optical data or multi-date data?

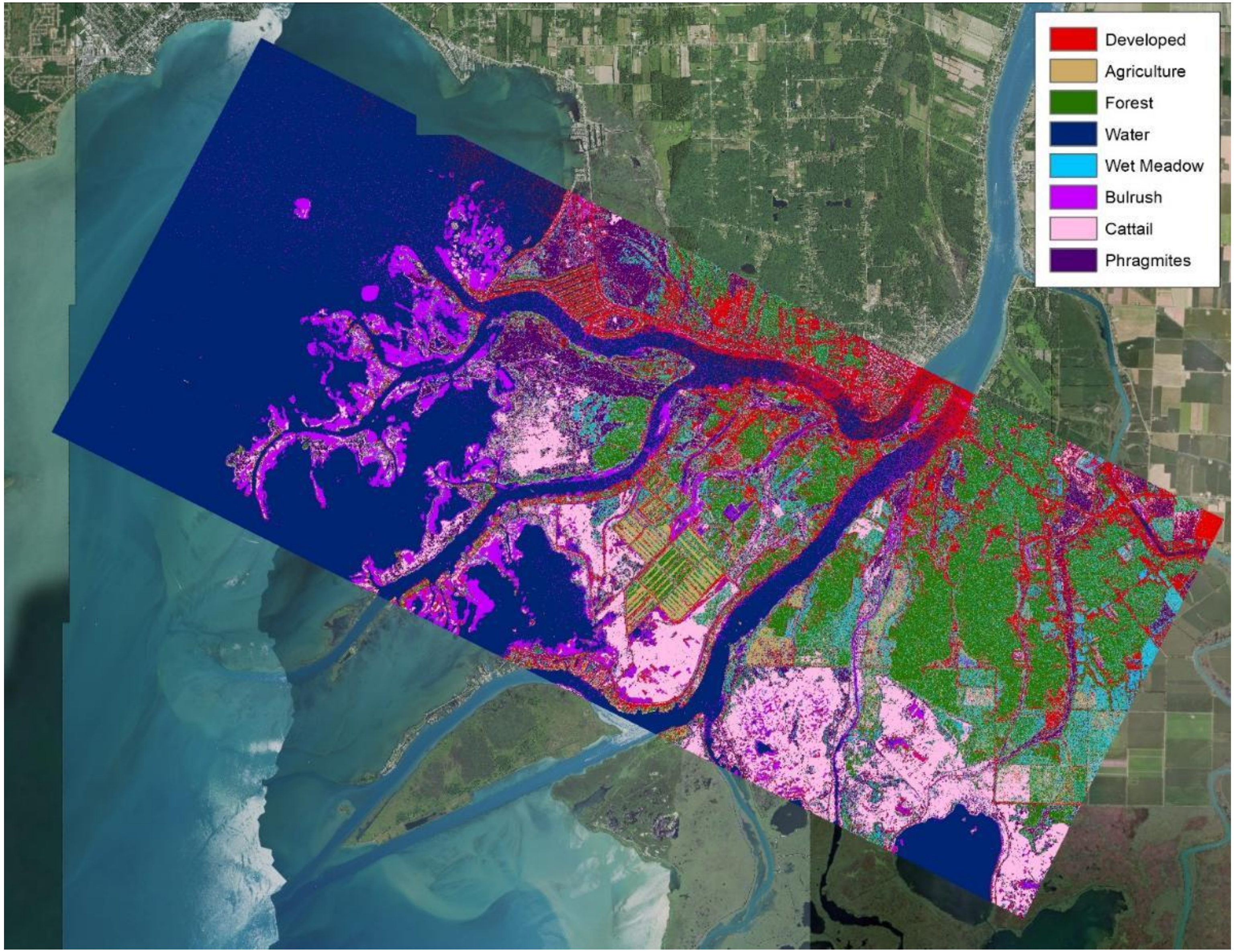
- The L- and S-band backscatter data and decompositions were used in a ML classifier to map wetland types and compared to an existing map using multi-temporal SAR-optical data



Typical wetland mapping approach

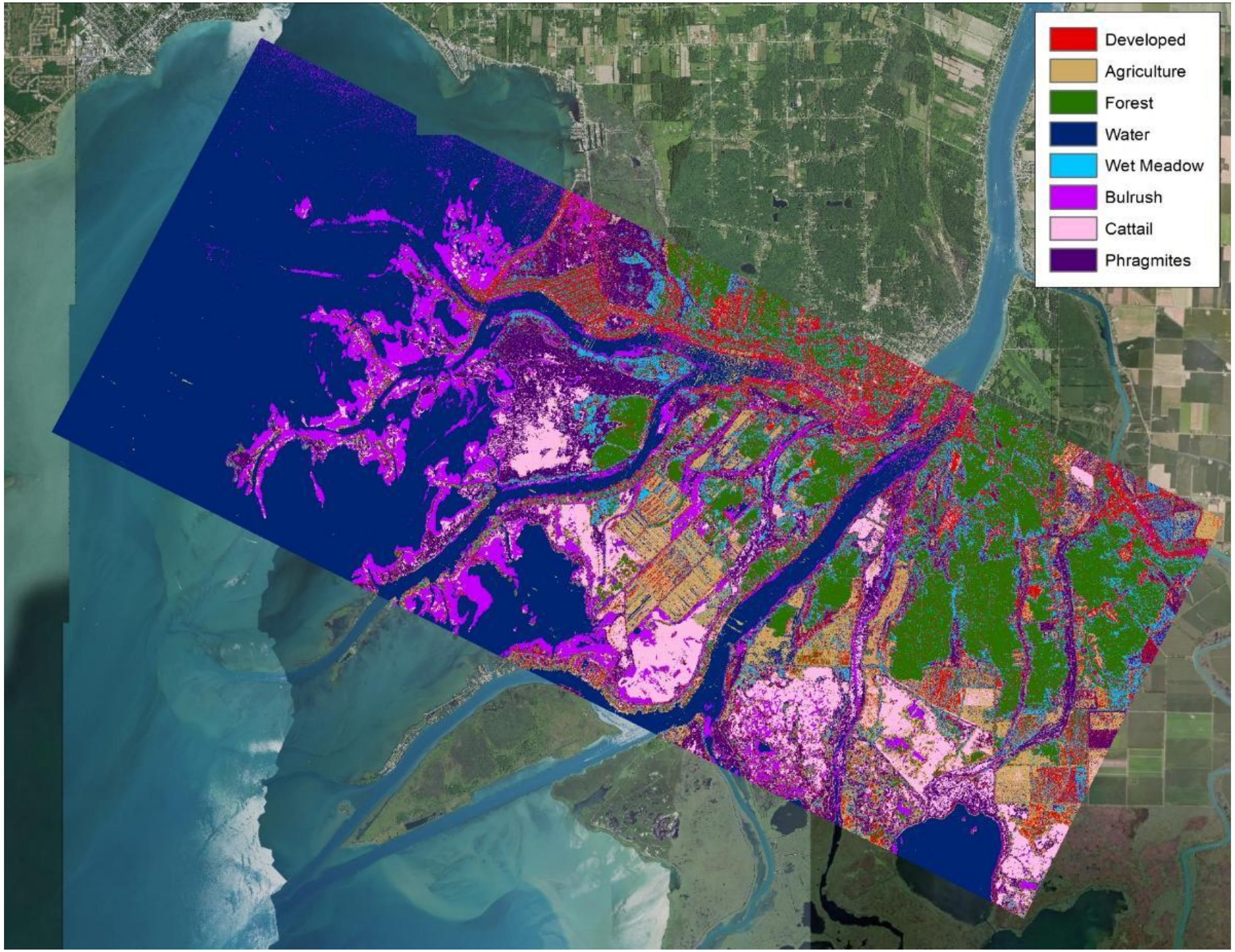


Classification results: S-band



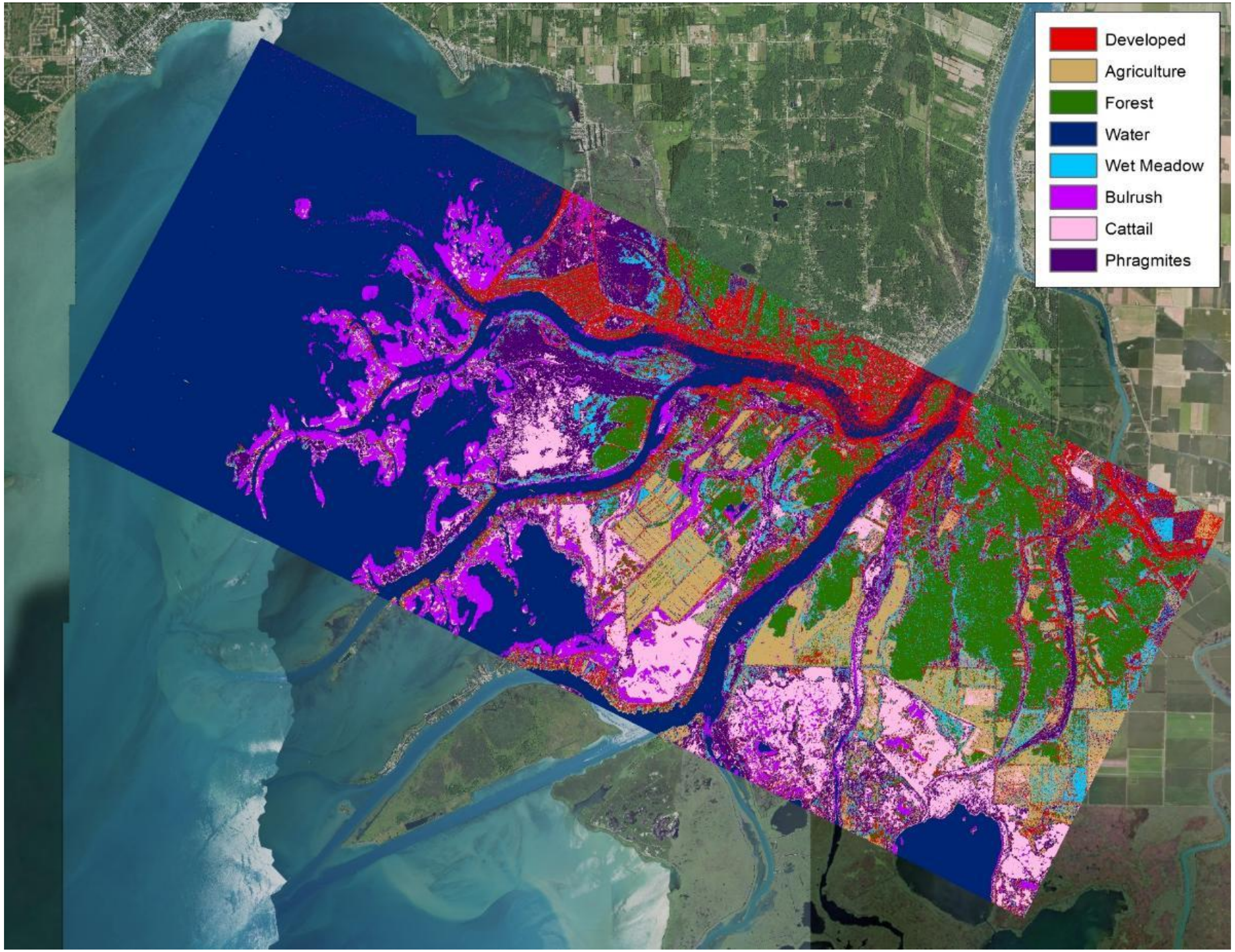
Overall Accuracy 77%
User's accuracies 53-93% for individual classes

Classification results: L-band



Overall Accuracy 83%
User's accuracies 55-97% for individual classes

Classification results: S-& L-band

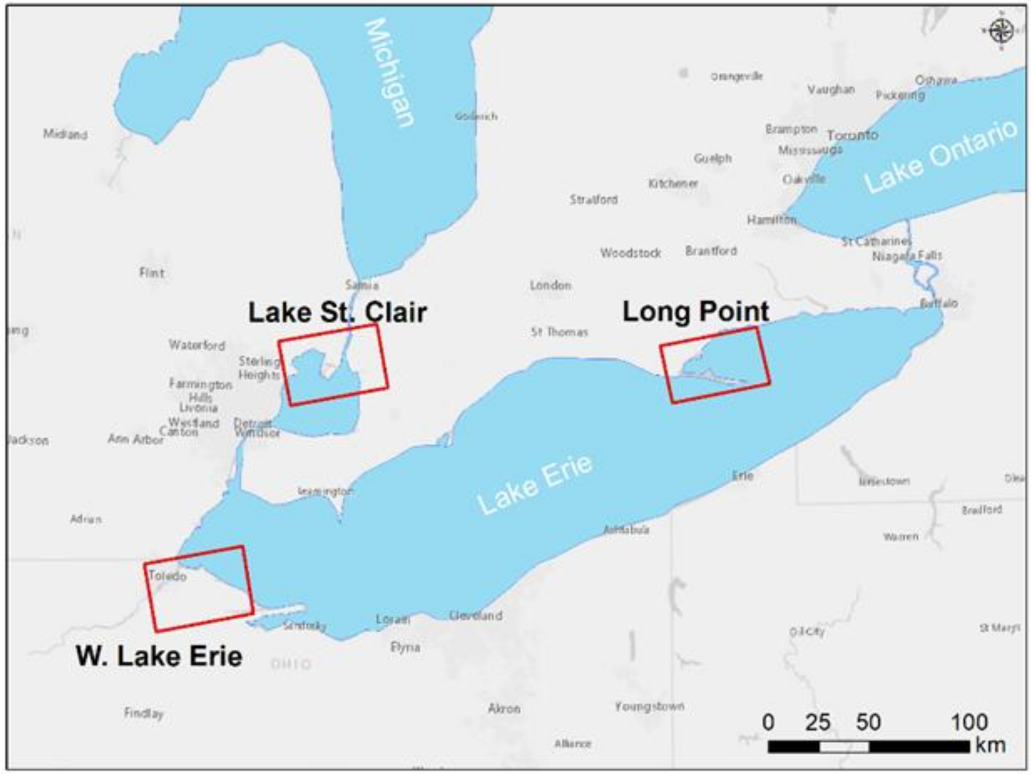


Overall Accuracy 92%
User's accuracies 74-98% for individual classes

Results are comparable to using optical and SAR

Research Question #2

2) Do physically based scattering models explain polarimetric L- and S-band SAR interactions with wetland systems or is anomalous behavior sometimes exhibited for double bounce, as was previously found for C- band (Atwood et al. 2019)?

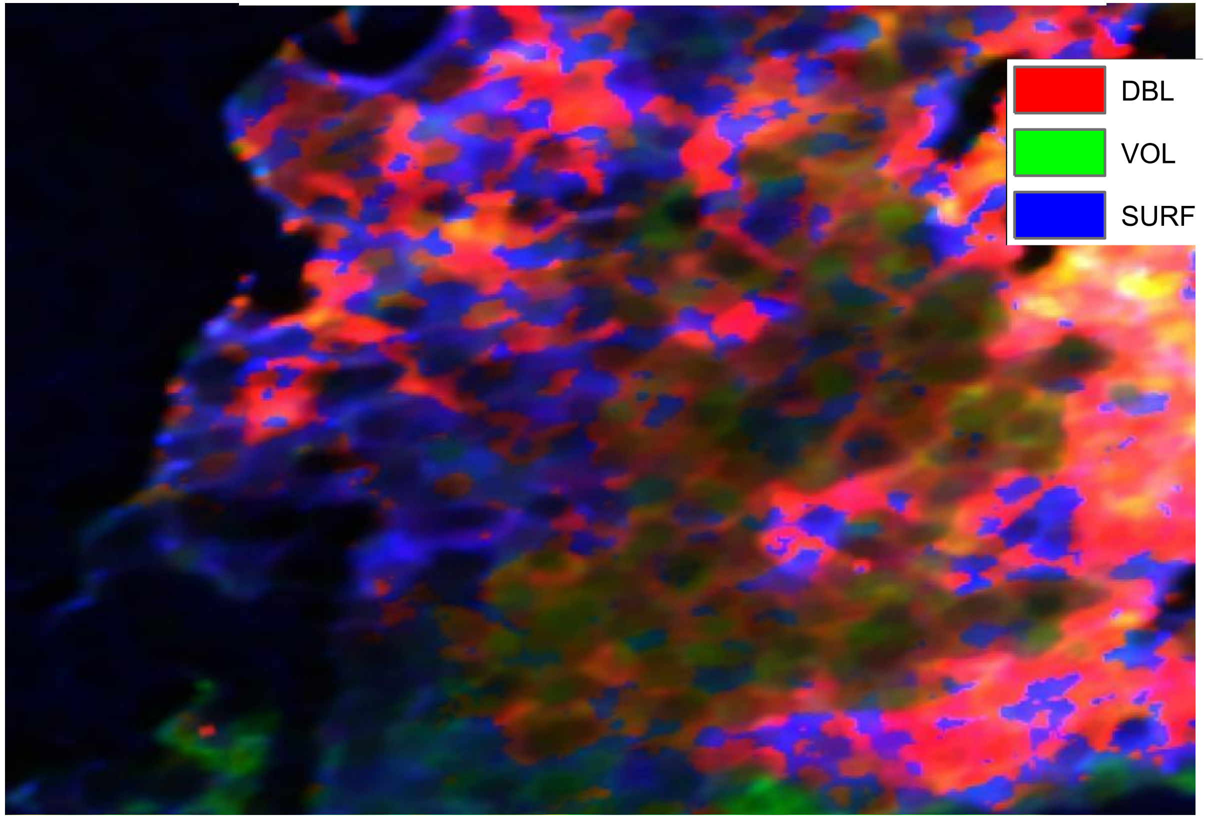


Double bounce was sometimes attributed to surface scatter at specific incidence angles and vegetation stem size

Misattribution of Scattering Mechanisms

- Common three component decompositions (Freeman-Durden, Yamaguchi, NNED, etc.) may misattribute double bounce scattering to surface scattering due to reliance on a static threshold of co-polarized phase difference (Atwood et. al, 2019; Ahern et. al, 2022)

Radarsat-2 C-band fall imagery



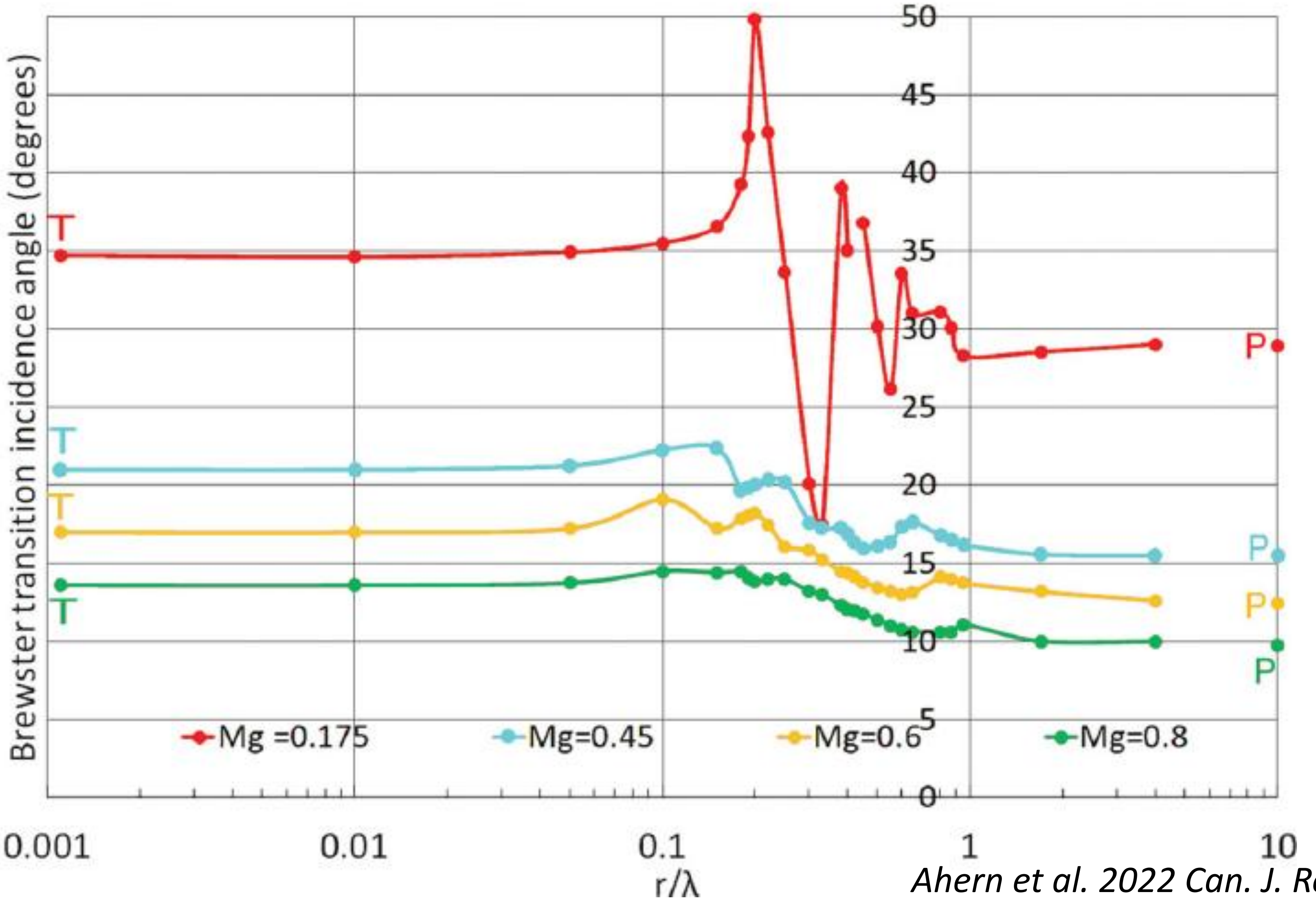
Brewster Transition Incidence Angle

Mg- gravimetric moisture of vegetation

Low moisture in vegetation results in larger anomalies

Radius of cylinders (vegetation stems) relative to the wavelength affect the anomaly (r/λ)

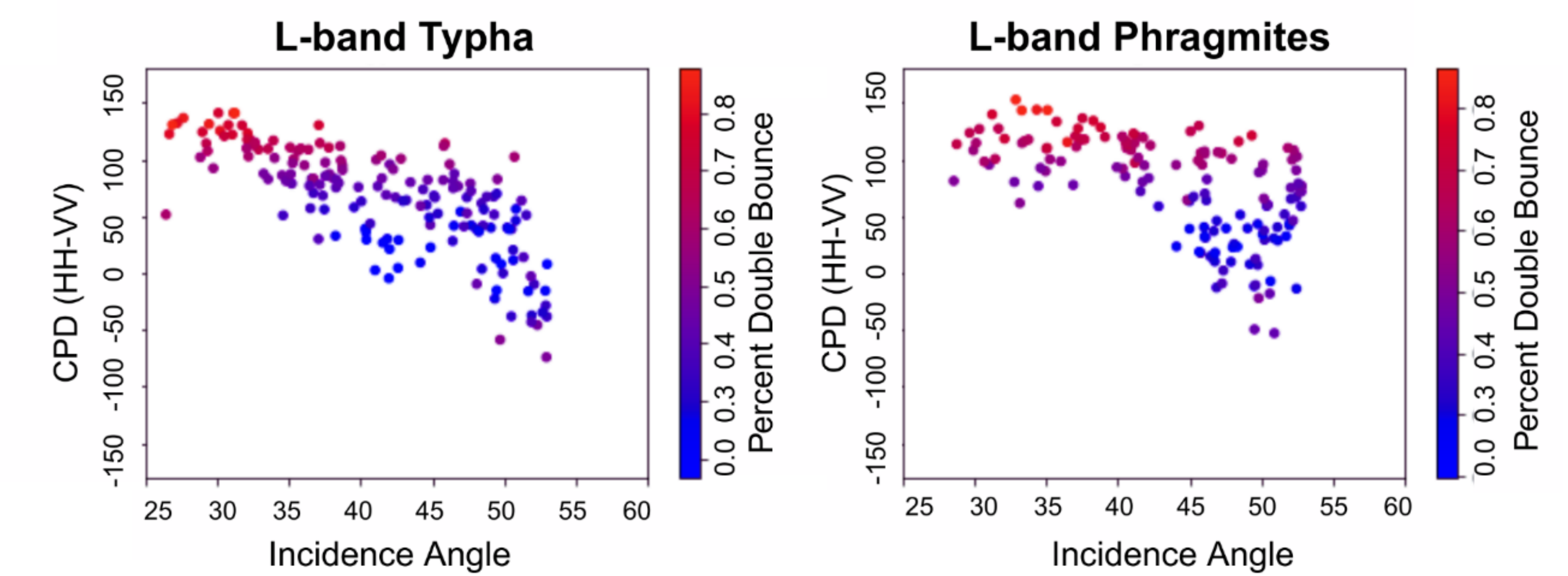
T- thin cylinder,
P - Planar



Ahern et al. 2022 Can. J. Remote Sensing

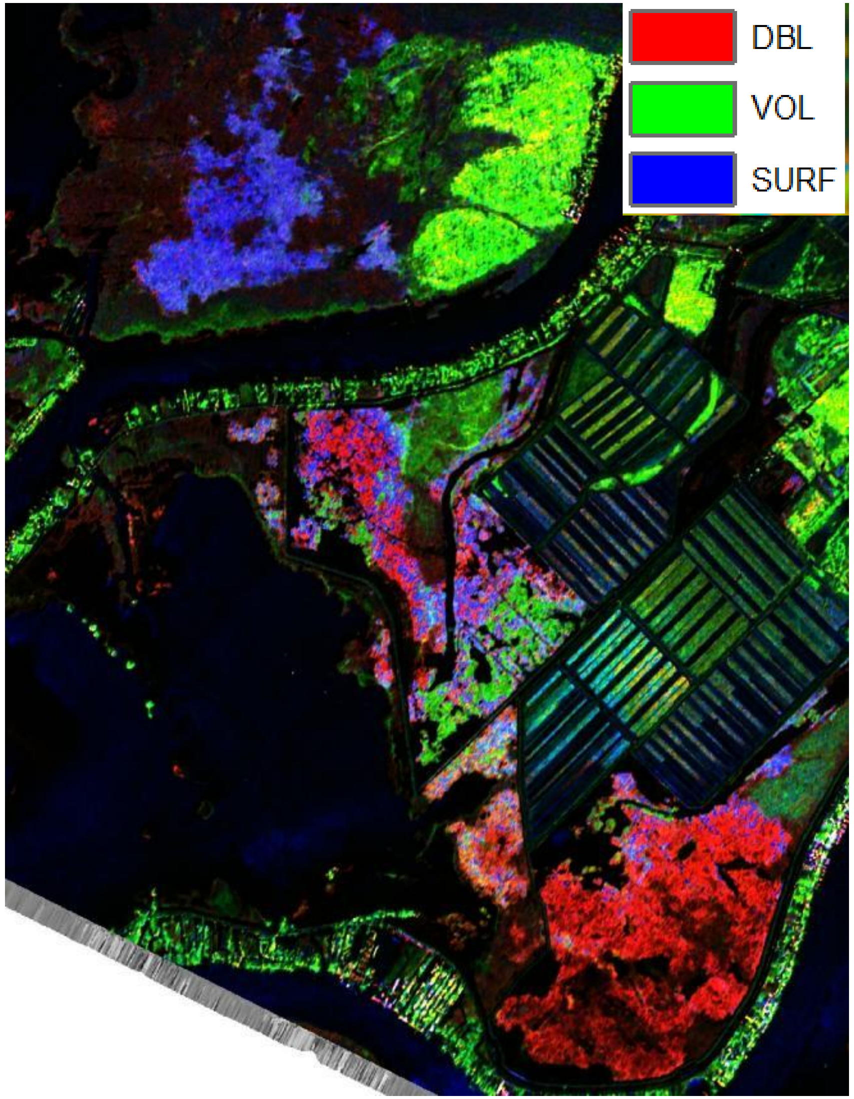
Co-Pol Phase Difference and Decomposed Double Bounce

- Single bounce scatter ideally (in the absence of noise) has an expected CPD of 0°,
- Double bounce scattering has expected CPD of 180°,
- Volume scatter has an expected uniform distribution from CPD -180° to 180°



- ASAR incidence angles transition from 26° to 53° over a swath width of approximately 10 km.
- For L-band, we found incorrect classification of double-bounce scattering was evident especially at shallow (large) incidence angles, with attribution as single bounce scattering becoming noticeable at approximately 35° and becoming completely misattributed at approximately 40°

L-band, 7/14/21, 26-53º inc. ang.

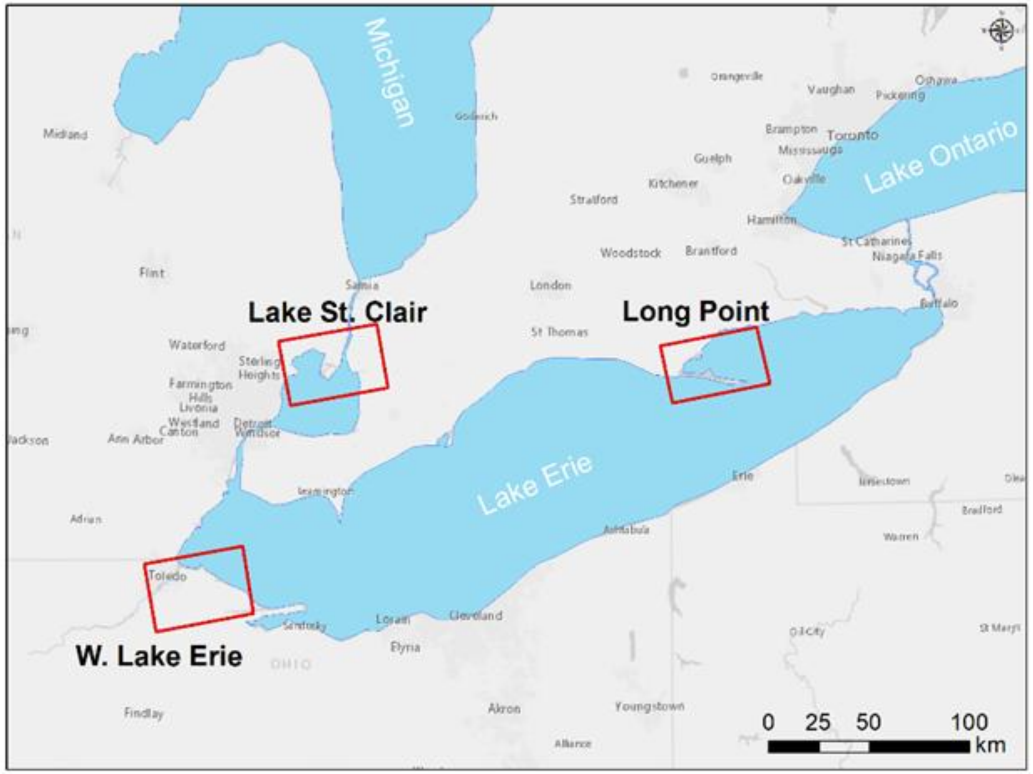


3-component decomposition

Co-Pol Phase Diff (HH-VV)

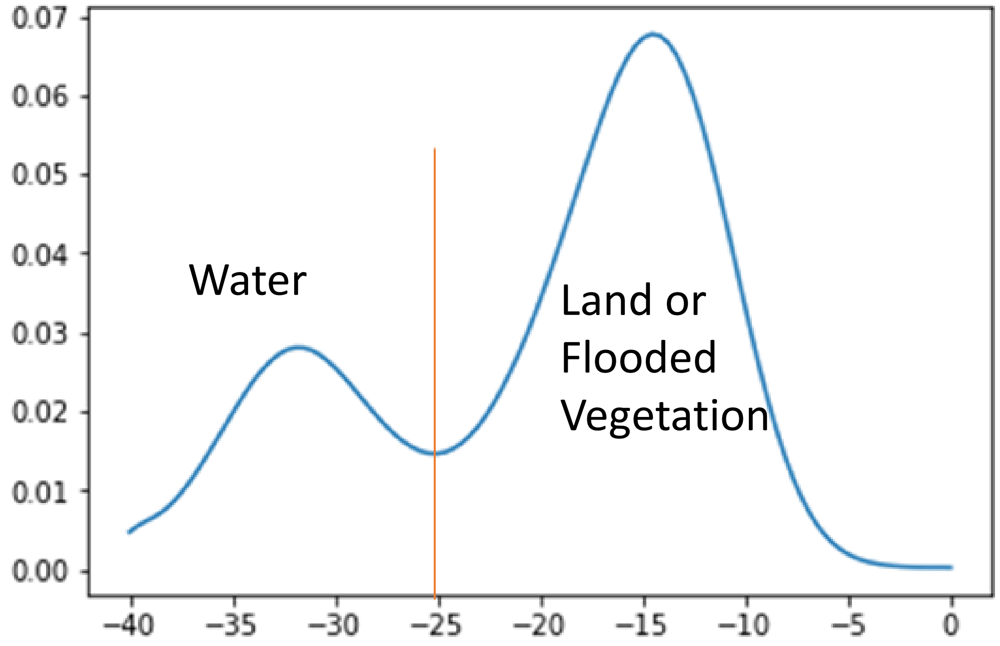
Research Question #3

3) What are the vegetation structure and biomass limitations of L-band vs. C- or S-band in monitoring wetland inundation?



Assessment of Vegetation Structure Limitations at C-, S-, L-band

- To do this we used L- and S-band ASAR and a Radarsat-2 C-band image collected within 10 days.
- We applied a thresholding method to distinguish flooded vegetation from open water and non-inundated areas at the 3 frequencies
- We use histograms of cross-polarized backscatter to separate open water from land and flooded vegetation via Otsu-thresholding
- We used the cross-polarized ratio (HH/VH or VV/VH) to distinguish flooded vegetation from non-flooded vegetation

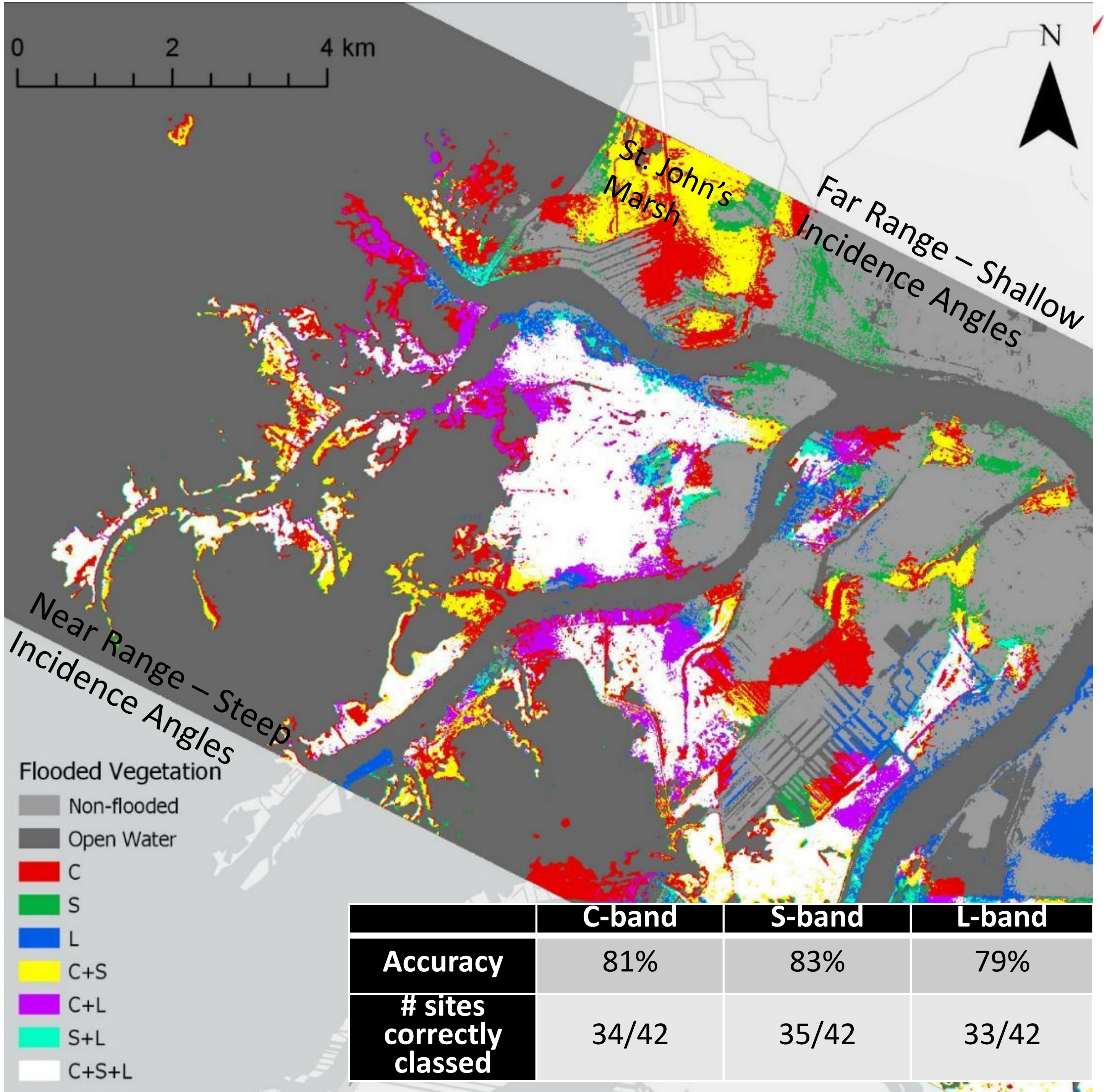


Threshold between land and water is selected by analyzing the PDF of the HV backscatter dB image

Mapping Inundation

Michigan Tech Research Institute

- S- and L-band are significantly impacted by incidence angle effects between near range of 26° and far range of 53° (south to north)
- C-band from Radarsat-2 had a range of just a few degrees (29°-32°) – no affect of incidence
- **NISAR has an incidence angle range of 33°–47°, covering a swath width of over 240 km**
- S-band was less impacted by shallow incidence angles, as evidenced by the extensive classification of inundated area in St. John's Marsh, in the northern portion of the St. Clair Delta study area (yellow)
- **Bottom line, incidence angle and wavelength-vegetation stem size and density dependencies exist**
  - Multiple frequencies provide the best assessment of inundation condition



	C-band	S-band	L-band
Accuracy	81%	83%	79%
# sites correctly classed	34/42	35/42	33/42

Summary

- Polarimetric S- and L-band SAR can effectively discriminate between common Great Lakes wetland taxa in flooded conditions
- Confirmed anomalous behavior of scattering and decompositions at L-, S- and C-band which explain errors that may occur in inundation and classification mapping as well as InSAR which requires high coherence
- The plant structure (diameters, heights and density) also restrict which frequency will have penetration limitations or fail to detect vegetation presence
- For all cases there were incidence angle limitations, and incidence angles shallower than 35° had higher uncertainty in inundation detection capability

Genera	Stem diameter mean	Stem height mean	Stem density (stems/m^2)	Inundation Map Success		
				C-band	S-band	L-band
Typha	1.6 cm	1.8-2.2 m	20-28	Y	Y	Y
Schoenoplectus	0.80 cm	1.4-1.96 m	13.8 - 195	Y	Y	Limited
Phragmites	0.81-1.04 cm	2.05-2.9 m	38-44	Volume scatter	Volume scatter	Y

Michigan Tech Research Institute

NISAR Wetland Publications

Special Issue

NISAR Global Observations for Ecosystem Science and Applications

Message from the Guest Editors

The NASA–ISRO Synthetic Aperture Radar (NISAR) mission, a collaboration between the National Aeronautics and Space Administration (NASA) and the Indian Space Research Organization (ISRO), was designed to provide observations of global ecosystems and land surfaces to systematically quantify their state and changes thereof. The mission is planned to launch in 2023, starting with the provision of data for use in a variety of ecosystem sciences and applications, including mapping vegetation above ground biomass, wetland inundation, cropland extent and classification, freeze/thaw monitoring and soil moisture monitoring. The proposed Special Issue calls for submissions presenting the results of NISAR-related research and the development of science algorithms for the ecosystem biophysical parameter retrieval, calibration and validation of science products, as well as applications of management and monitoring in different ecosystems.

Guest Editors

Dr. Sassan Saatchi
NASA Jet Propulsion Laboratory, Pasadena, CA 91109, USA

Prof. Dr. Paul Siqueira
Department of Electrical and Computer Engineering, University of Massachusetts Amherst, Amherst, MA 01003, USA

Dr. Anup Das
Indian Space Research Organization–Space Applications Centre (SAC), Ahmedabad, India

Deadline for manuscript submissions

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Evaluation of L- and S-Band Polarimetric Data for Monitoring Great Lakes Coastal Wetland Health in Preparation for NISAR

by Michael J. Battaglia and Laura L. Bourgeau-Chavez *

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Remote Sens. **2025**, *17*(21), 3506; https://doi.org/10.3390/rs17213506

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(This article belongs to the Special Issue NISAR Global Observations for Ecosystem Science and Applications)

Open Access | Article

Characterizing Tidal Marsh Inundation with Synthetic Aperture Radar, Radiometric Modeling, and In Situ Water Level Observations

by Brian T. Lamb [1,2,*], Kyle C. McDonald [1,2,3], Maria A. Tzortziou [1,2,4] and Derek S. Tesser [1,2,5]

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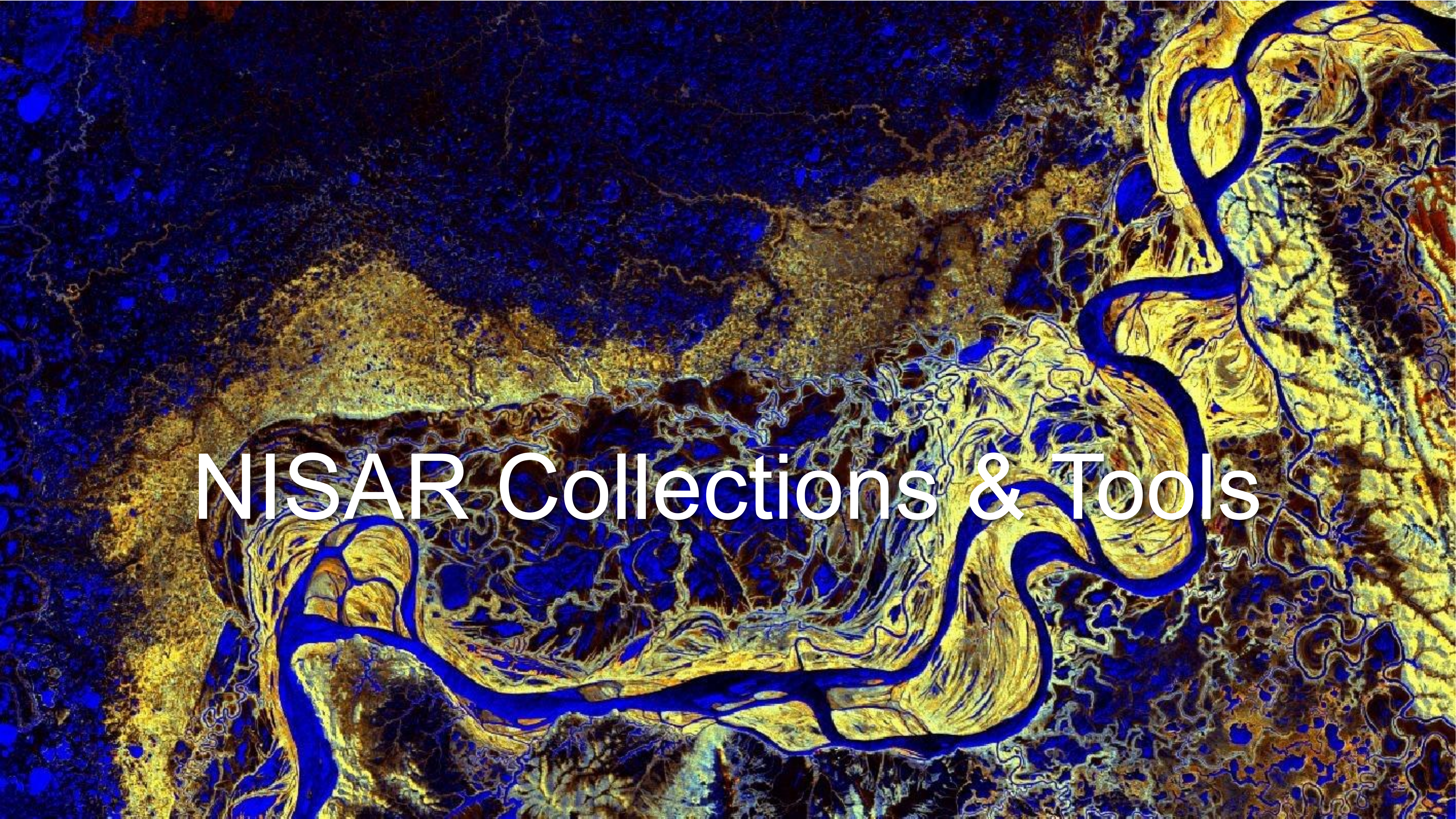
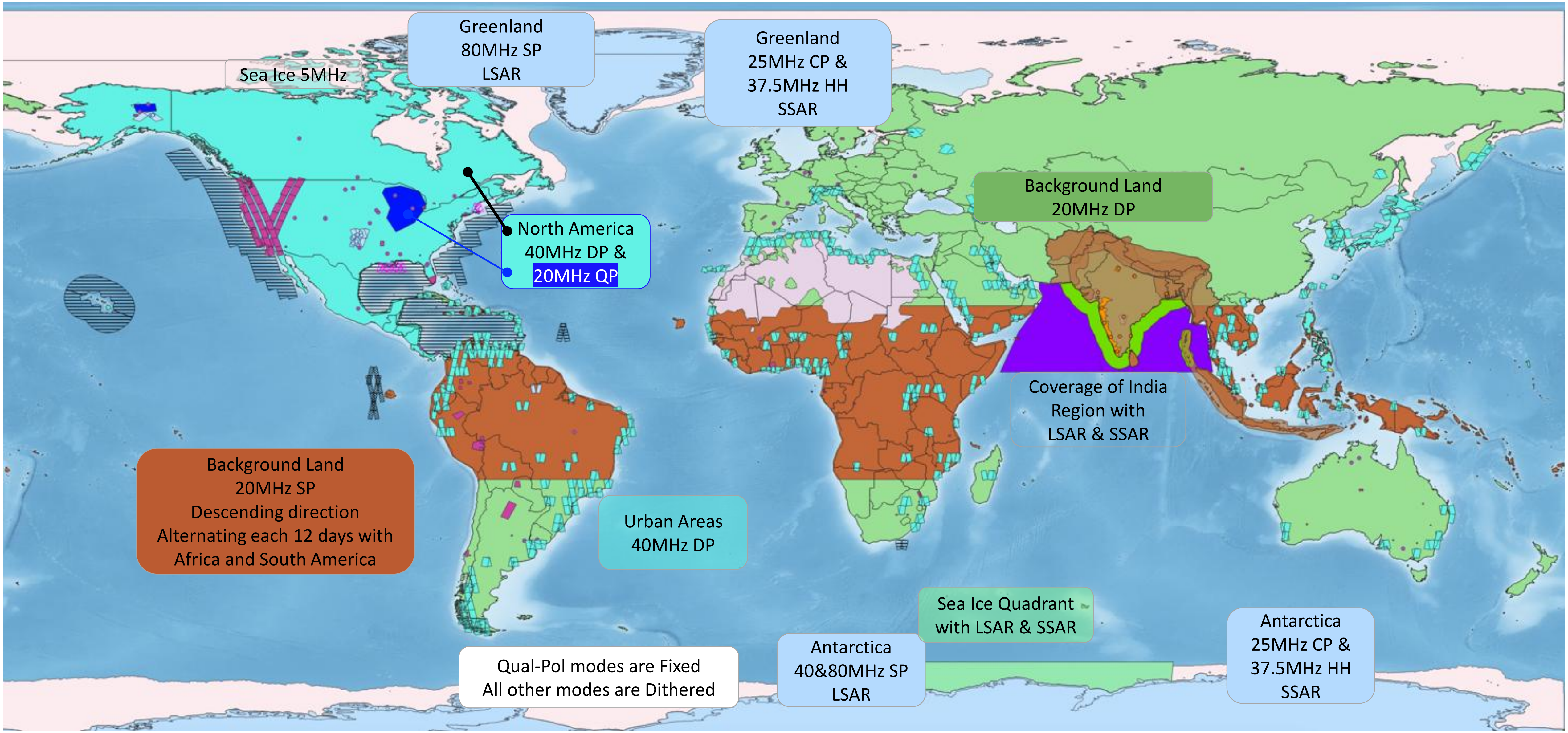
* Author to whom correspondence should be addressed.

Remote Sens. **2025**, *17*(2), 263; https://doi.org/10.3390/rs17020263

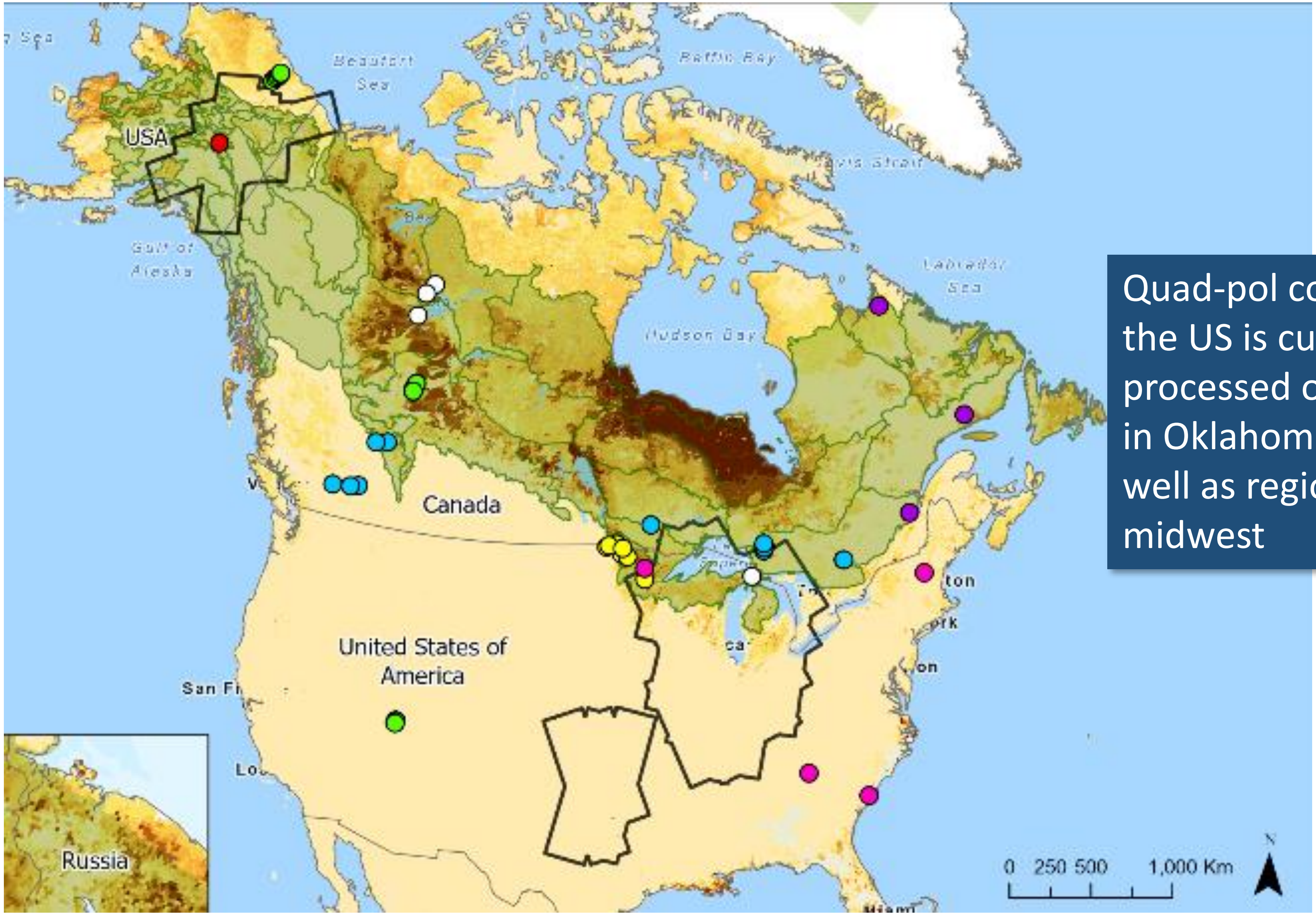
NISAR Collections & Tools



Observing land–based coverage

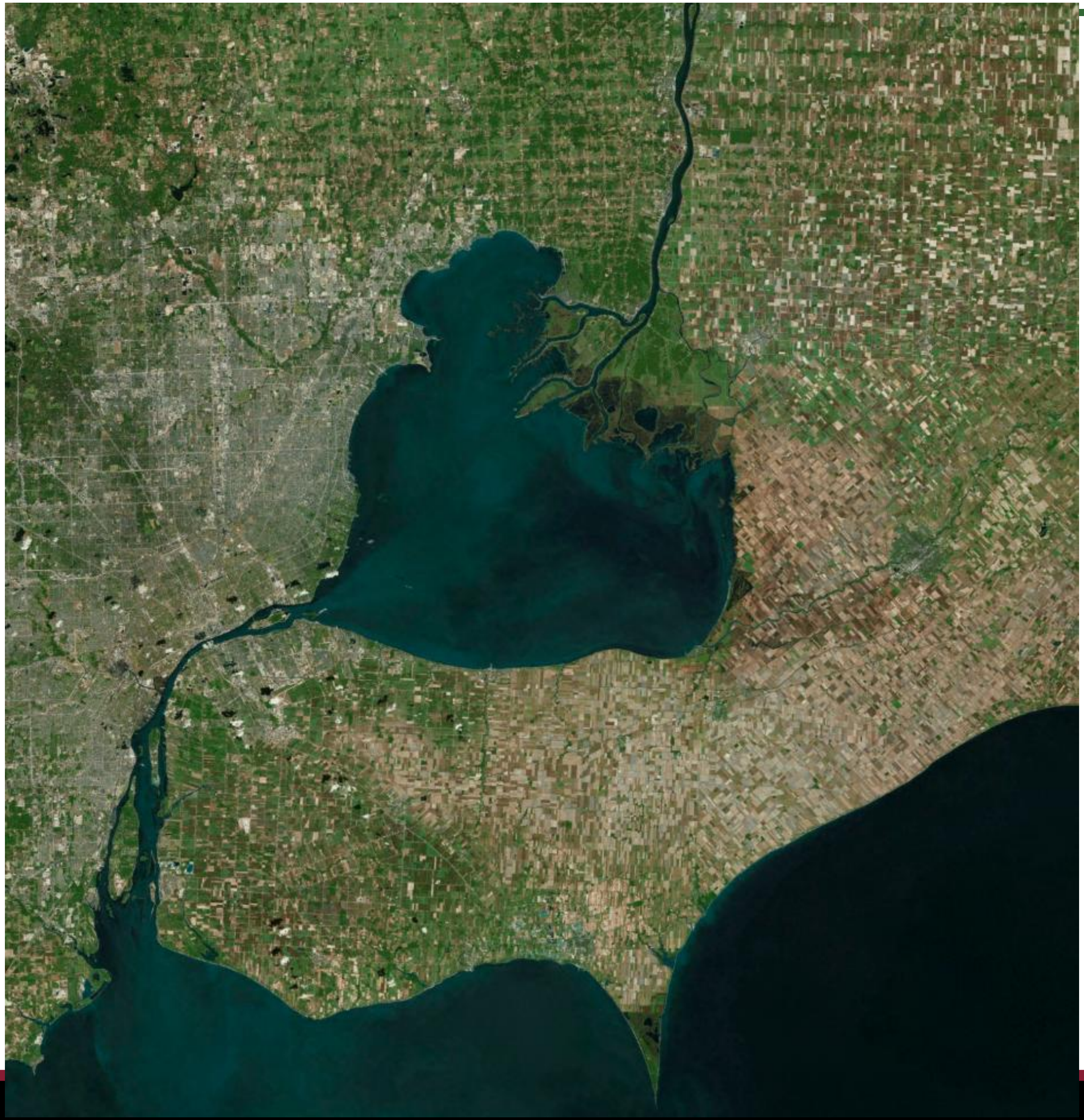


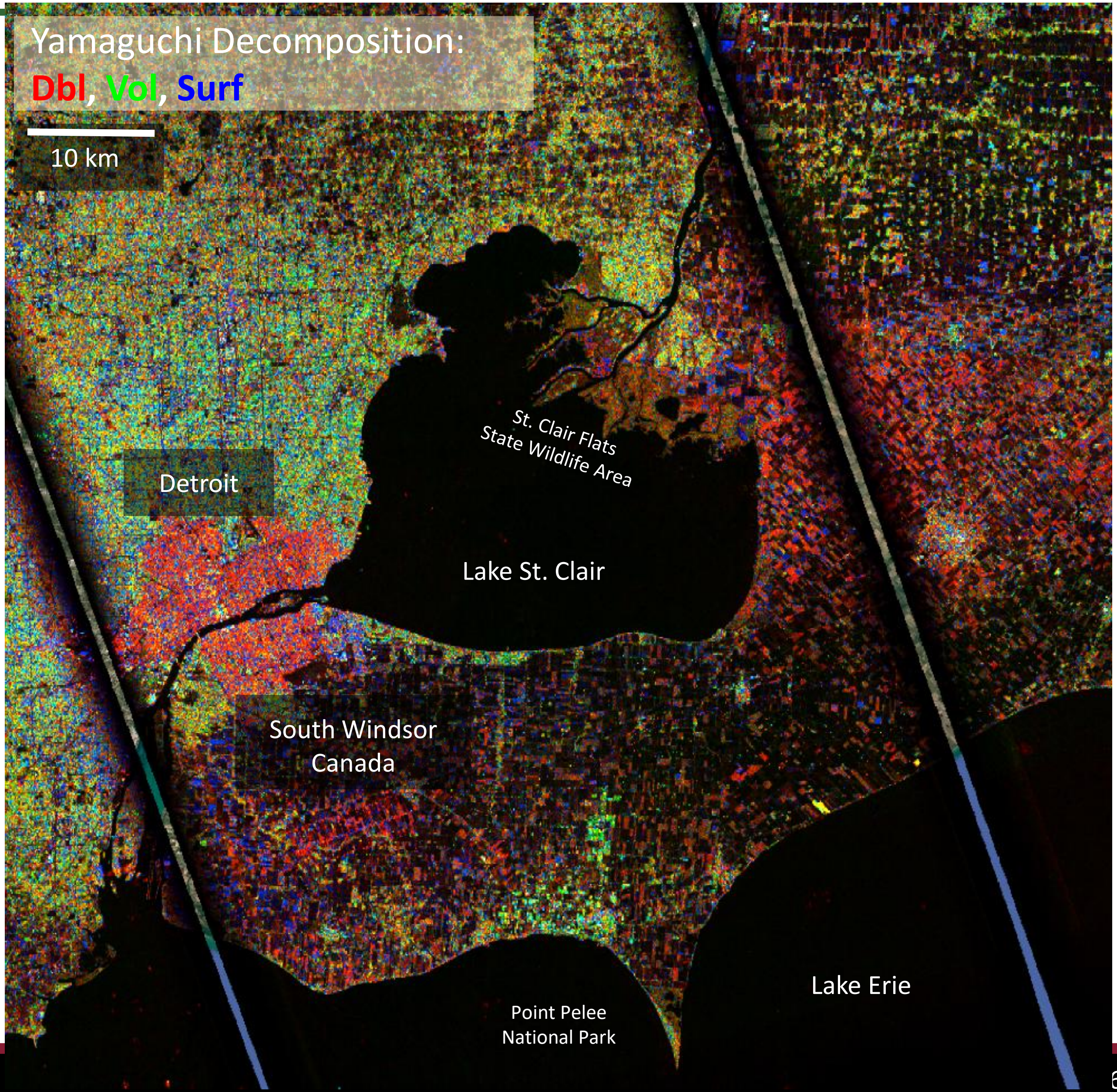
Quad-pol coverage and processing over the US



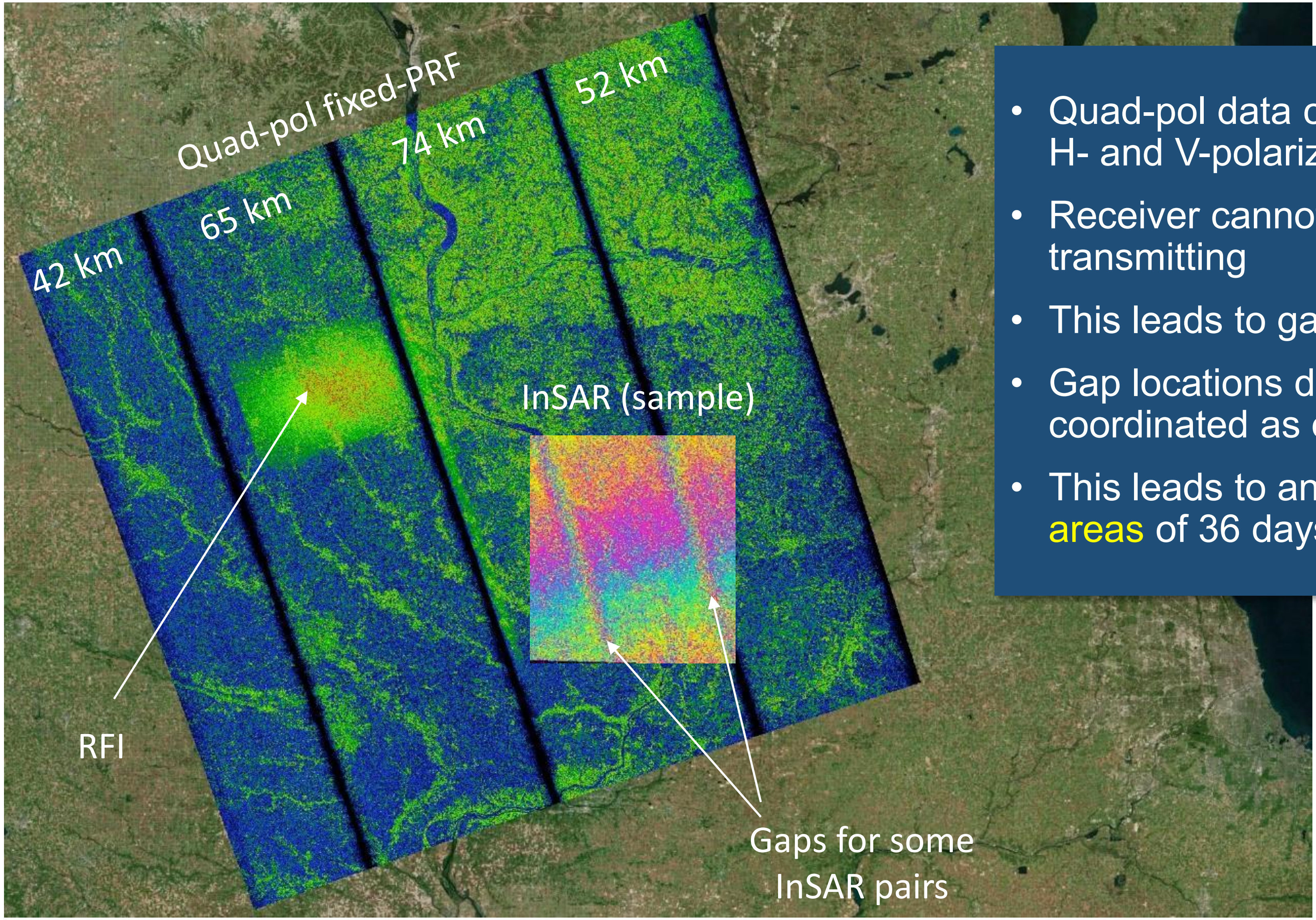
Quad-pol coverage over the US is currently being processed over cal/val sites in Oklahoma & Alaska, as well as regions in the US midwest

Quad-pol NISAR data
Yamaguchiu Decomposition

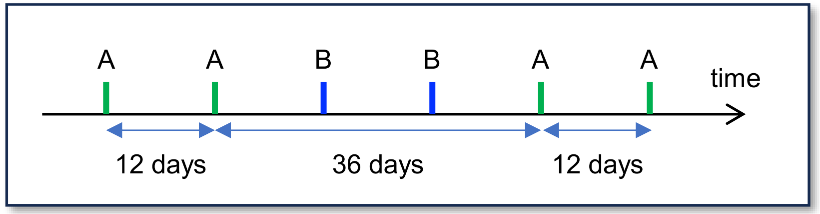


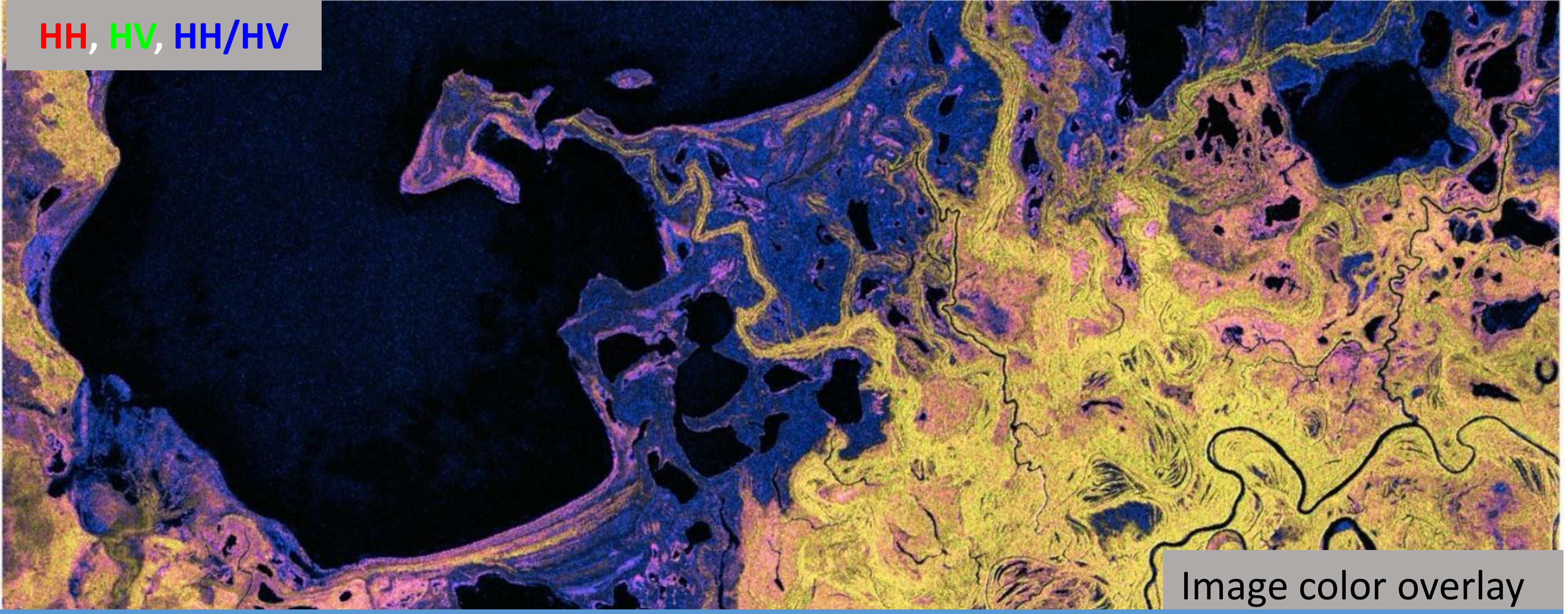


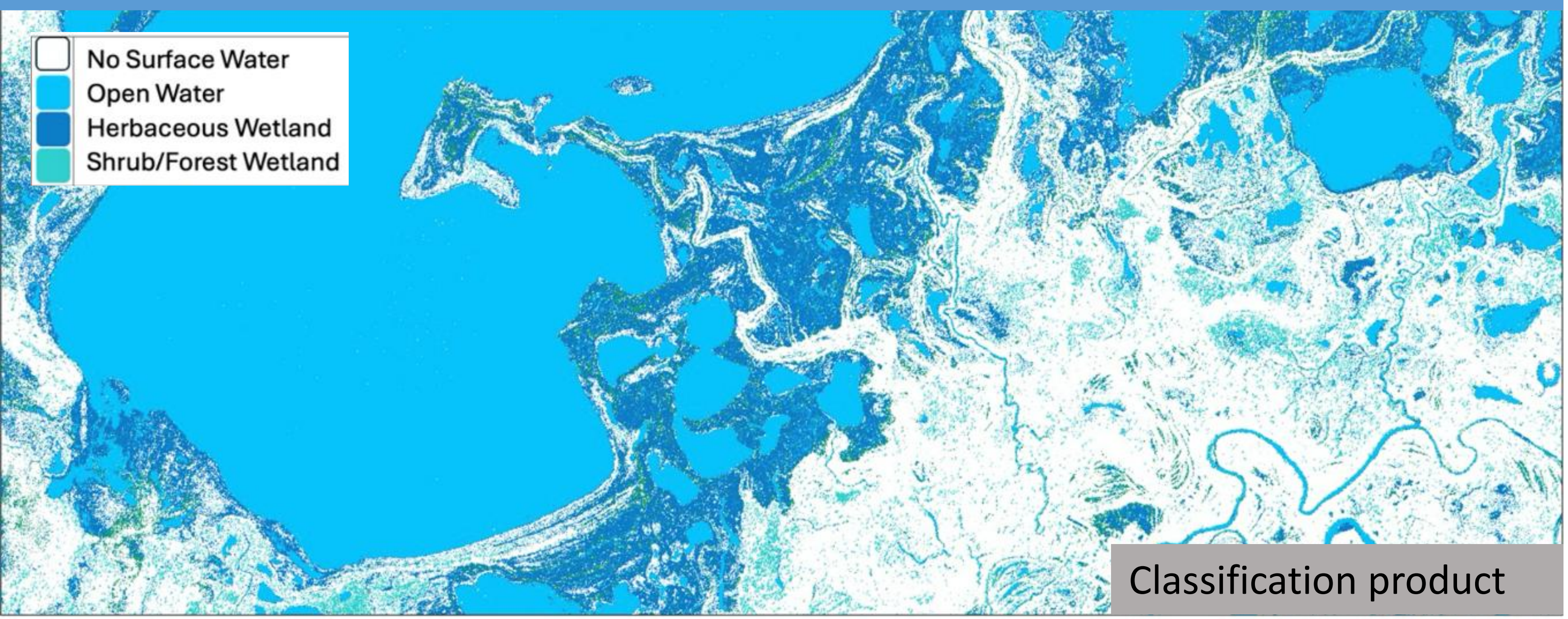
Quad-Pol Imaging with Gaps



- Quad-pol data collection has to alternately transmit H- and V-polarizations
- Receiver cannot operate when the system is transmitting
- This leads to gaps in the ground projected data
- Gap locations depend on one of two positions and coordinated as observation pairs
- This leads to an effective repeat-orbit period in some areas of 36 days instead of 12 days.







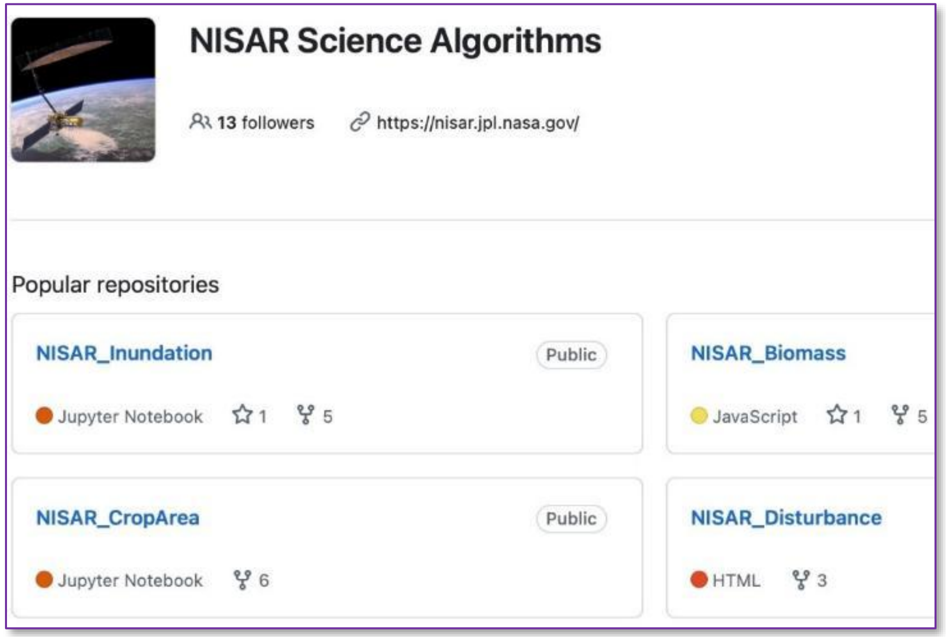
NISAR Inundation

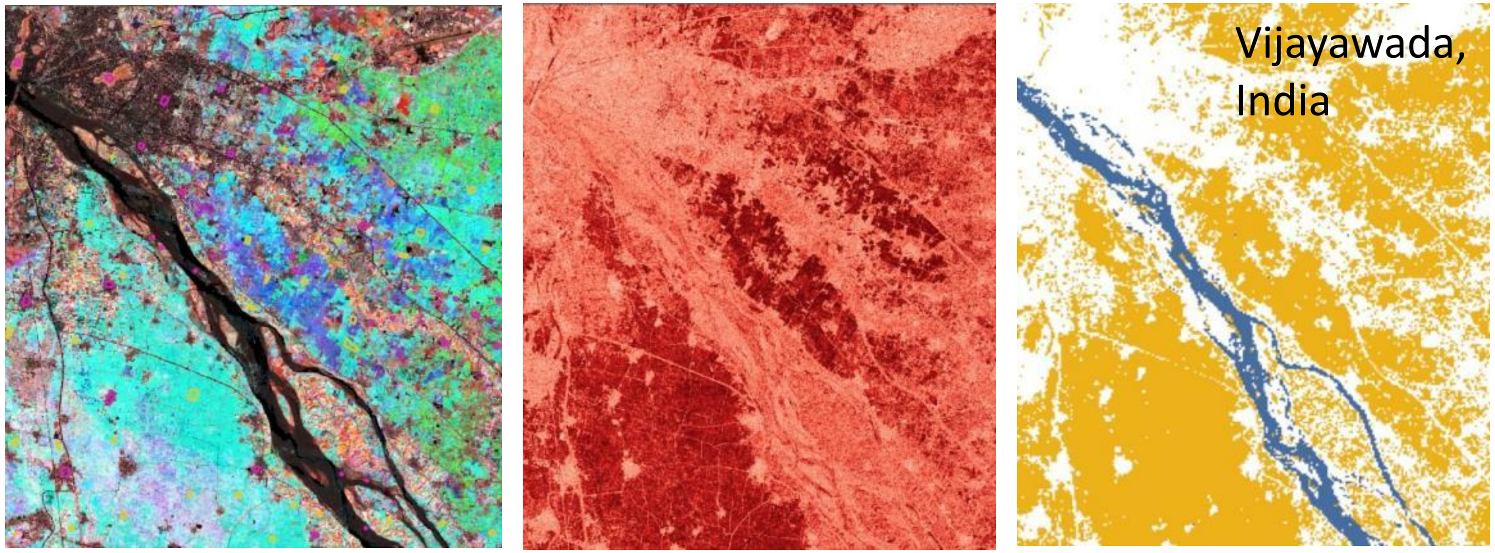
- Peace-Athabasca Delta, Alberta, Canada
- NISAR image collected on September 20, 2025
- L-band Dual-pol (HH/HV) at 20 MHz reveals striking sensitivity to water surface extent
- NISAR captures the state of the wetland inundation with classification of each pixel in Open Water, Herbaceous Wetland, Shrub/Forest Wetland, and No Surface Water

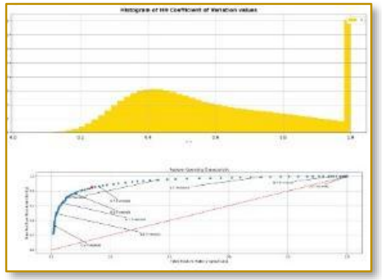
Courtesy of B. Chapman

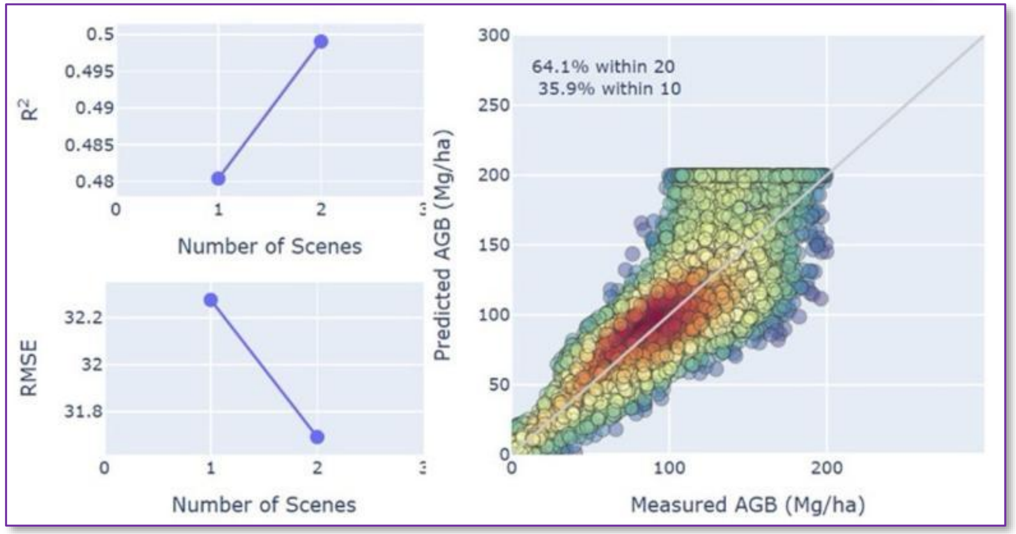
Jupyter Notebooks for Ecosystems

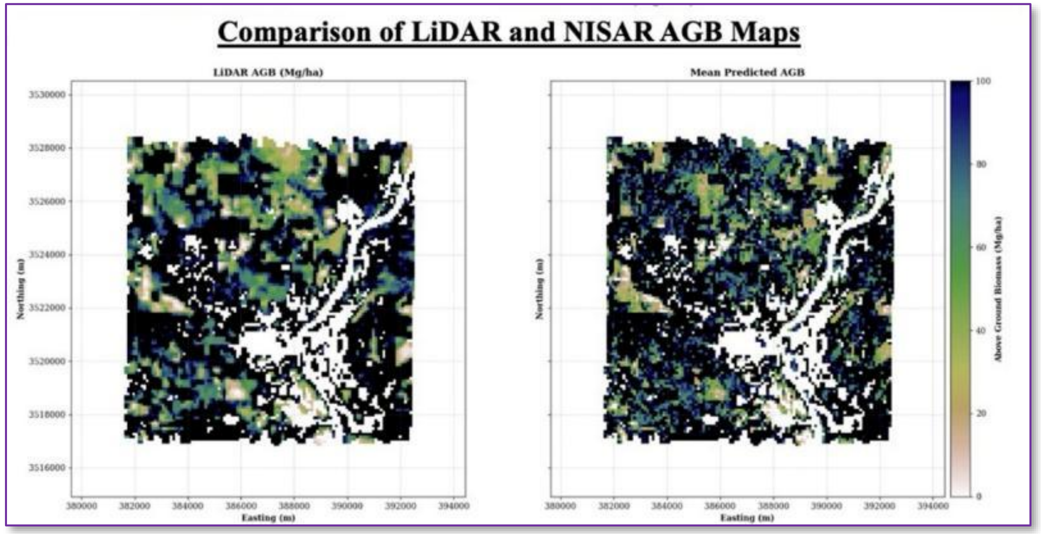
github.com/NISAR-Science-Algorithms





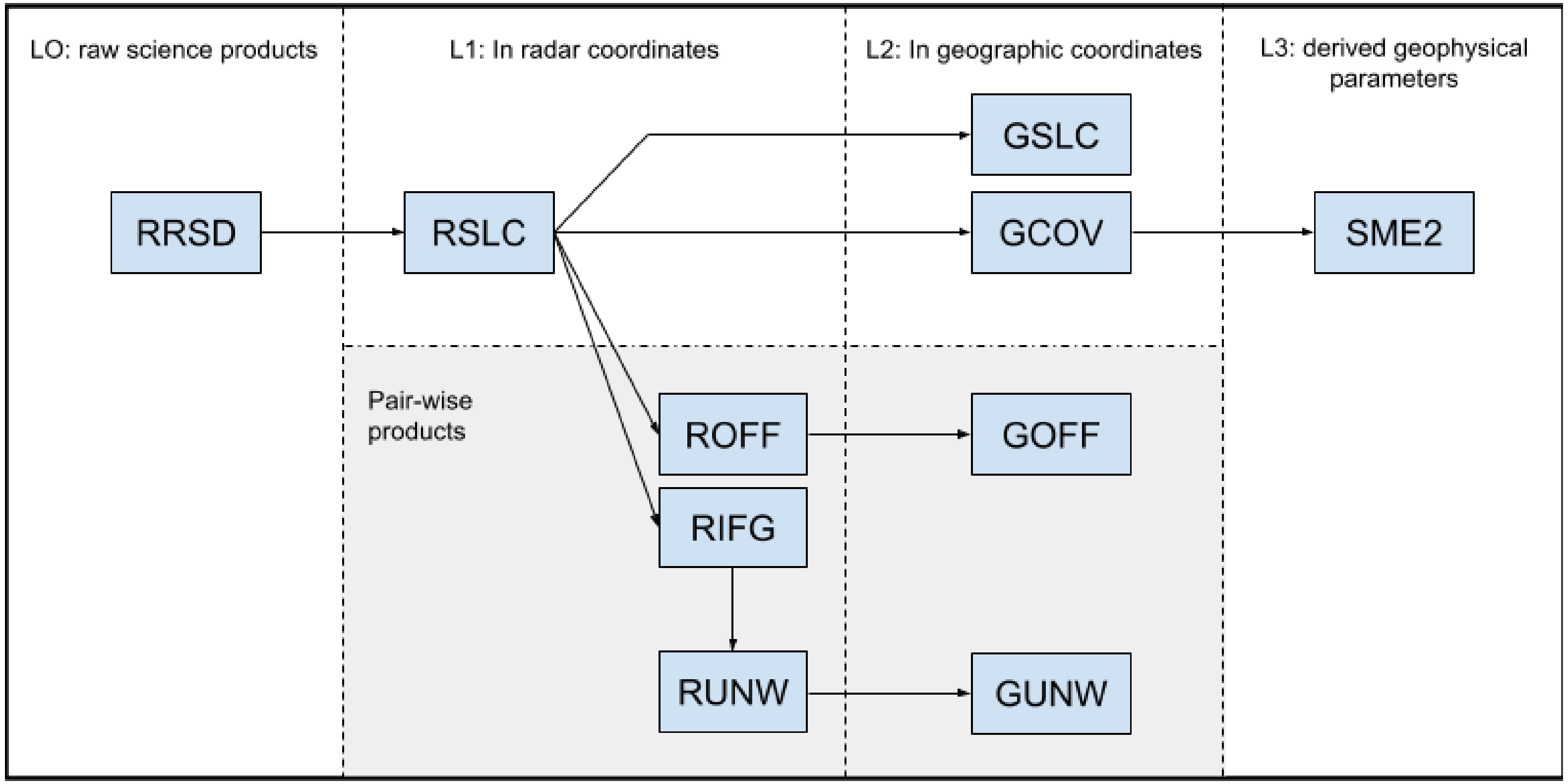






Different Flavors of NISAR data

- Historically, working with SAR data has required additional skills
  - remove topographic signatures (radiometric terrain correction)
  - geolocation & co-registration
  - interferometric products
- NISAR project team has worked hard to remove these barriers and make it easy for end users to start working with data



https://nisar-docs.asf.alaska.edu/products-overview/

NASA ARSET NISAR Training

Harnessing NISAR: Next-Generation Radar Observations for Earth Applications

- July 2, 9, & 16, 2026
- 11:30-1:30 (English) or 14:30-16:30 (Spanish) EDT
  - Session 1: An Introduction to NISAR
  - Session 2: NISAR Data Access and Tools
  - Session 3: Monitoring Earthquakes, Volcanoes, and Landslides with NISAR's InSAR Capability
  - https://go.nasa.gov/4x2qqVG

polsartools

Principal author:
Narayanarao Bhogapurapu (now at NIT),
and also Paul Siqueira, Avik Bhaticharya

- Working with polarimetric data for large data sets like NISAR can become overbearing.
- A command-line tool has been built to
  - read data sets & convert them into standard matrix format
  - perform speckle filtering
  - apply basic methods for decomposition
  - create informative plots

Installation is as easy as

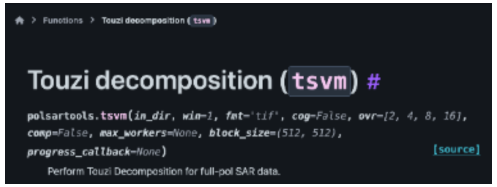
```
pip install polsartools
```

source code and further details are on GitHub


Yamaguchi 4-Component decomposition (yam4c_fp)

polsartools.yam4c_fp(in_dir, model='', win=1, fmt='tif', cog=False, ovr=[2, 4, 8, 16], comp=False, max_workers=None, block_size=(512, 512), progress_callback=None) [source]

Perform Yamaguchi 4-Component Decomposition for full-pol SAR data.

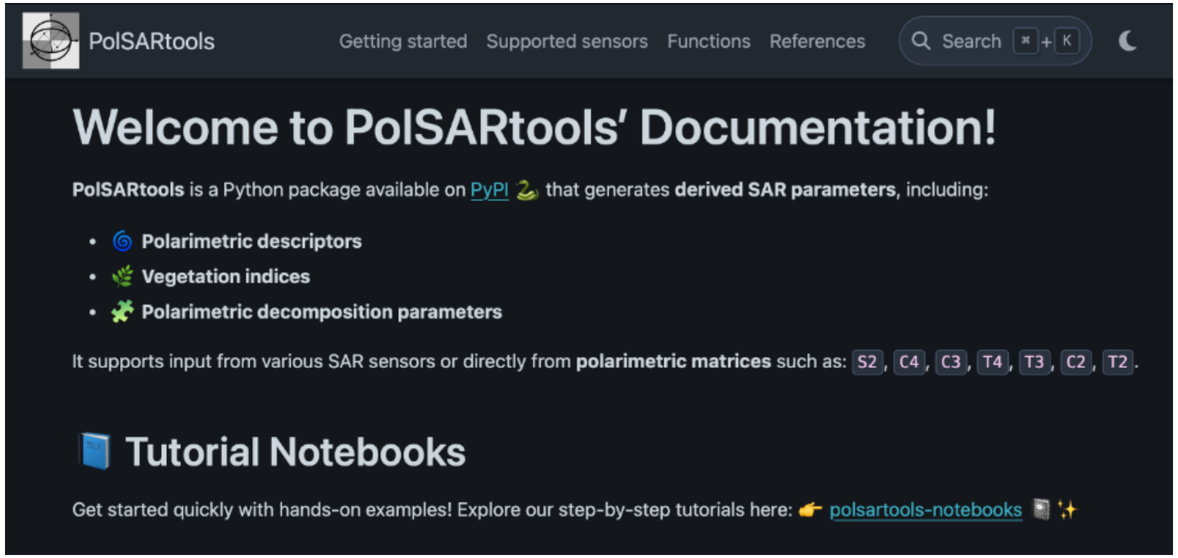

Functions > Touzi decomposition (tsvm)

Touzi decomposition (tsvm) #

polsartools.tsvm(in_dir, win=1, fmt='tif', cog=False, ovr=[2, 4, 8, 16], comp=False, max_workers=None, block_size=(512, 512), progress_callback=None) [source]

Perform Touzi Decomposition for full-pol SAR data.

```
pst.import_nisar_gslc(h5file[0], azlks=4, rglks=2,mat='C4')
pst.rgb(red_channel, green_channel, blue_channel)
```


PolSARtools   Getting started   Supported sensors   Functions   References   Search

Welcome to PolSARtools' Documentation!

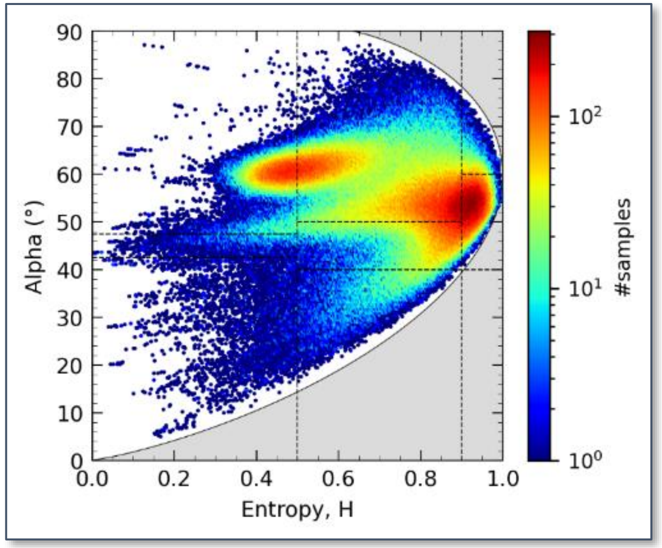
PolSARtools is a Python package available on PyPI that generates **derived SAR parameters**, including:

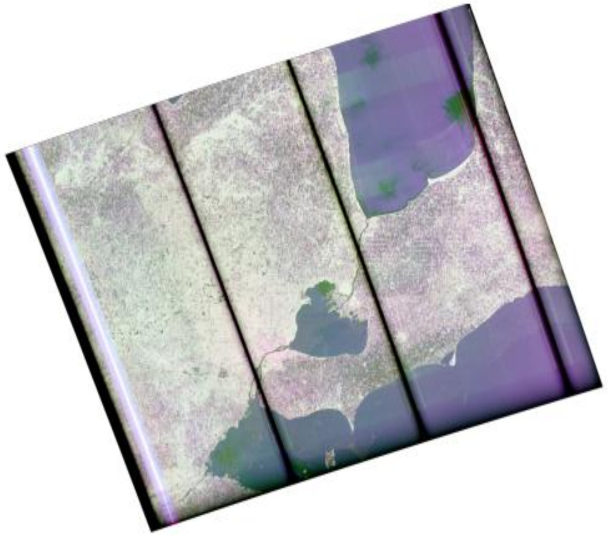
- **Polarimetric descriptors**
- **Vegetation indices**
- **Polarimetric decomposition parameters**

It supports input from various SAR sensors or directly from **polarimetric matrices** such as: S2, C4, C3, T4, T3, C2, T2.

Tutorial Notebooks

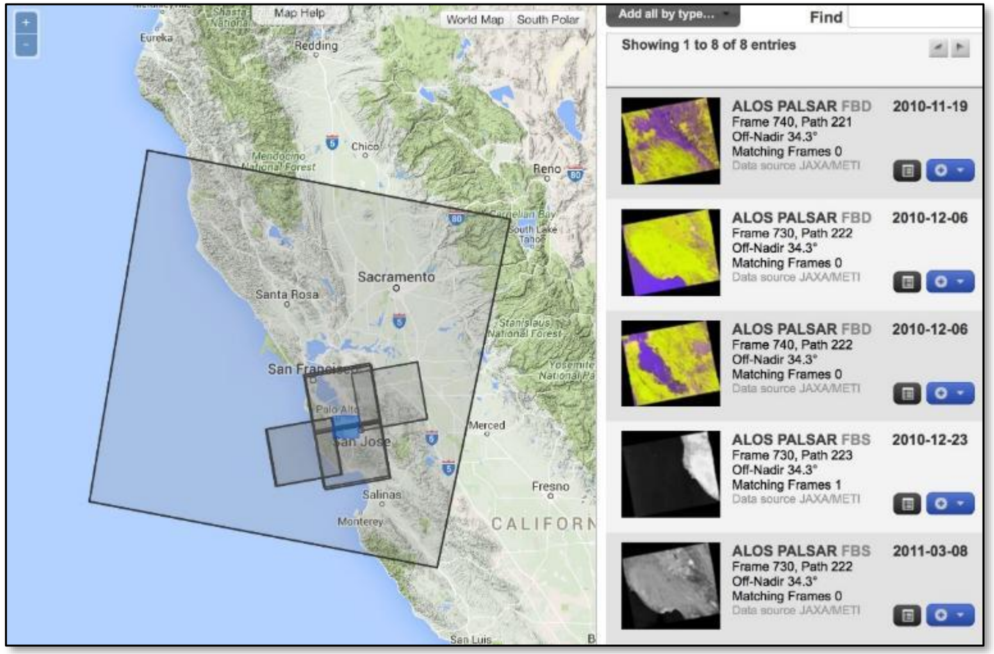
Get started quickly with hands-on examples! Explore our step-by-step tutorials here: polsartools-notebooks

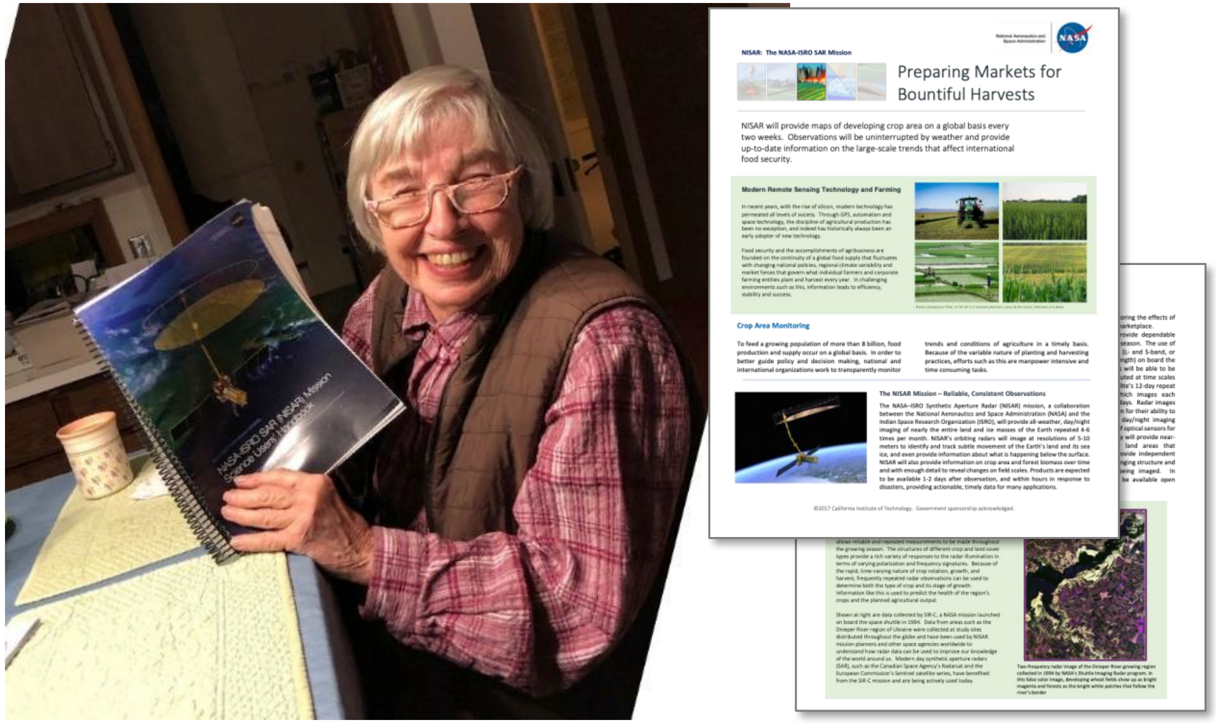




Where to access data and learn more

- Alaska Satellite Facility (ASF; asf.alaska.edu) and Earthdata (earthdata.nasa.gov) have facilities to interactively explore and download data
- Educational resources and computational environments available via these websites
- NISAR resources for learning and exploring applications (nisar.jpl.nasa.gov)
- White papers that provide 1-page flyers that talk about specific applications (science.nasa.gov/mission/nisar/documents/)





NISAR Take Home Messages

- The NISAR mission launched on July 30, 2025
- Starting February 2026 data started to be released to the community
- Mapping resolution is10 m for North America and 20 m globally
- 240 km swath, collected over all land surfaces, globally, two times every 12 days

NISAR will change the way that we use remote sensing data for Ecosystems

The volume of the data is large. This presents both a challenge and opportunity

- Challenge: Working with large data sets, looking at temporal availability, will push algorithms to be executed in the data and computing cloud.
- Opportunity: Data from an instrument like NISAR have not been available before. This will create new pathways to support decision making and learning about the world around us.

Thank you - Questions?

lchavez@mtu.edu