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Monitoring Canada's dynamic water resources using SAR

Brian Brisco

Canada Centre for Remote Sensing

Introduction to Synthetic Aperture Radar for Agriculture
Carleton University February 19-22, 2019



Canada

Outline

- Dynamic Surface Water Mapping
- Flooded Vegetation Mapping
- Wetland Classification
- SAR/Lidar Fusion
- SAR Coherence for Wetland Mapping
- InSAR water Level Estimation

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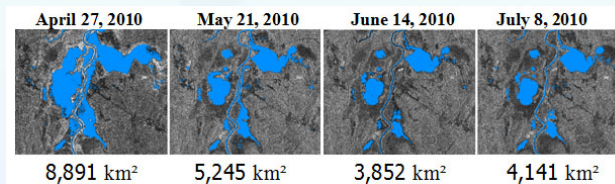
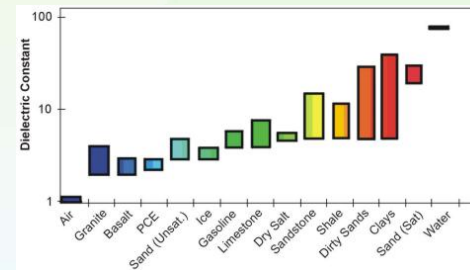
SAR and Water

Well suited for surface water and flood mapping (cloud cover, heavy rains, etc.)

Excellent water/land separation

Can penetrate through vegetation, to identify flooded vegetation

- Dielectric Constant – major target parameter
Water ~ 70 Ice ~ 2-5 Air ~ 1
- Standing Water – Specular
- “Bound” Water – in general backscatter magnitude increases as water increases while penetration depth decreases



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SAR Surface Scattering

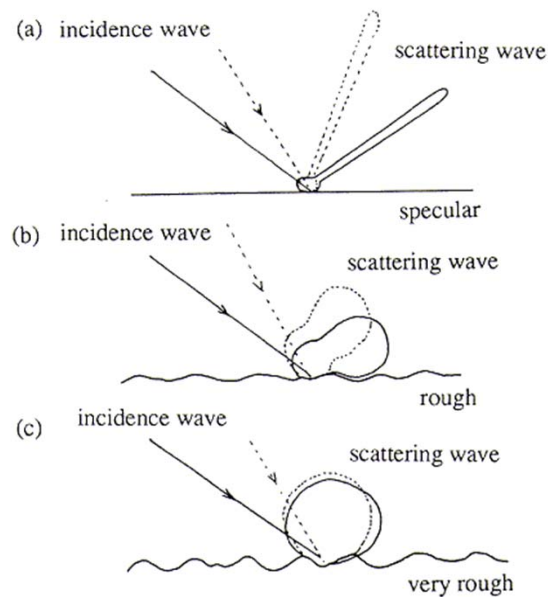


Figure 3.4.1 Surface scattering pattern with different surface roughness



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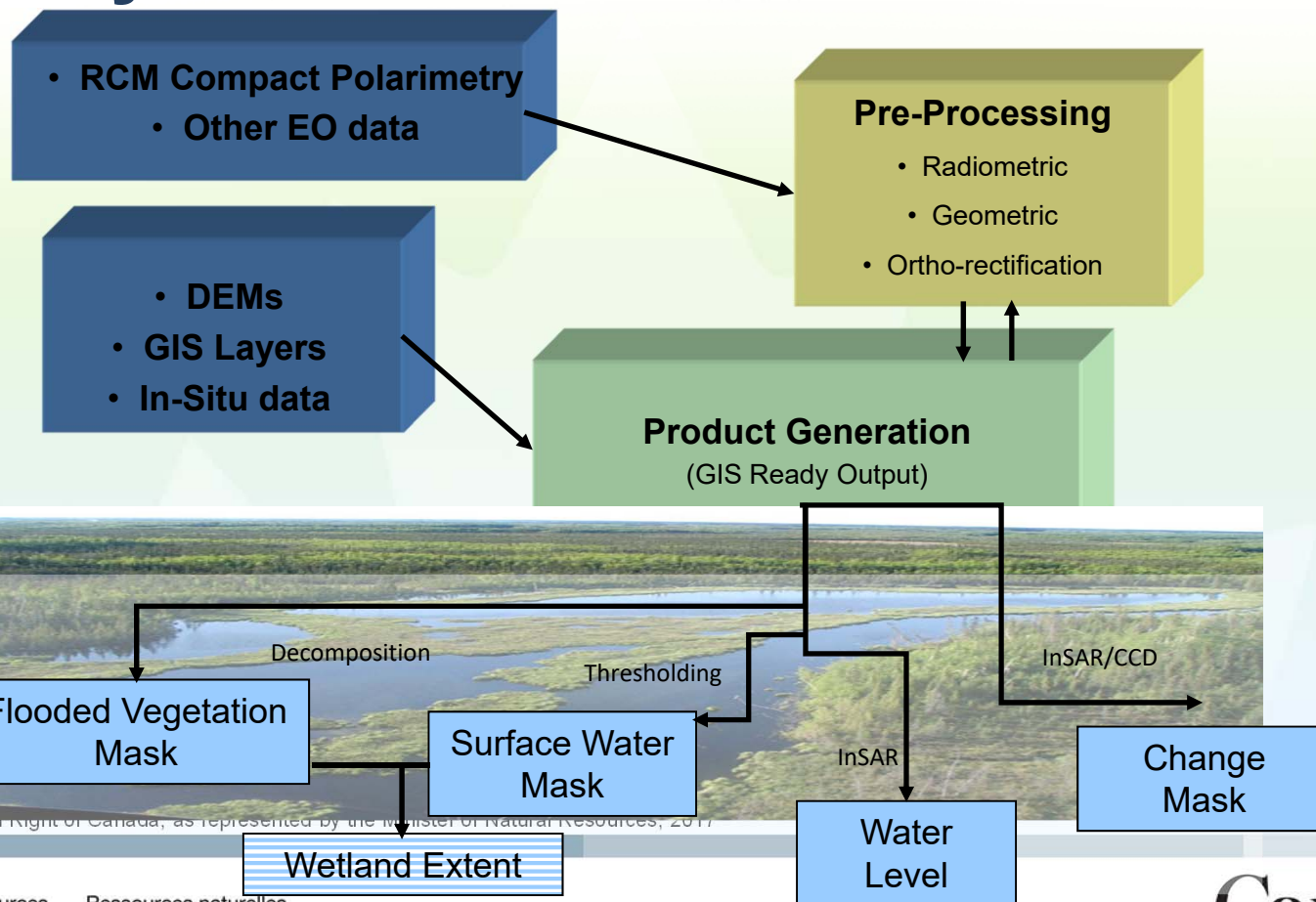


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SAR Dynamic Surface Water Monitoring



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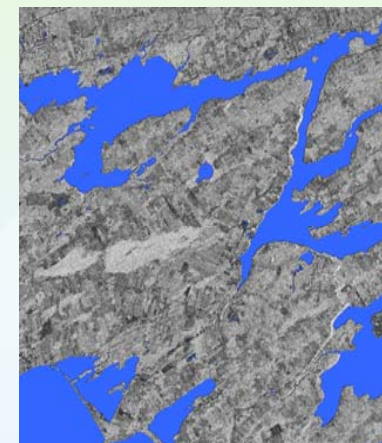
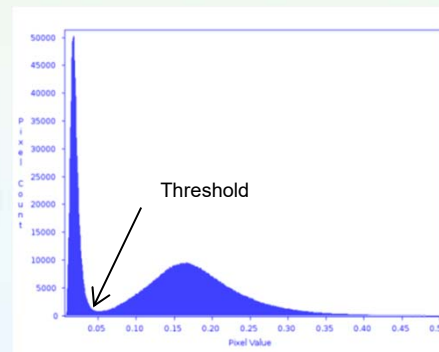
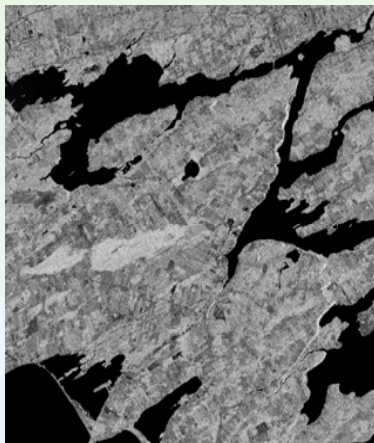
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Open water extraction

- RADAR – Water Seeker
- Standing Water – Specular reflection
- Empirical method of thresholding is used to map open water



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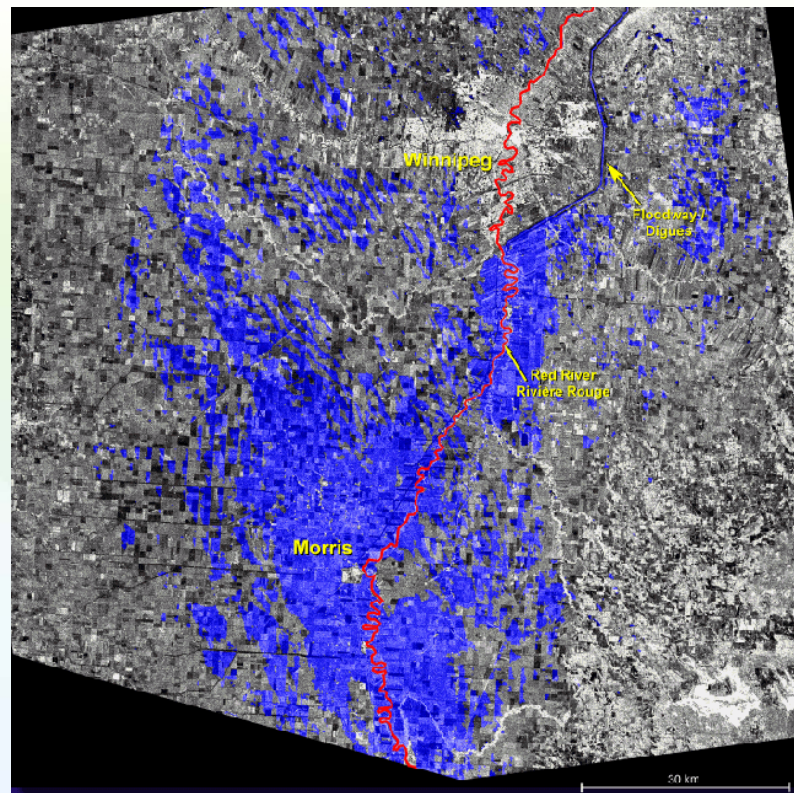
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Flood Mapping

First Operational Flood Application in Canada Red River, Manitoba



April 27, 1997 7:48 AM

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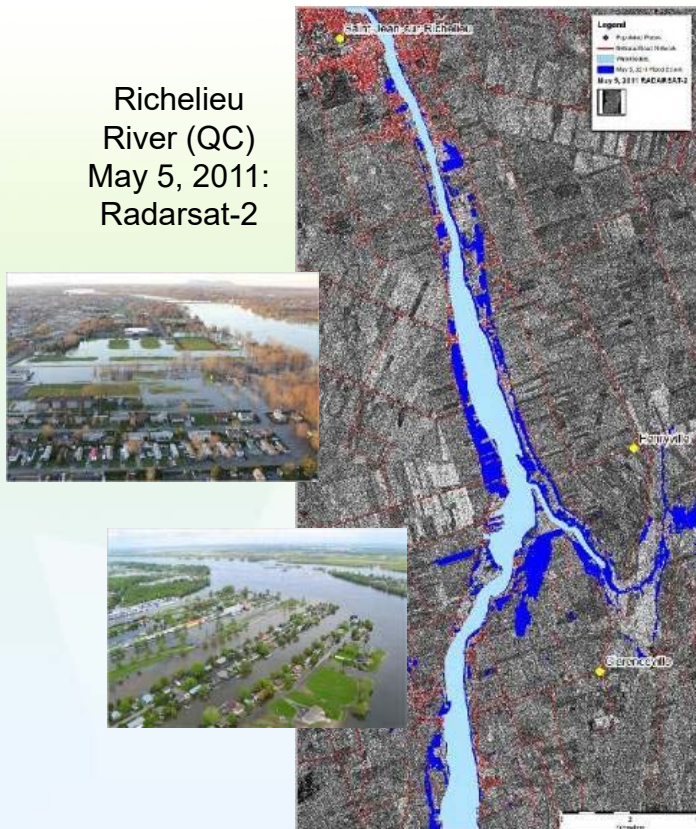
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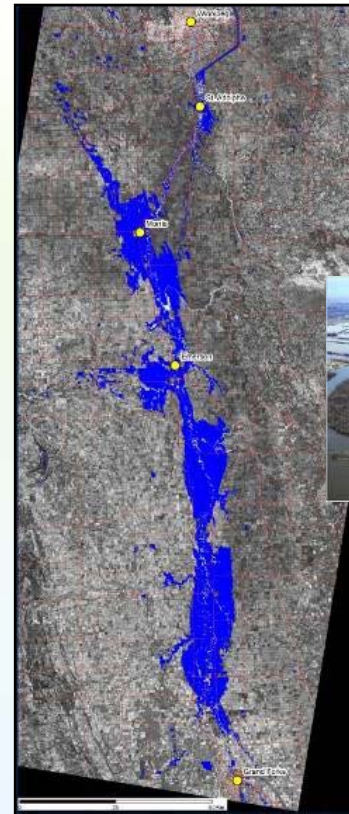
2011 Flood Products

8

Richelieu
River (QC)
May 5, 2011:
Radarsat-2



Red River (MB)
April 28, 2011 :
Radarsat-2



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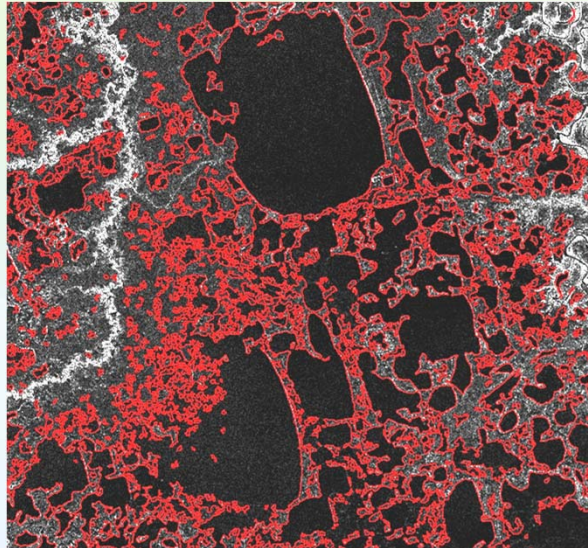
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SAR and Surface Water Extent

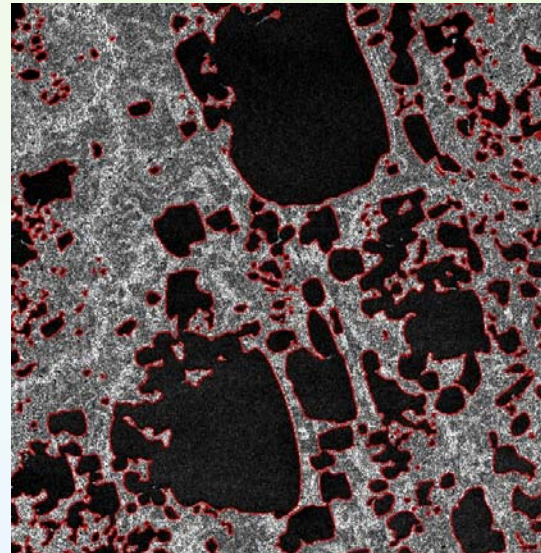
- Intensity Thresholding – Surface water extent
- Operational today (e.g. EGS) – new EC GRIP
- Cannot detect flooded vegetation

Seasonal Change Old Crow Flats, 25 May, 2000

Spring – Snow melt
and flooding



Summer -- Lower water levels



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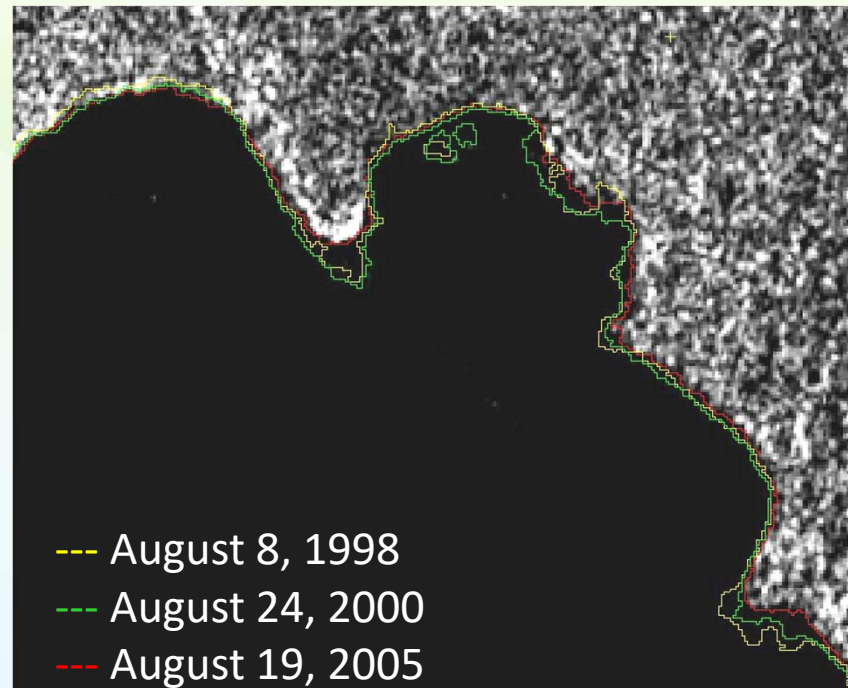
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McClelland Lake, Fort Mackay, AB

**Inter-annual
variability in lake
extent**

**Background image is
August 19, 2005**



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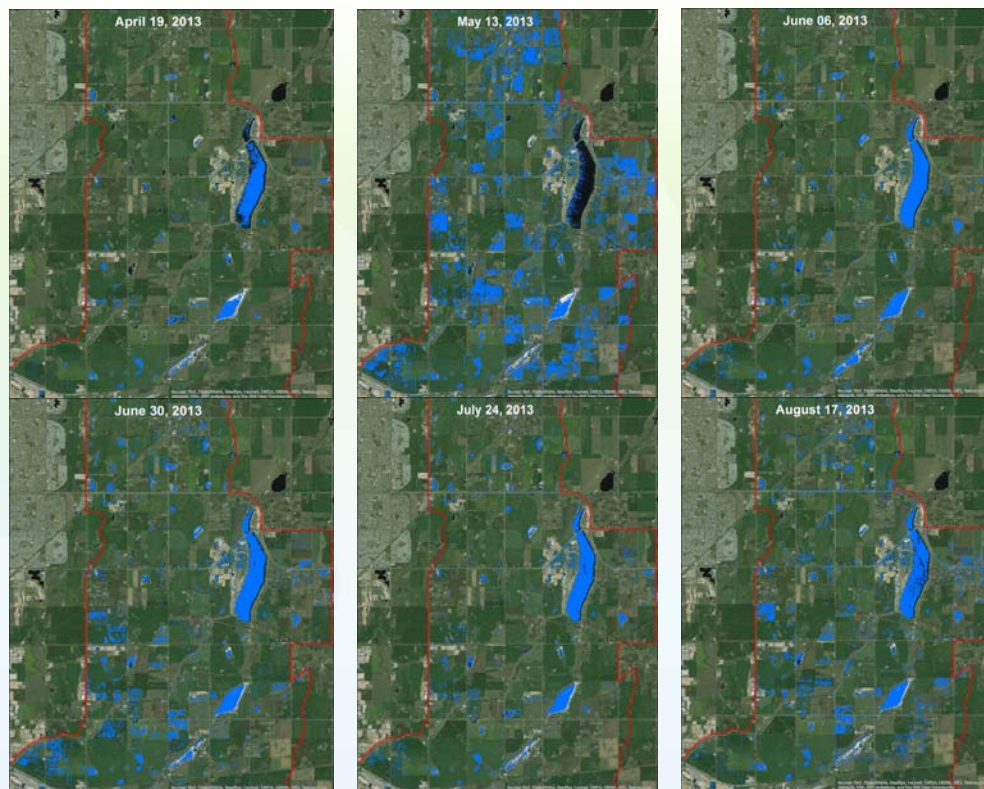


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Calgary 2013 Surface Water



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PAD 2012/13 Surface Water



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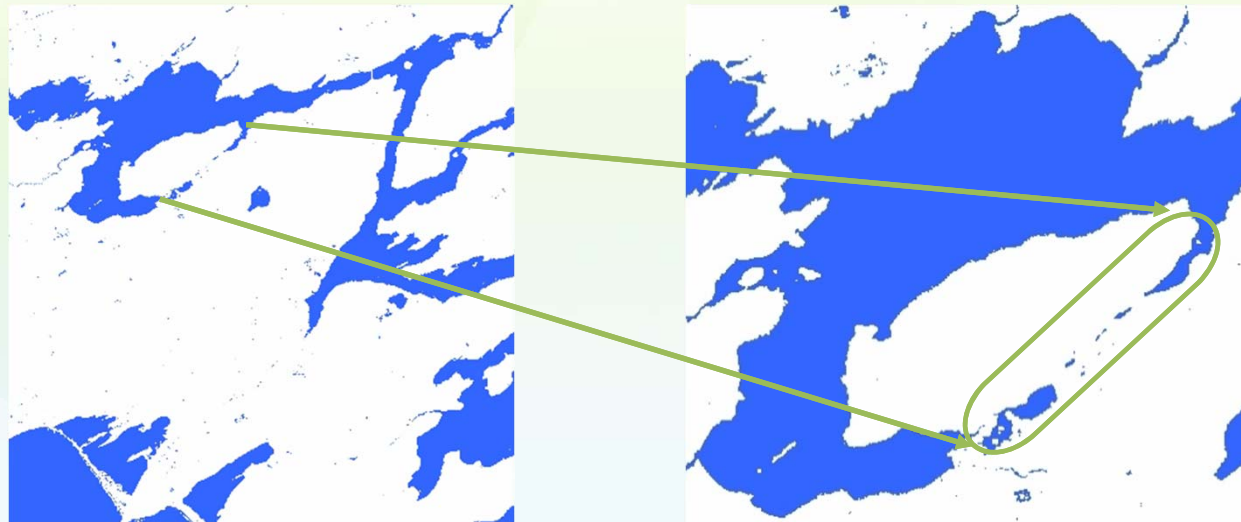


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Bay of Quinte open water animation (2016)



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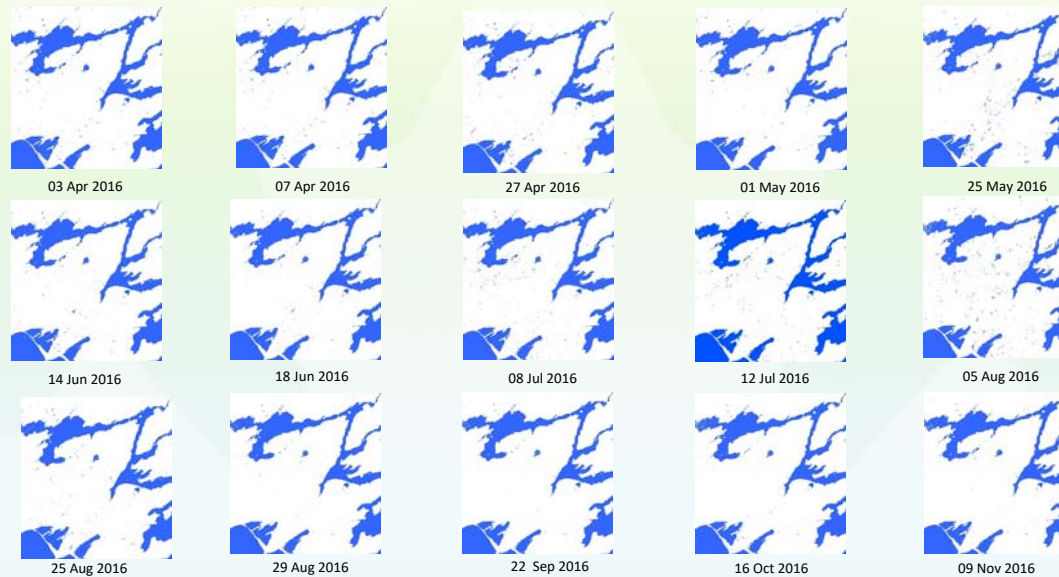


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Open water of Bay of Quinte



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Current Research Thrusts

- Multi-source
- Automated threshold
- Automate Clean Up
- Machine Learning
- Big Data

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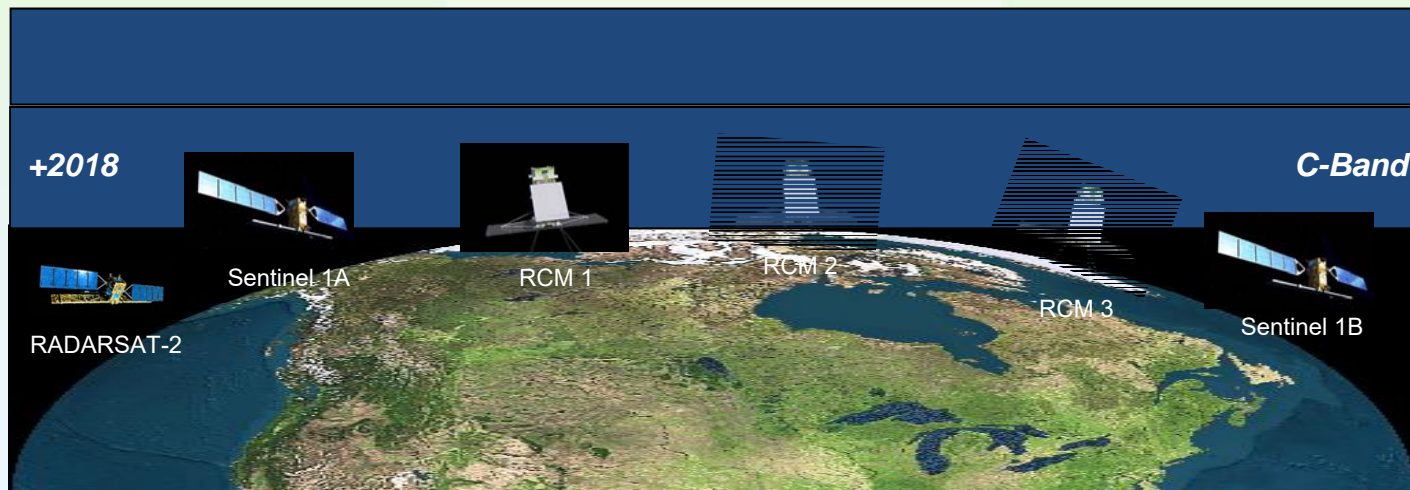
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Towards Operational Surface Water Mapping

- Significant national investment in C-band SAR continuity for decades to come
- Daily coverage of all of Canada – Capture water dynamics
- NRCan research is enabling SAR to be the central dataset underpinning routine surface water mapping



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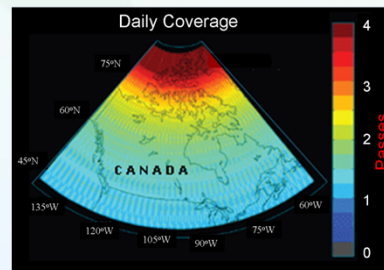
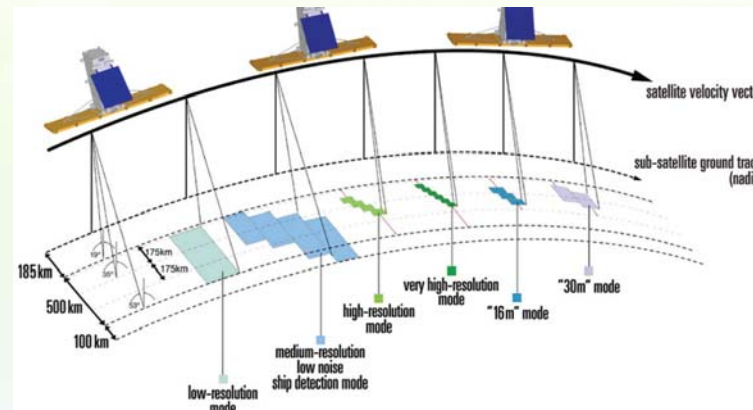
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RCM: RADARSAT Constellation Mission

- **Three-satellite SAR mission**
 - First launch: 2016
- **10 SAR modes**
 - C-Band
 - Single pol, linear dual-pol, **Compact pol**, exp Quad pol
 - Swath up to 500 km
- **Rapid Revisits & CCD**
 - Daily coverage of Canada's land and oceans
 - Four day InSAR capability



Operational Mission Drivers

- Ecosystem Monitoring
- Disaster Management
- Maritime Surveillance

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Flooded Vegetation Mapping

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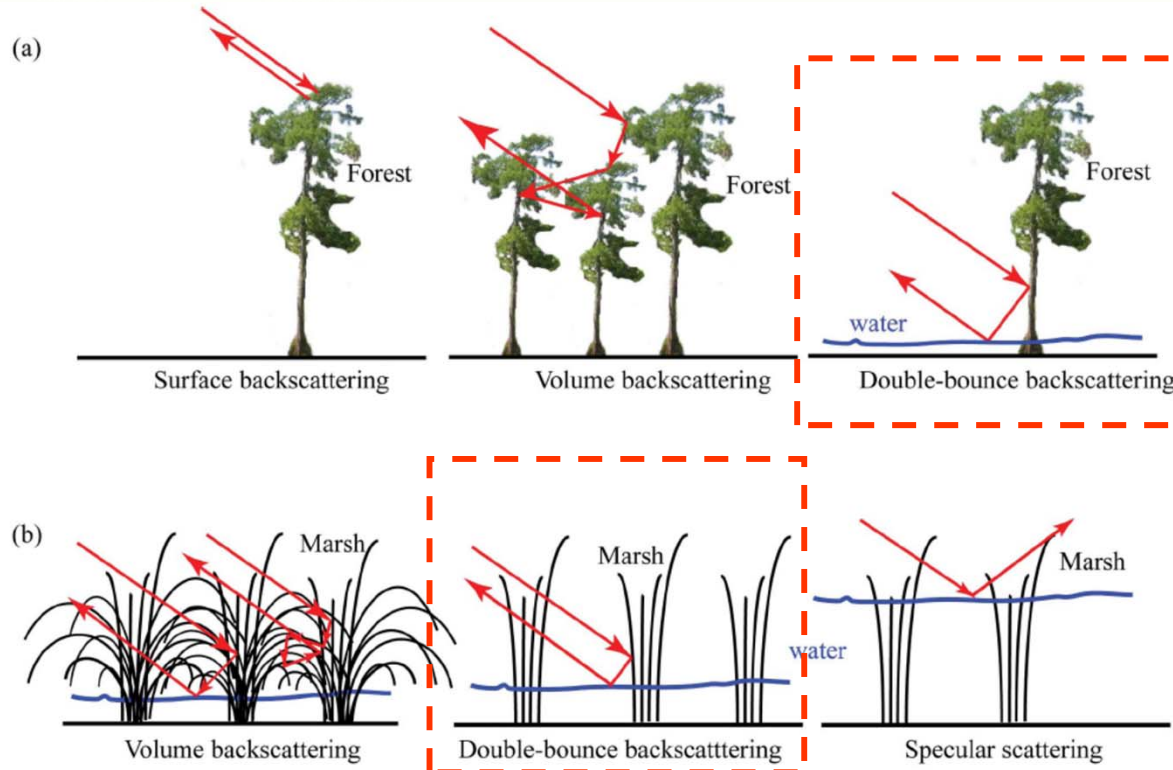


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Scattering Mechanisms



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Polarimetry provides...



$$\sigma^{\circ} \cong \sigma_{\text{ground}}^{\circ} + \sigma_{\text{vegetation-ground}}^{\circ} + \sigma_{\text{vegetation}}^{\circ}$$

5 independent measures

$$E^s = \frac{e^{jk_0 r}}{r} \begin{pmatrix} S_{vv} & S_{vh} \\ S_{hv} & S_{hh} \end{pmatrix} E^i$$

Scattering matrix
(complex)

3 Backscatter coefficients σ°
e amplitudes: S_{vv}, S_{hh}, S_{hv}

2 Phases differences $\Delta\phi$

$$\phi_{\text{like}} = \phi_{hh} - \phi_{vv}$$

$$\phi_{\text{cross}} = \phi_{hh} - \phi_{hv}$$

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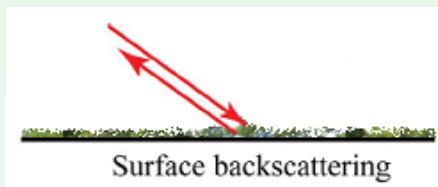
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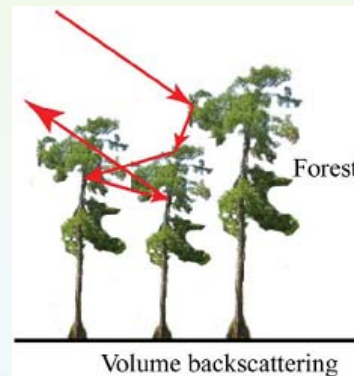
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Freeman-Durden Decomposition

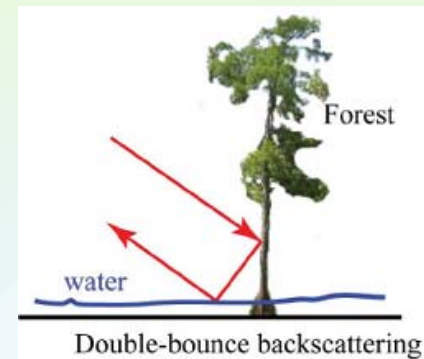
$$|S_{HH}|^2 + |S_{HV}|^2 + |S_{VH}|^2 + |S_{VV}|^2 =$$



+



+



= Total Intensity

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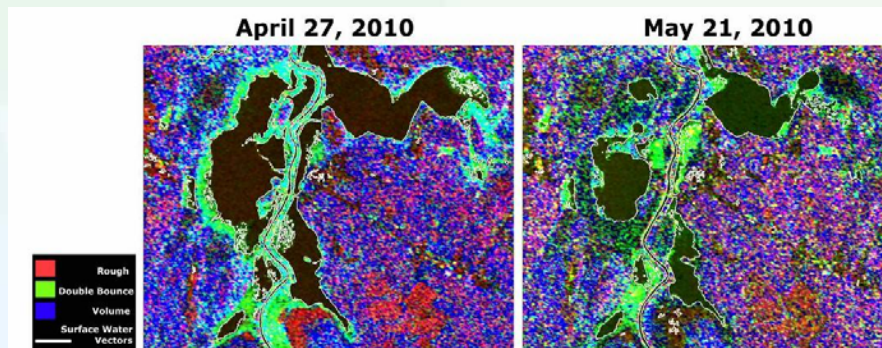
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SAR and Flooded Vegetation

- Prototype techniques and approaches have been developed for the application of satellite SAR to the mapping of flooded vegetation
- Flooded vegetation has dominant double bounce scattering
- Polarimetric decomposition can be used to highlight flooded veg



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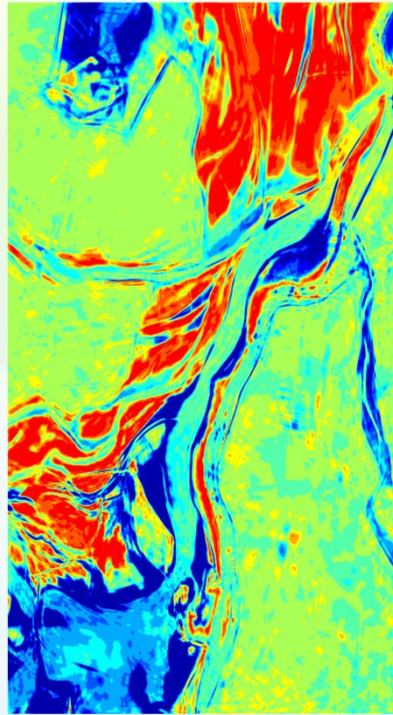


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SAR and Flooded Vegetation



Dong Ting Lake
 Δ Double Bounce

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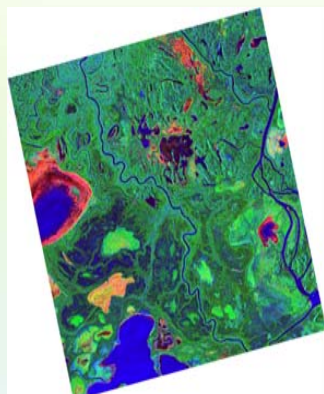


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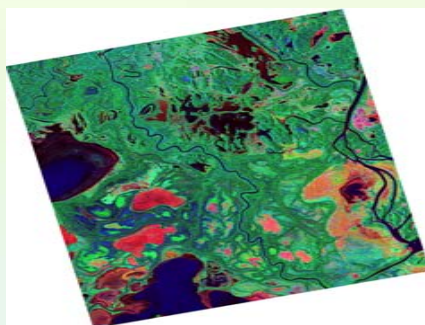
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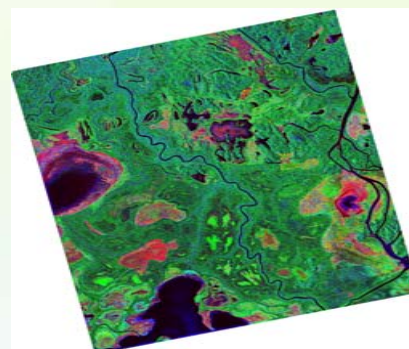
PAD Flooded *Vegetation*



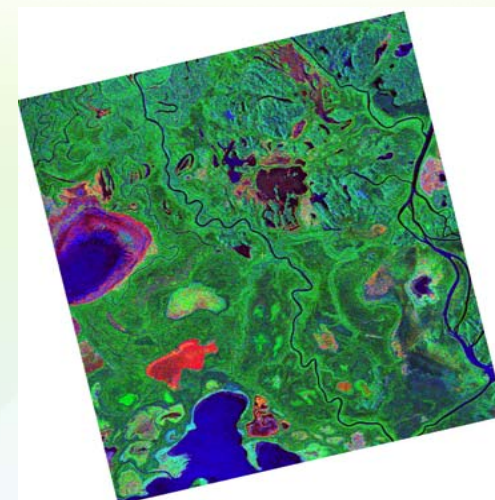
June 14



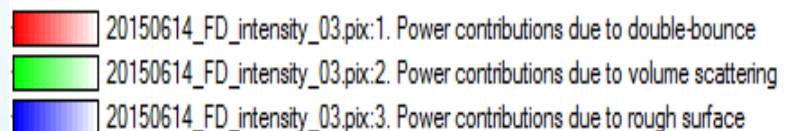
June 19



August 6



October 17



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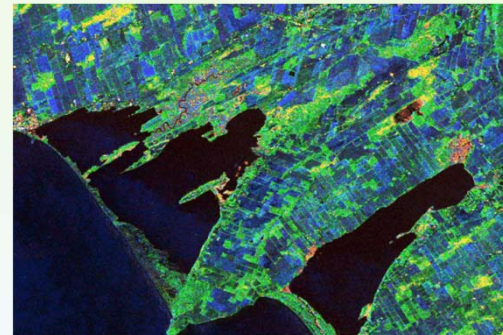


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Bay of Quinte wetland FDD animation (2016)



Freeman Durden Decomposition
R: Double bounce, G: Volume scattering, B: Rough surface

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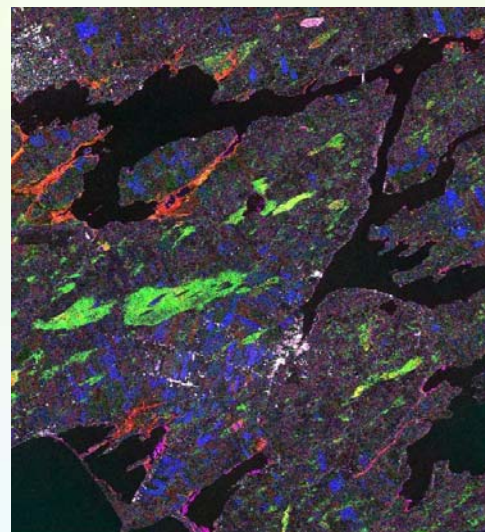
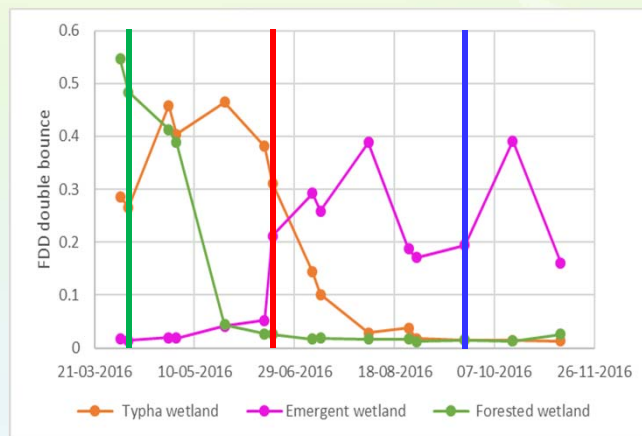


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Temporal behaviour of FDD parameter



- Urban
- Forested wetland
- Typha wetland
- Emergent Wetland

Freeman Durden Decomposition
Double bounce: R: 18 Jun 2016, G: 07 Apr 2016, B: 22 Sep 2016

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Frequency Effects

- Need L-band to penetrate woody swamps and high biomass wetlands
- X-C bands better for herbaceous vegetation like marsh and shallow water emergents

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Flooded Vegetation Research Thrusts

- New Improved Decompositions
- CP m-chi decomposition
- Multi-source
- Water, flooded Vegetation and saturated soil for dynamic wetland extent

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Wetland Classification

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CWI

The **Canadian Wetland Inventory (CWI)** was established in 2002 by DUC, Environment Canada, the Canadian Space Agency and the North American Wetlands Conservation Council. As a resource, the CWI is valuable for a number of other purposes. It helps to:

- Focus conservation, restoration and wetland monitoring programs
- Assess changes in wetland abundance and classification in relation to climate change concerns
- Assist industry, governments and conservation groups to develop land-use policies and protocols
- Measure performance of those policies and protocols towards landscape sustainability objectives

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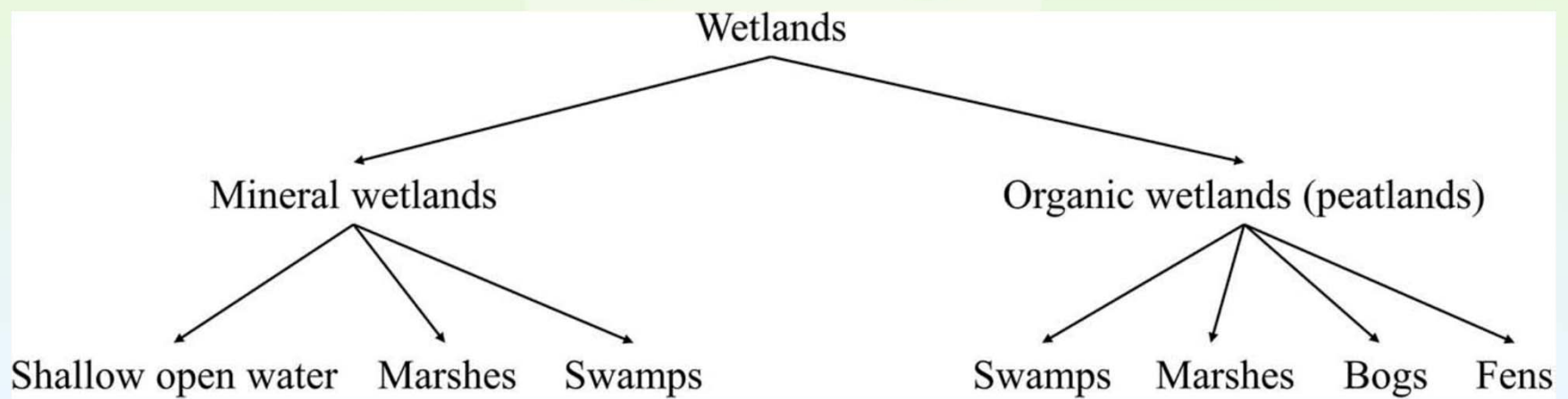
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CWCS

Canadian Wetland Classification System



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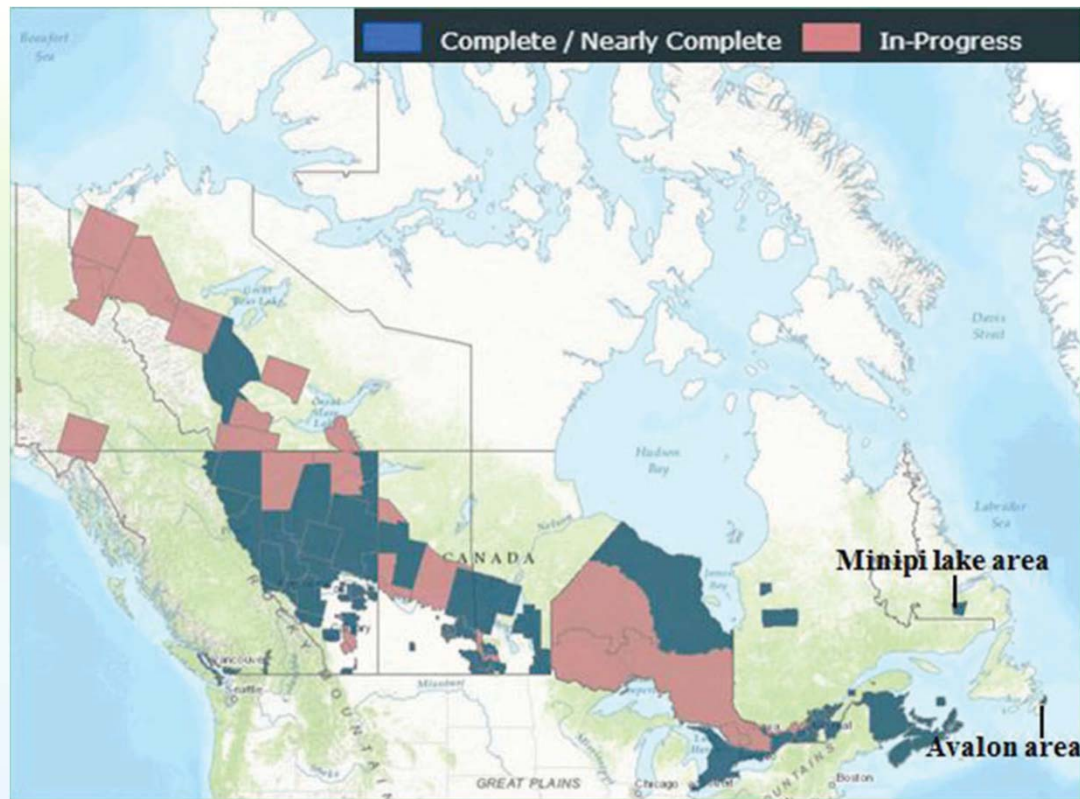


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CWI Status



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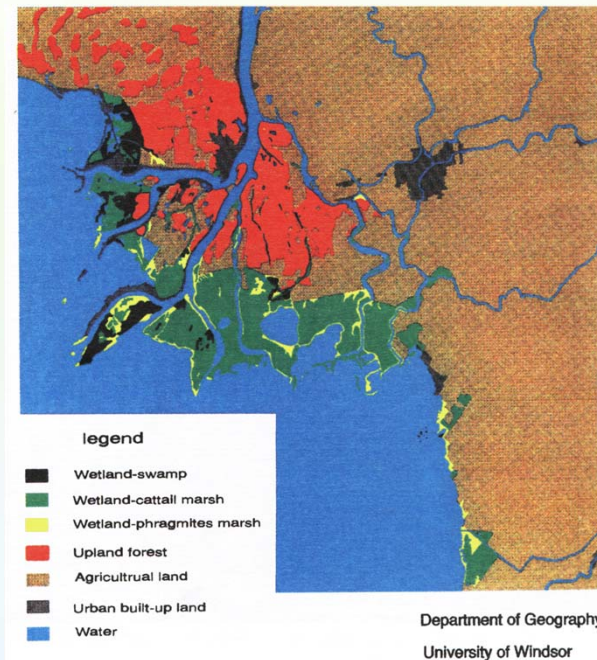
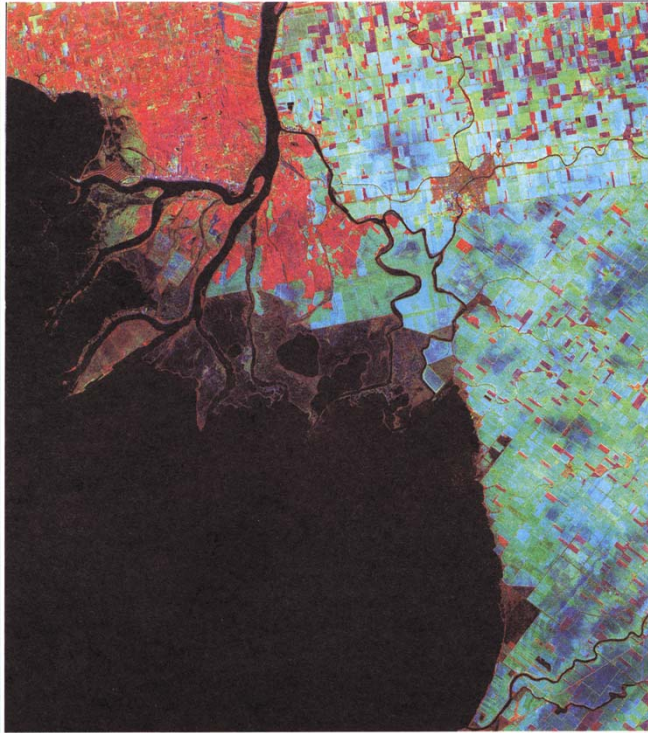


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Wetland Mapping



Lake St. Clair ERS-1/TM PCA

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Wetland Classification SOA

- Object based classification
- Optical, SAR, and DEM layers
- Multi-temporal (Spring and summer)
- Machine Learning algorithms
- Big Data processing capabilities

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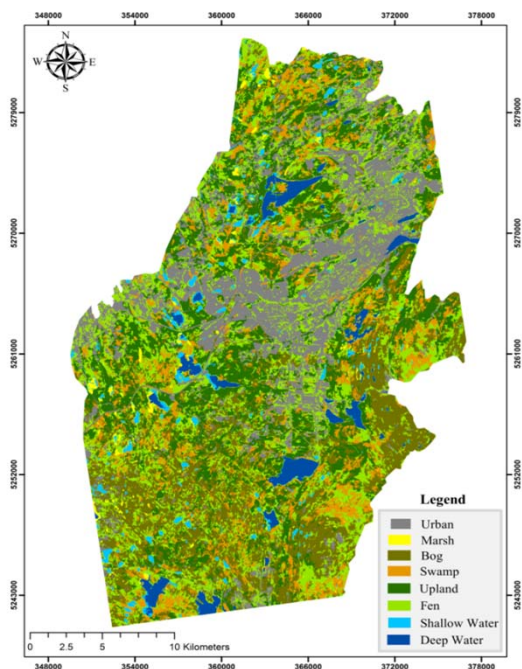


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Avalon Peninsula SAR



Sensor	Time interval	# of images	Image mode	Inc. angle (°)	Resolution (m)	Polarization	Direction
ALOS-1	Feb 2007 to November 2010	7	FBS	38.7	10	HH	Ascending
		10	FBD	38.7	20	HH-HV	Ascending
RADARSAT-2	April to August 2016	5	U16W2	42.13	2.5	HH	Descending
		4	FQ22	42	8	Quad-pol	Ascending
		3	FQ30	48	7	Quad-pol	Ascending
TeraSAR-X	August to November 2016	9	StripMap	21.55	3	HH	Descending

SVM classification
85 % accuracy
Kappa 0.82

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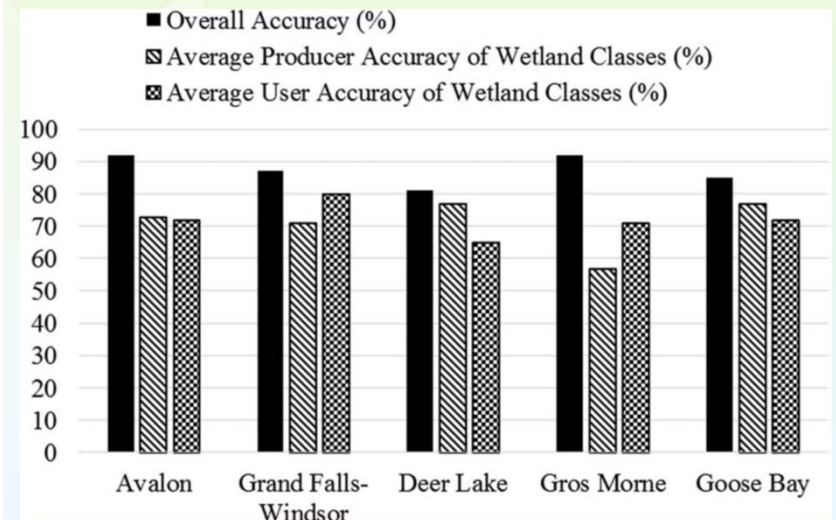
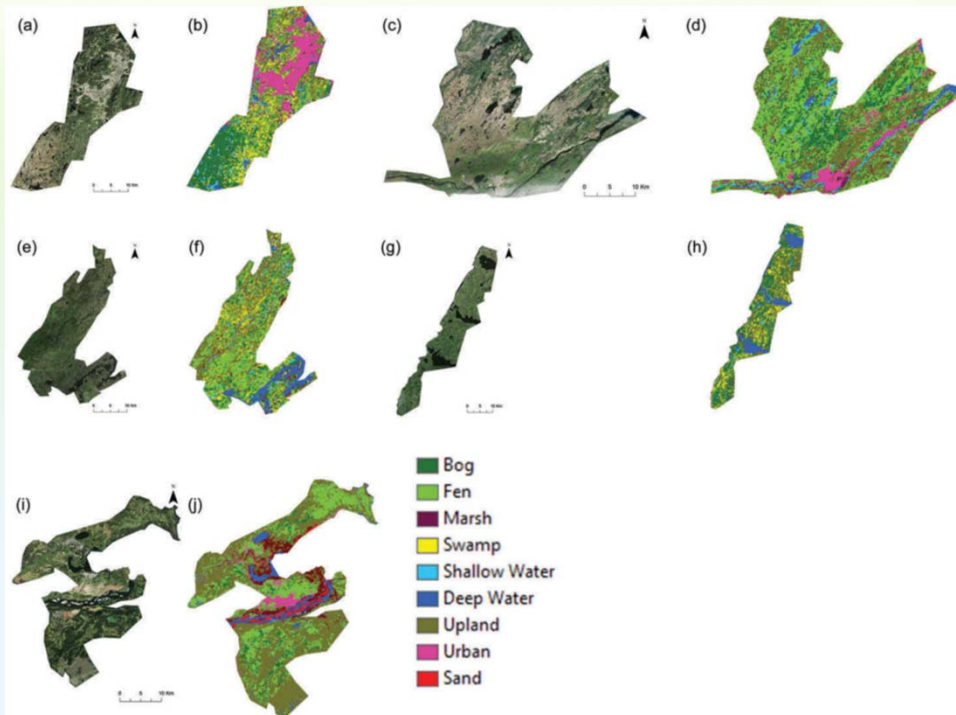


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Newfoundland Sites SAR/Optical



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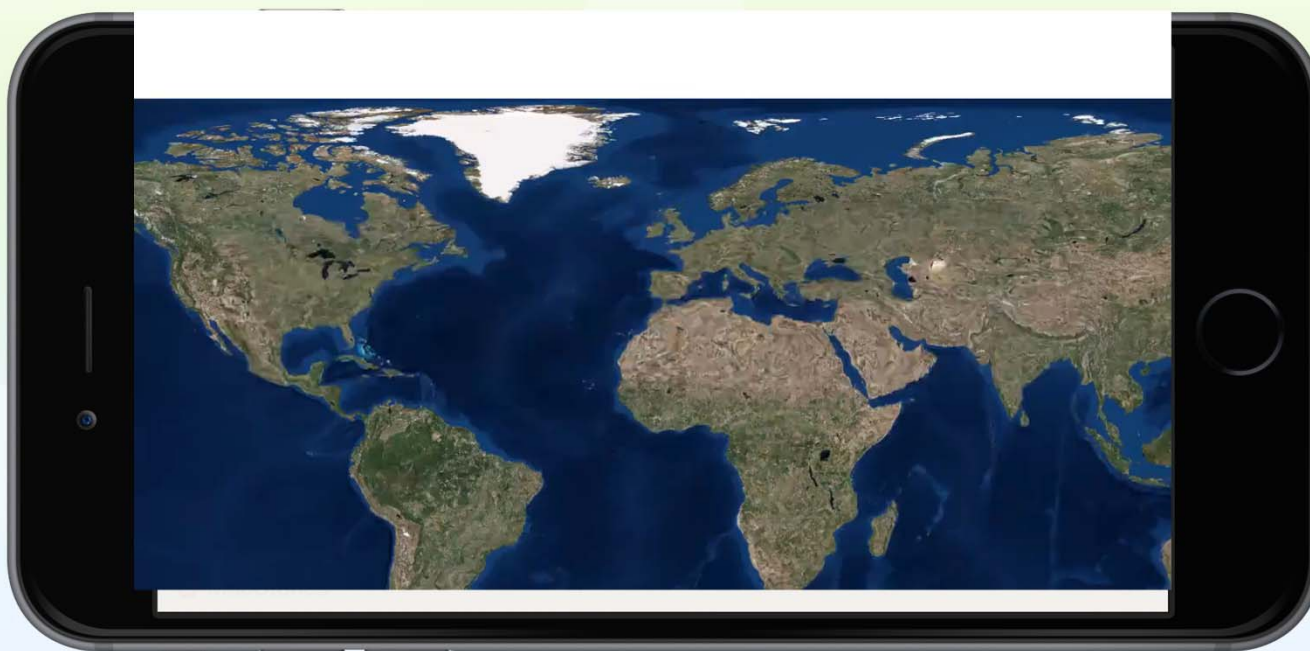


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First Newfoundland Wetland Inventory Map



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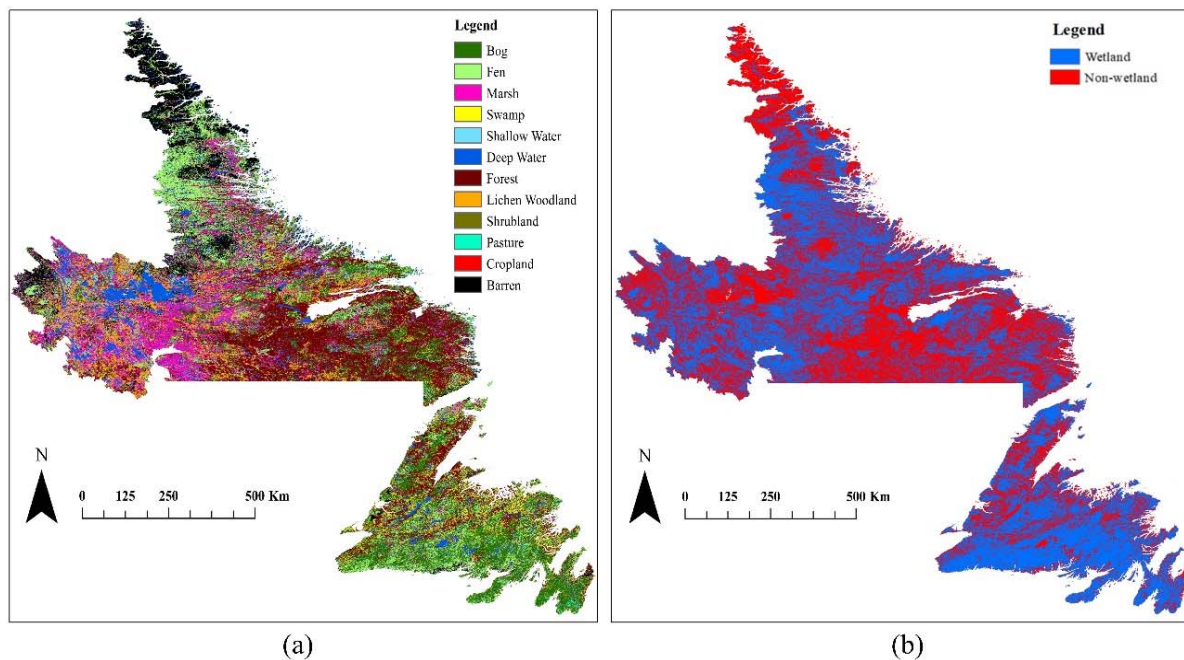


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Newfoundland/Labrador Wetland Classification



(a) NL-wide wetland classification considering a total of 12 classes, (b) wetland vs. non-wetland areas within the province of NL.

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Wetland Classification Research Thrusts

- Higher resolution in time and space
- Multi-source – L-band coming
- Machine Learning classification strategies
- Big Data analytics

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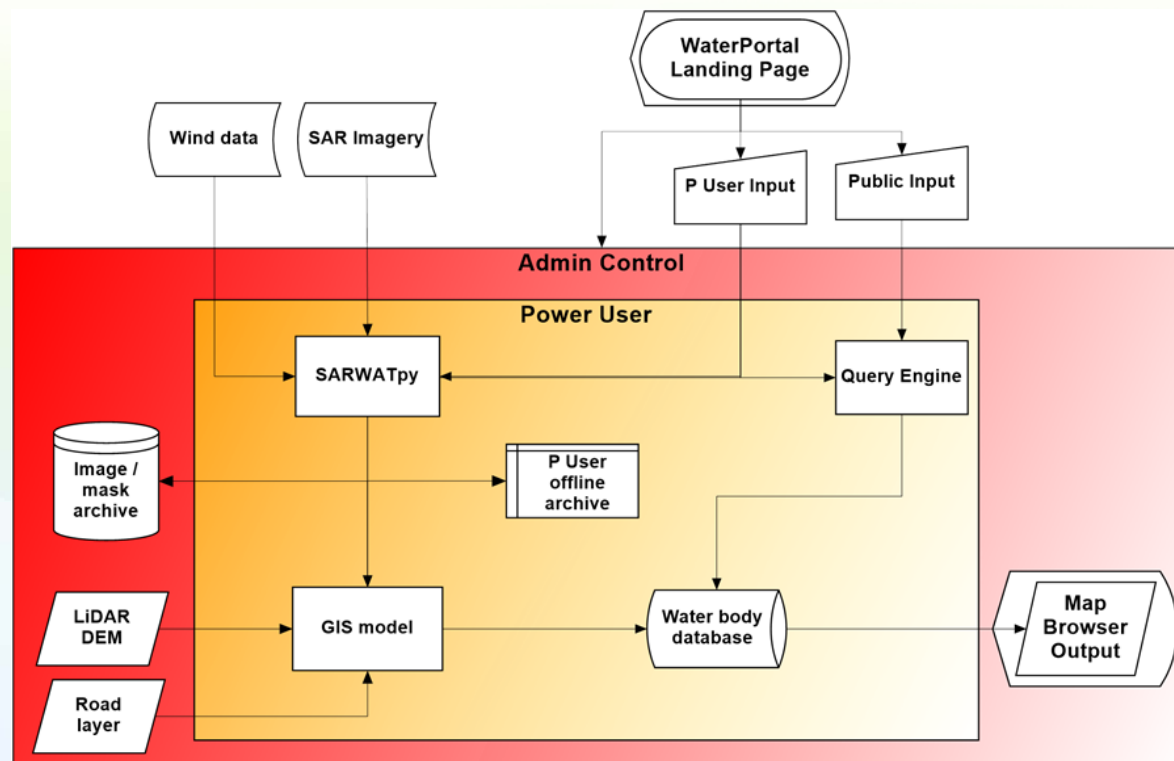


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SAR/LiDAR Water Portal



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SAR/Lidar Fusion

- Lidar or other high resolution DEM and multi-temporal SAR for hydro-period determination
- Periodic Lidar and derivatives for fixing errors of omission and commission using simple logic
 - Roads and human footprints not water
 - Pasture and bare ground above water level not water
 - Vegetation too tall or dense below water level if flooded vegetation

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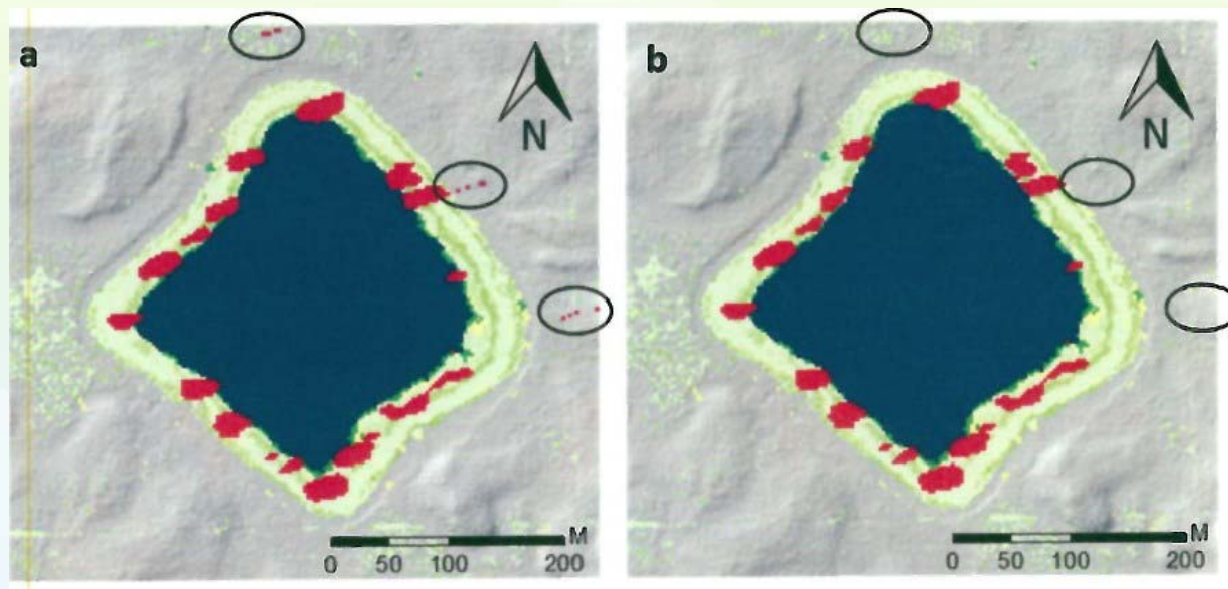


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Example Error Correction



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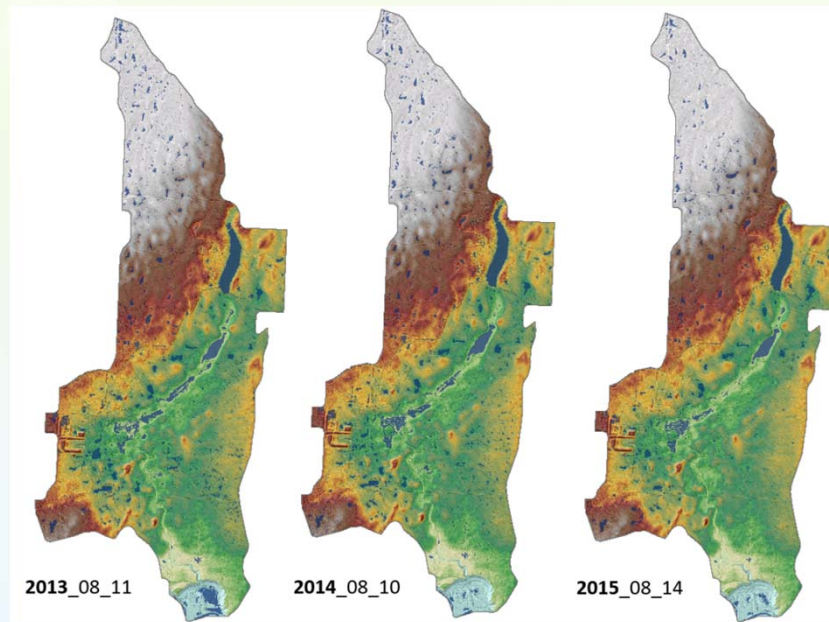
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SAR/LiDAR Sheppard Slough

- SAR derived surface water and flooded vegetation errors of omission and commission fixed by use of LiDAR products such as bare earth DEM, top of canopy and vegetation density
- LiDAR done periodically while SAR provides temporal monitoring



SAR/LiDAR Fusion – Sheppard Slough Calgary

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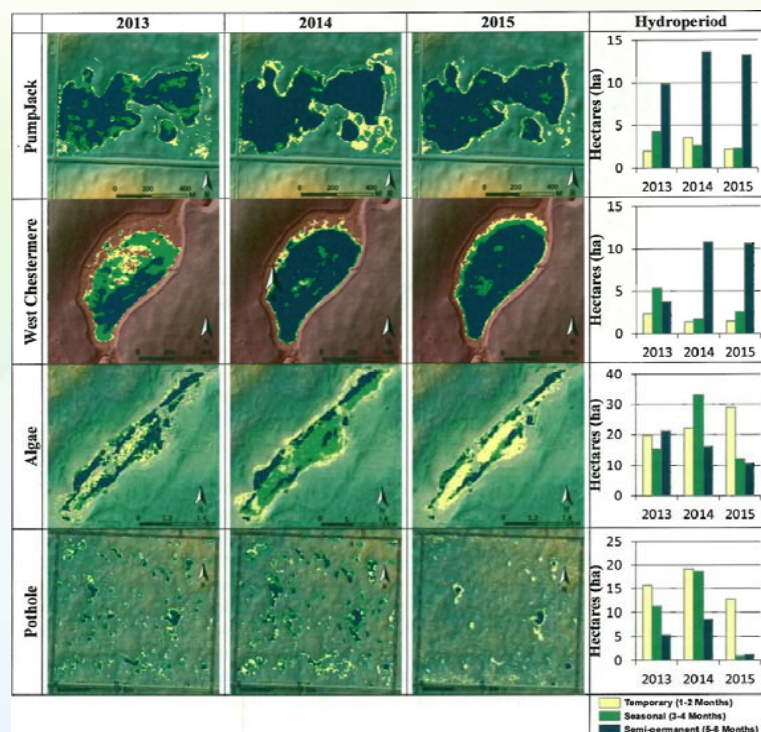


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Hydro-period Determination



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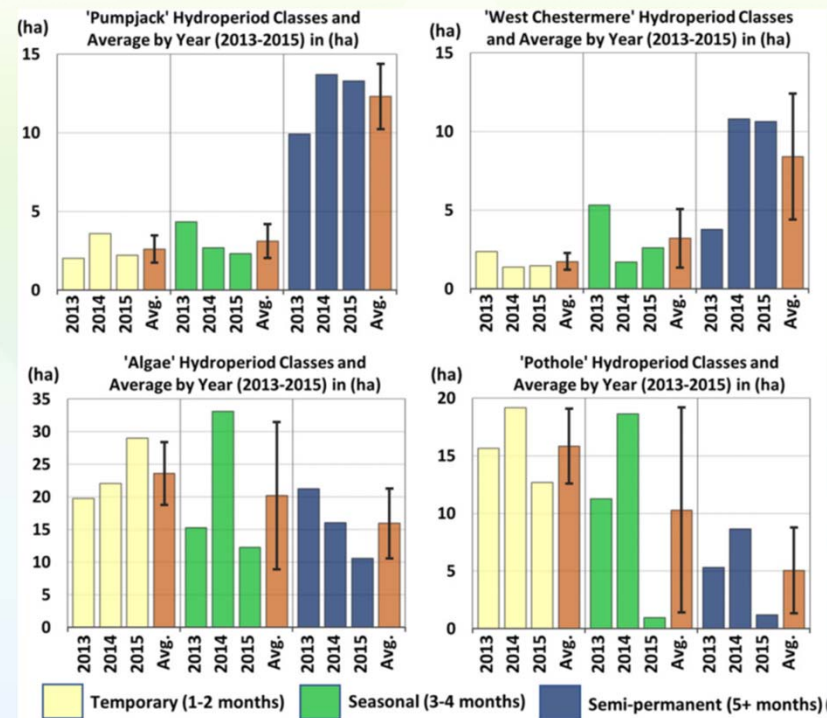


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Hydroperiod classes



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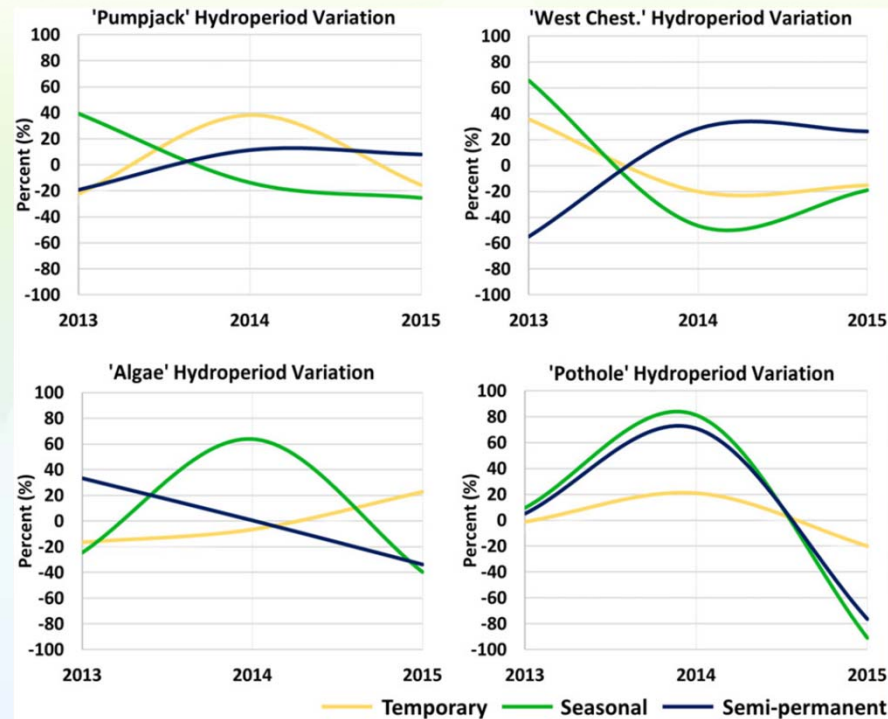


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Interannual variation wetland hydroperiod class



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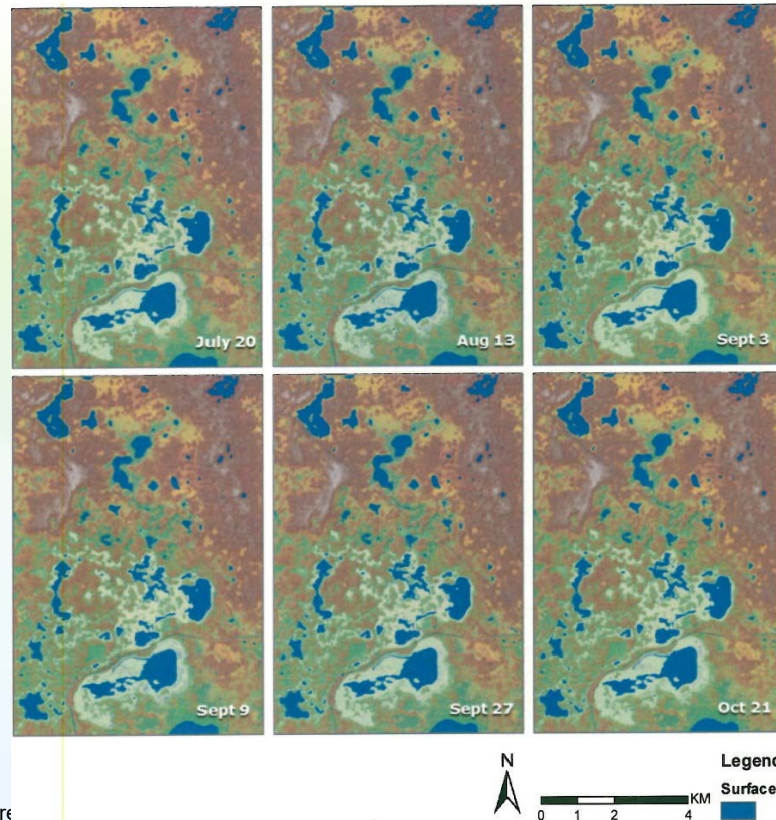


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SAR Derived Water Masks URSA



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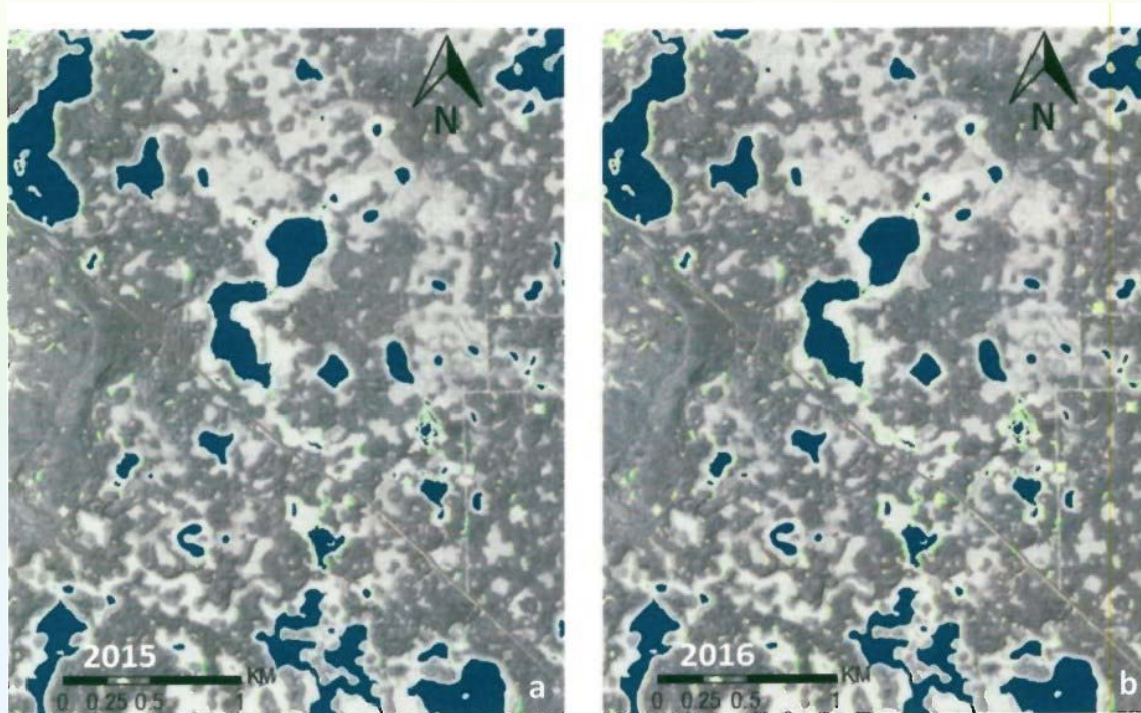


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URSA Hydroperiod



Yellow – temporary
Green – seasonal
Blue - permanent

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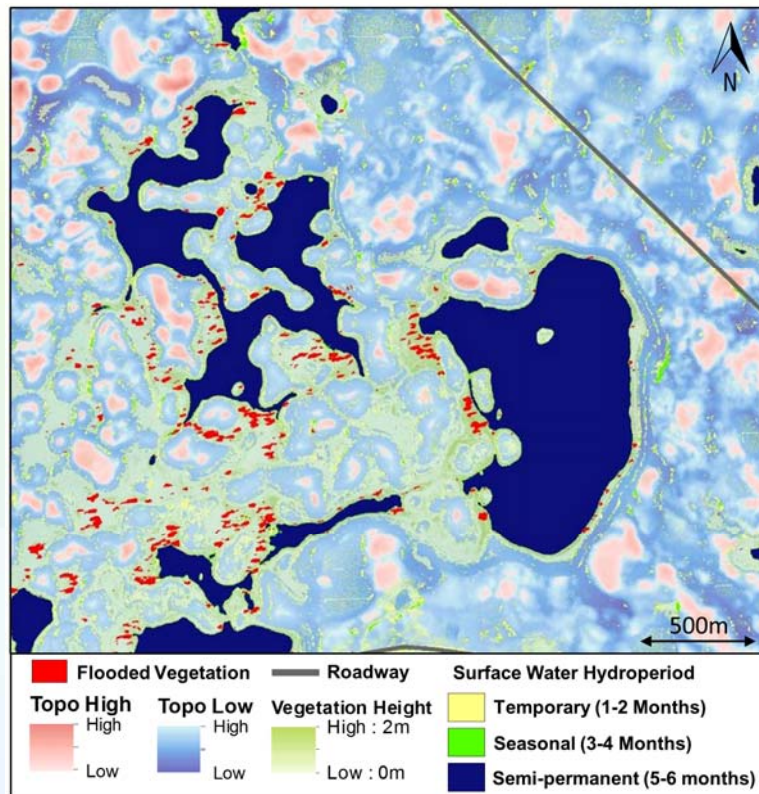


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URSA Hydro-period



Complete data fusion product in the URSA region showing all wetland attributes and characteristics based on data fusion methodology.

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Future thrusts

- National Lidar program and RCM natural fit to fuel this approach
- High res optical rather than Lidar
- In-situ data assimilation
- GIS framework for “other” inputs

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SAR Coherence for Wetland Mapping and Monitoring



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Outline

- SAR Coherence in Wetlands
- CCD
- Temporal coherence
- Coherence classification
- Summary



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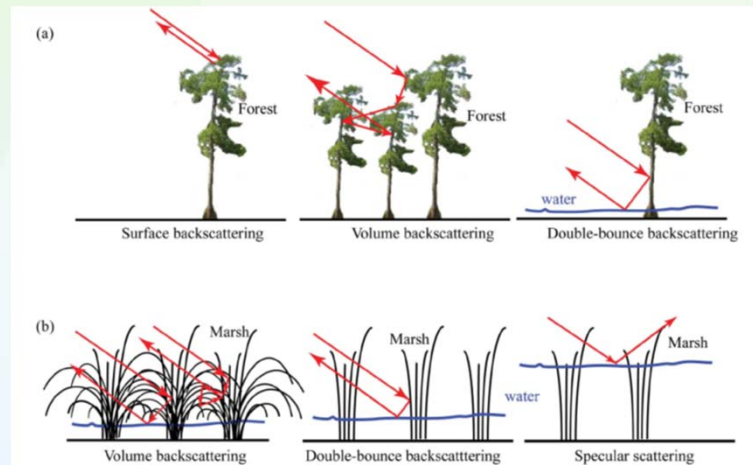
SAR COHERENCE

Coherence is related to the degree to which surfaces are identical, it is measured on a scale of 0 (low) to 1 (high).

Low coherence → usually water (unusable)

Moderate coherence → growing or moving veg (sometimes usable)

High coherence → desert, rock, infrastructure, **flooded vegetation** (usable)



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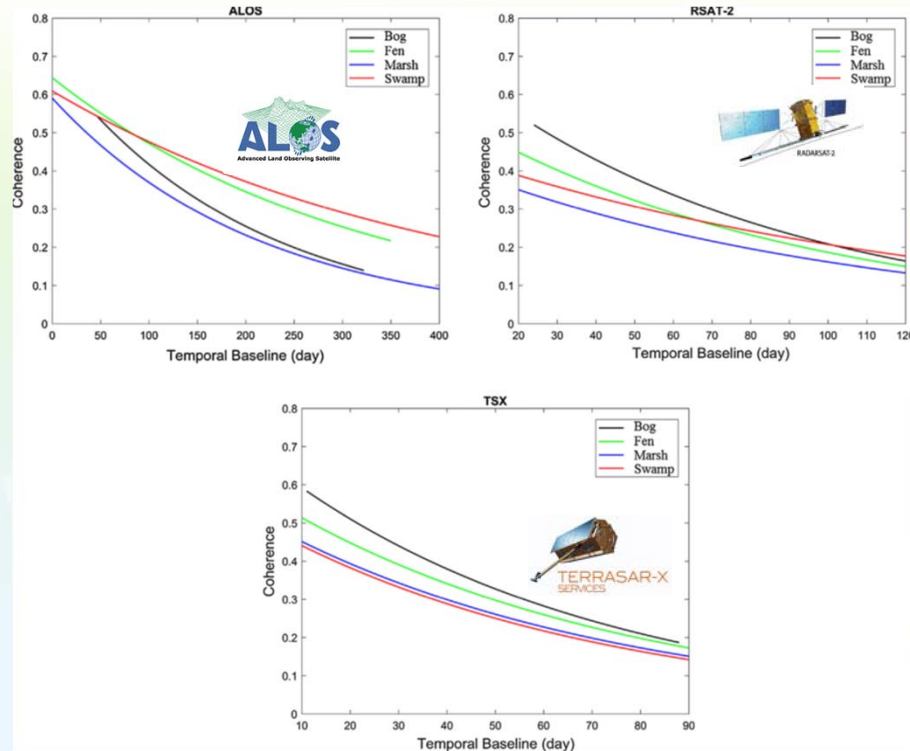


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Wetland Coherence vs Temporal Baseline



temporal baseline of less than 20 days is required to obtain a coherence of greater than 0.4 for C- and X-band data.

Mohammadimanesh et al., 2018, ISPRS Journal Photogrammetry and Remote Sensing

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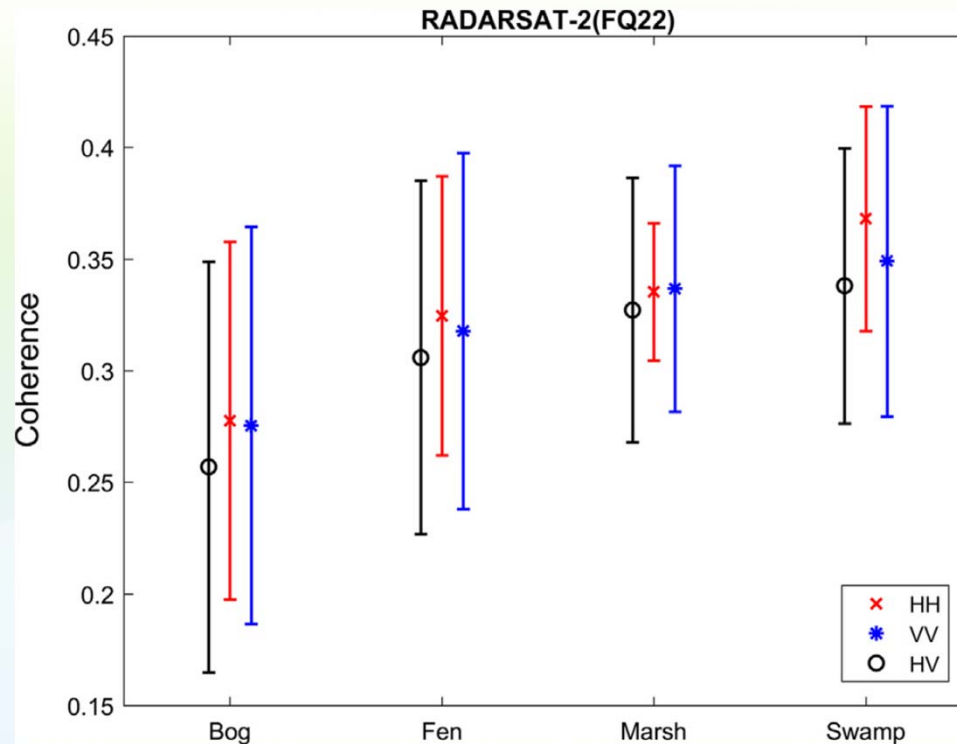


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SAR Coherence vs Polarization



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Mohammadimanesh et al., 2018, ISPRS
Journal Photogrammetry and Remote Sensing

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Coherence Change Detection

High Coherence both dates – flooded vegetation

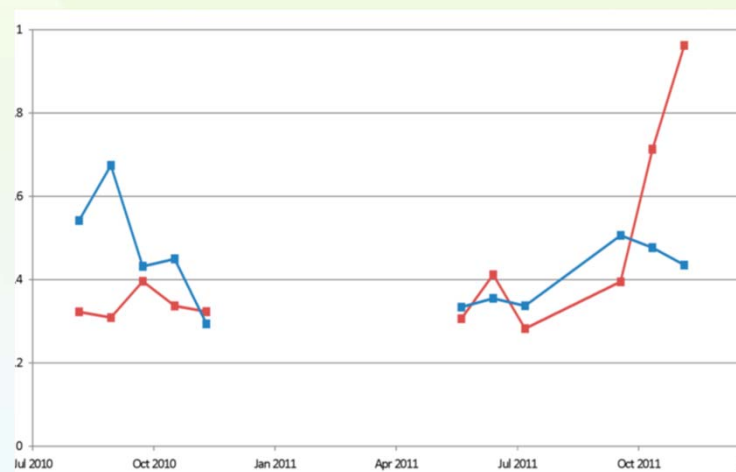
High Coherence but dropping – ephemerally flooded veg and dropping water level

High Coherence but sudden drop – drainage or vegetation change

Med to Low Coherence then increasing - water level increase

Low to High Coherence – recently flooded

Coherence



Brisco et al., 2017, Remote Sensing

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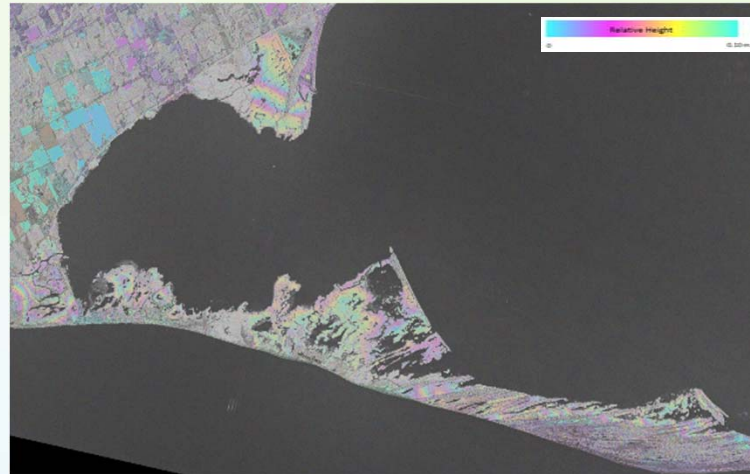
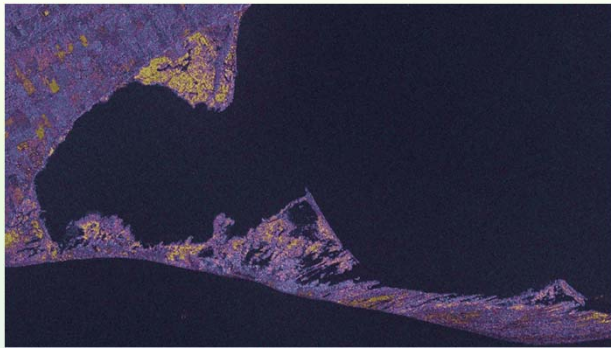
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Time

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Coherence/Water level animation (2016)



Long Point, Ontario – RADARSAT-2

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Methodology Raster Temporal Coherence

- Ice-off season (May 15-Oct 15)
- 6-9 Co-registered Intensity Images
- 5-8 24 day interval coherence estimates
- Statistical Analysis per pixel
 - Mean
 - Standard Deviation – normalization
- Visualization

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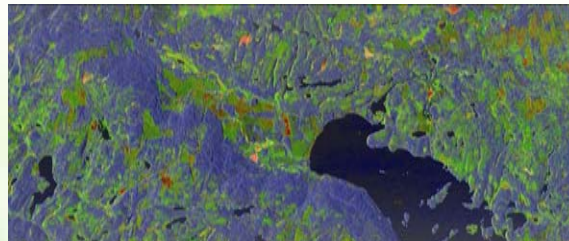
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Raster Temporal Coherence Lake Clear

Red – Mean Coherence
Green – Std Dev Coherence
Blue - Intensity



2011



2012



2013

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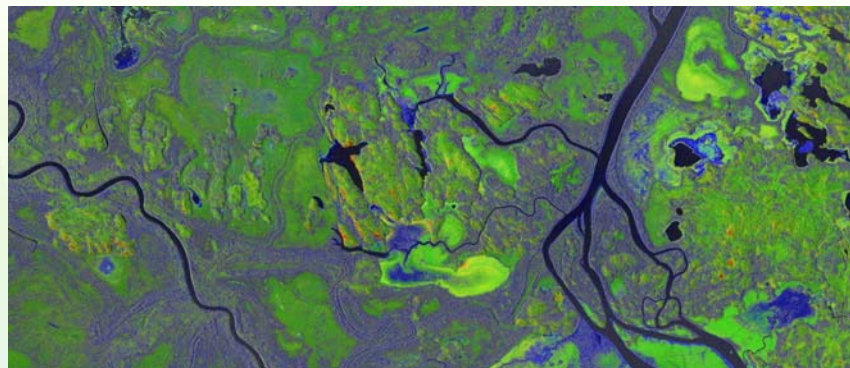
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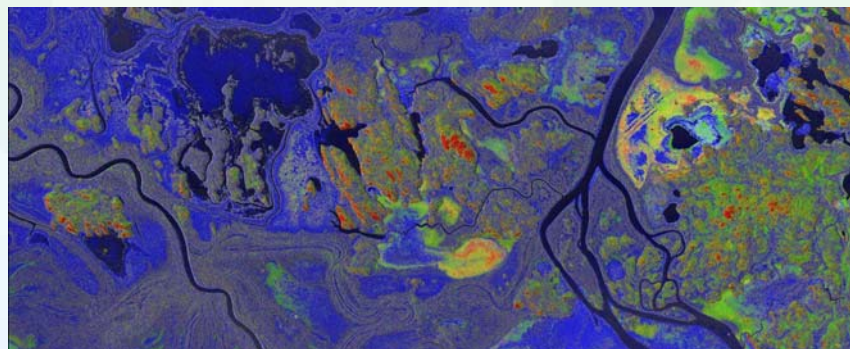
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Raster Temporal Statistics PAD

Red – Mean Coherence
Green – Std Dev Coherence
Blue - Intensity



2013



2014

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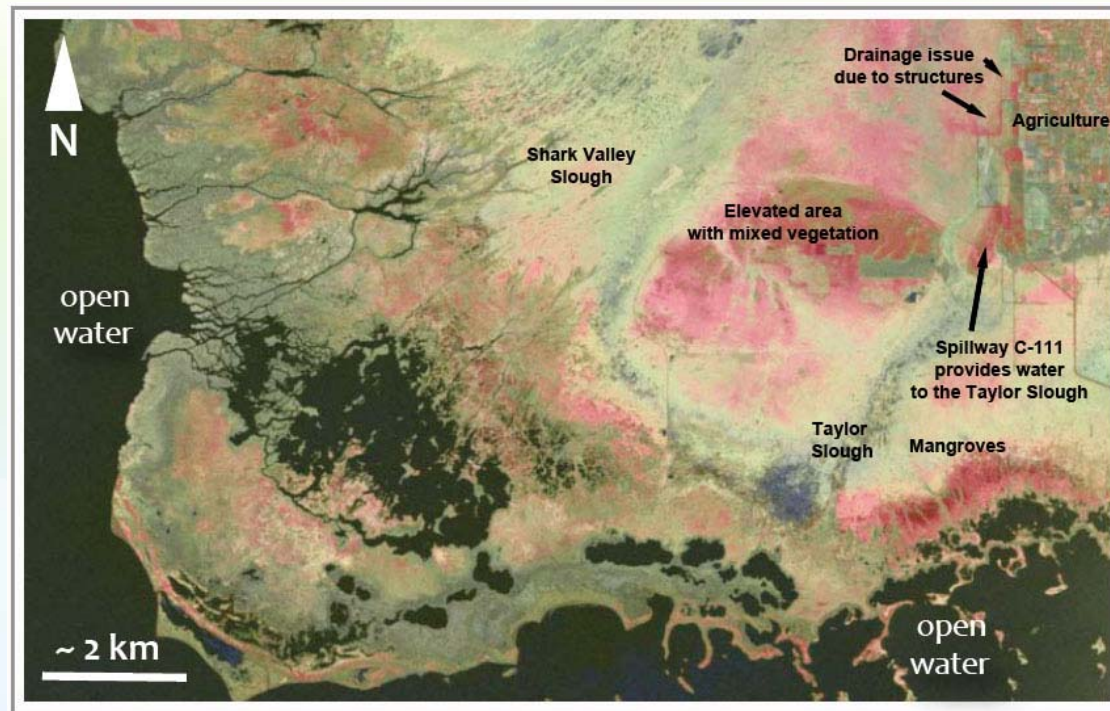


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Everglades National Park



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RADARSAT-2 Temporal Coherence

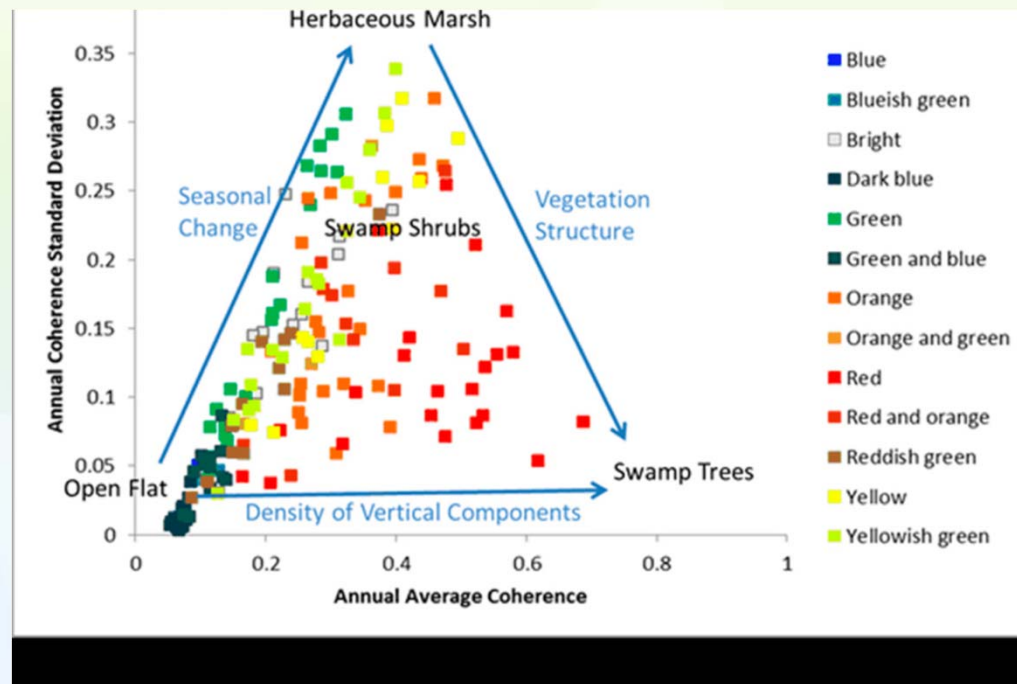


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Annual Coherence for Wetland Monitoring



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Brisco et al., 2017, Remote Sensing

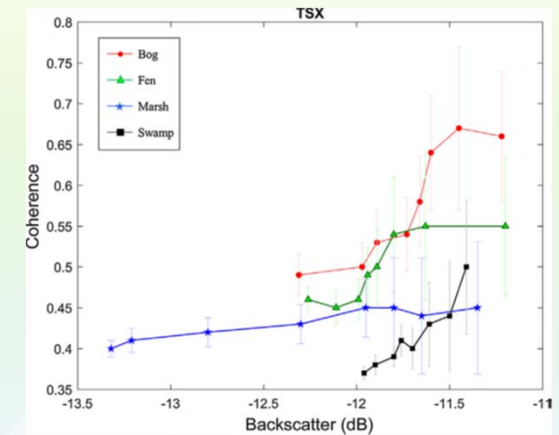
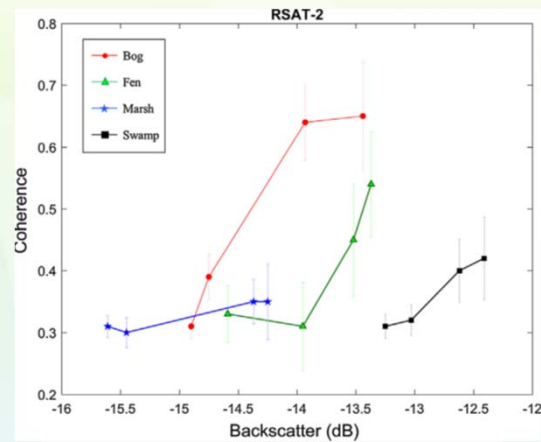
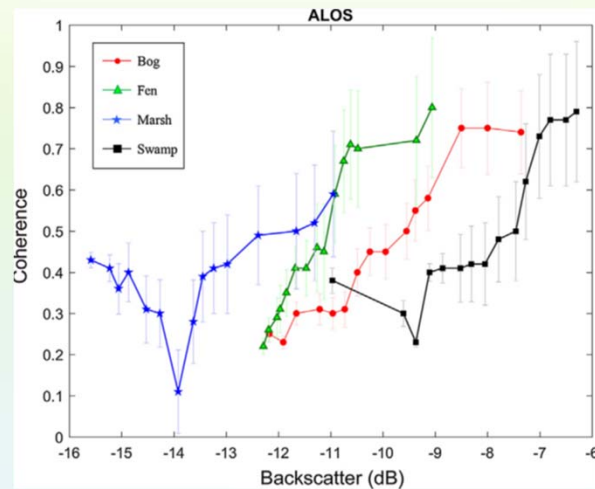


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Coherence and Intensity Wetland Classification



Mohammadimanesh et al., 2018, ISPRS
Journal Photogrammetry and Remote Sensing

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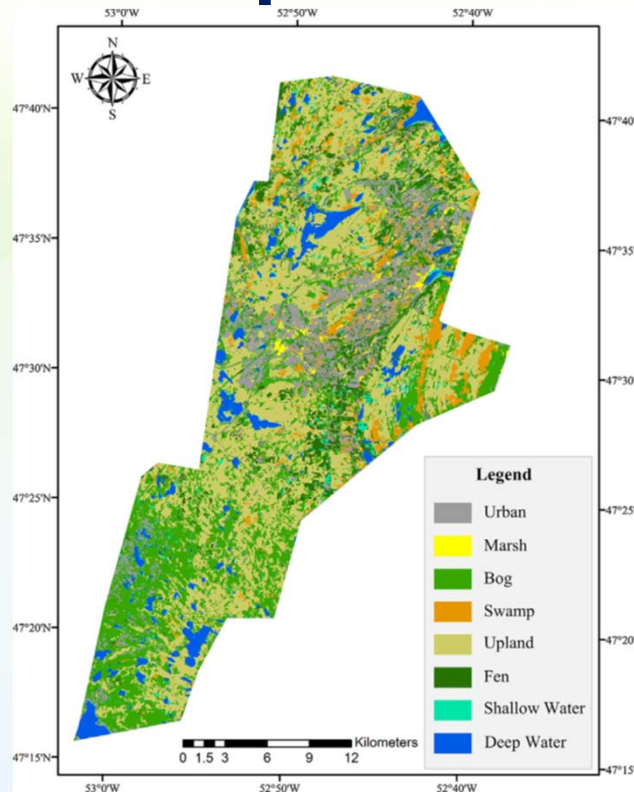
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Classification Map – RADARSAT-2

Avalon Peninsula
Nfld/Labrador

overall accuracy of
74.33% and a Kappa
coefficient of 0.66
were obtained.

*Mohammadimanesh et al.,
2018, ISPRS Journal
Photogrammetry and Remote
Sensing*



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SAR Training

- Side-looking, active, coherent sensor
- Effective use of products still requires knowledge
- Tutorials and textbooks are numerous to support self training
- Short courses also offered

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Implementing Coherence Applications

- Coherence level 4 products possible
- Use as another channel in classification
- Use for CCD
- Use temporal coherence for monitoring water level status
- Other applications being developed

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Conclusions

- Coherence depends on system parameters and
 - Wetland vegetation characteristics
 - Water level
- Temporal Coherence measurements can be used for wetland mapping and monitoring using CCD
- Seasonal/Annual visualization of coherence metrics can be used for wetland monitoring
- Coherence can supplement intensity for classification
- Training recommended as SAR is unique
- Level 4 product possible for easy implementation

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InSAR Water Level

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SAR COHERENCE

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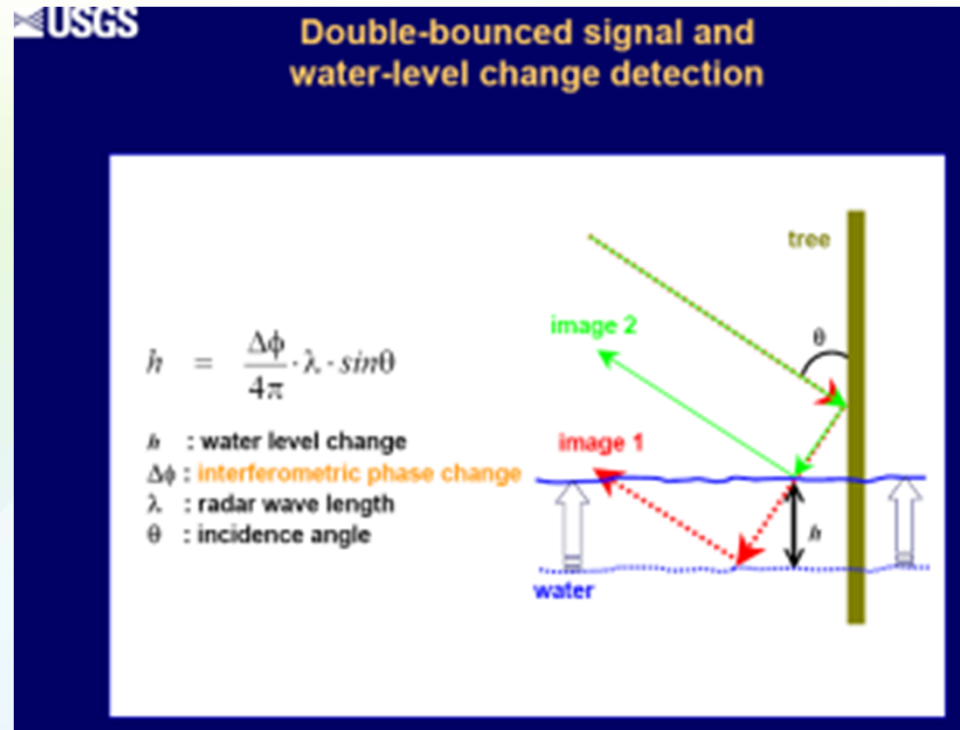


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InSAR for water level



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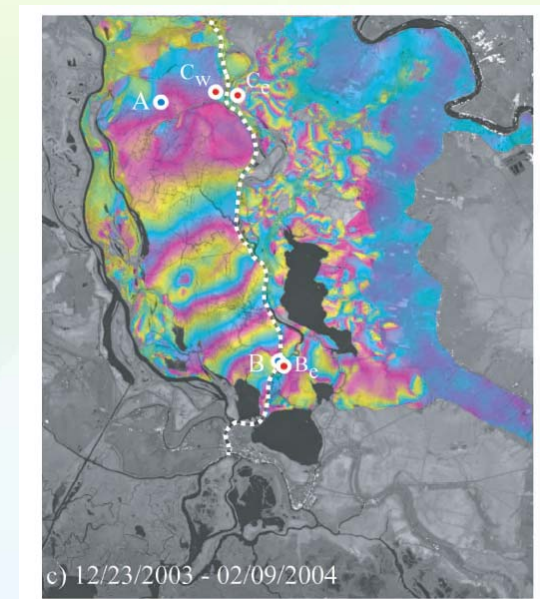
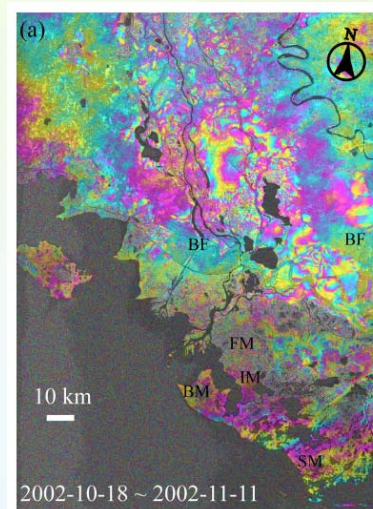
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INSAR for Wetlands

- Wetland coherence allows interferogram generation
- Water level changes can then be determined from interferograms



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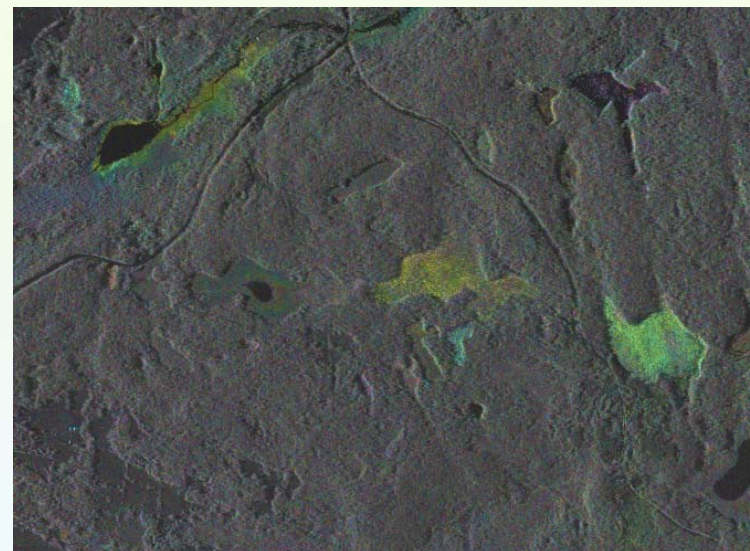
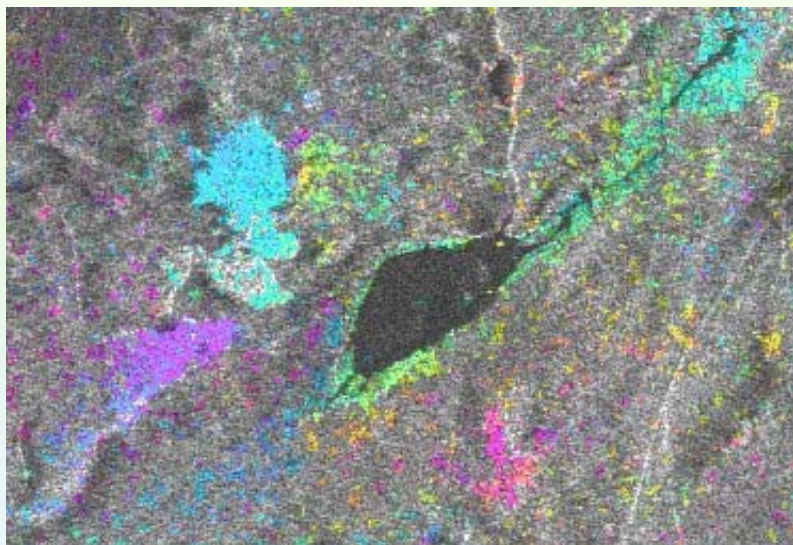
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Lu and Kwoun 2008

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Radarsat-2 Spotlight Interferograms



Relative Phase



2π

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0



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InSAR Water Level Approach

- Satellite Acquisitions
- Fieldwork – Install Instruments
 - Radar reflectors
 - Water Gauges
- InSAR stack processing



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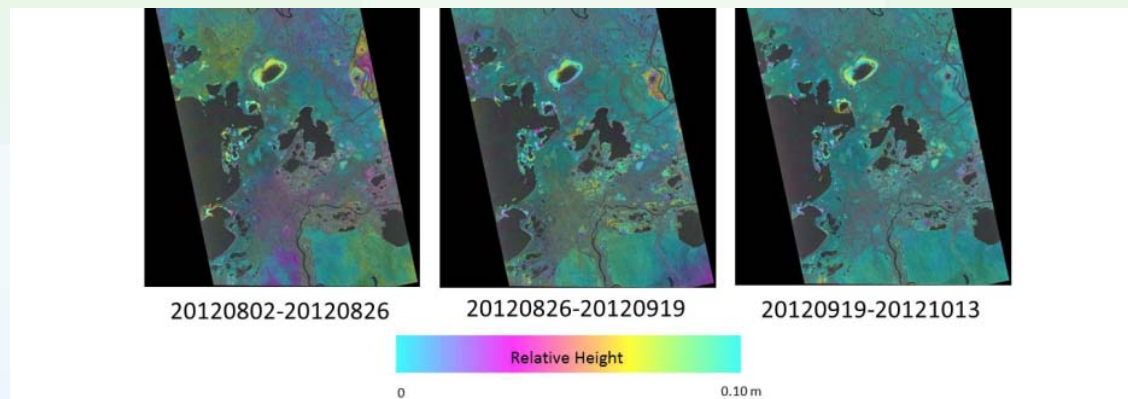
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InSAR water level

- Can use interferometric SAR processing in flooded vegetation to monitor water level changes at the mm scale
- Improved water volume for hydrologic modelling, weather forecasting, and ecological applications

Water level change



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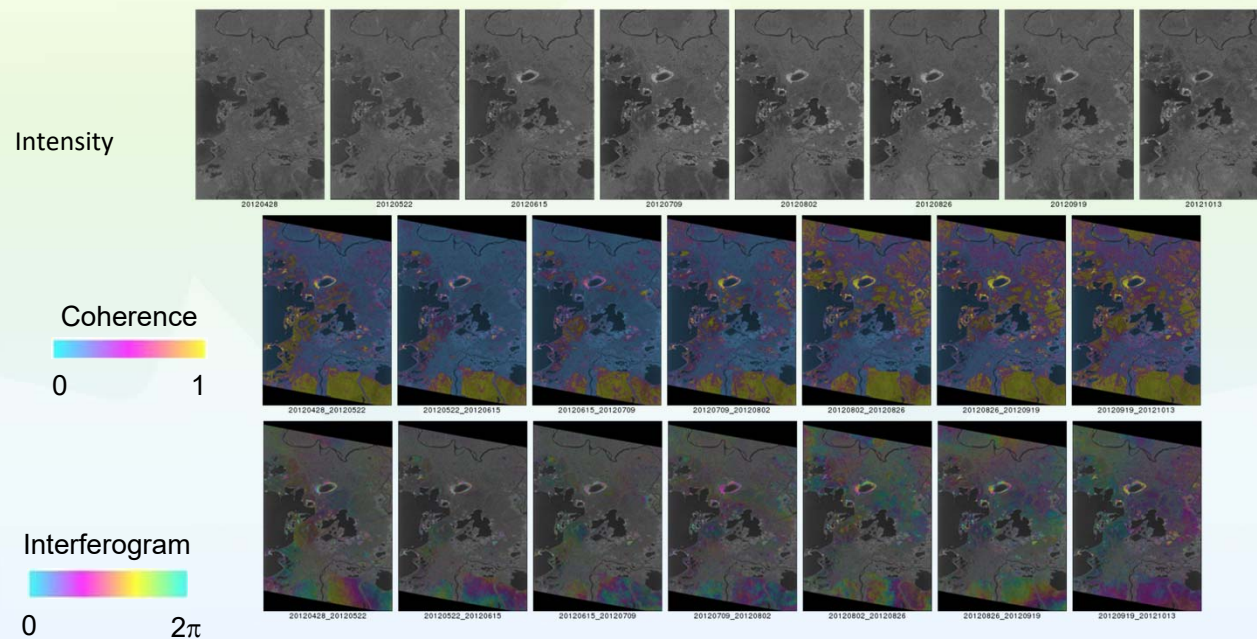
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PAD 2012 InSAR

April – October 2012



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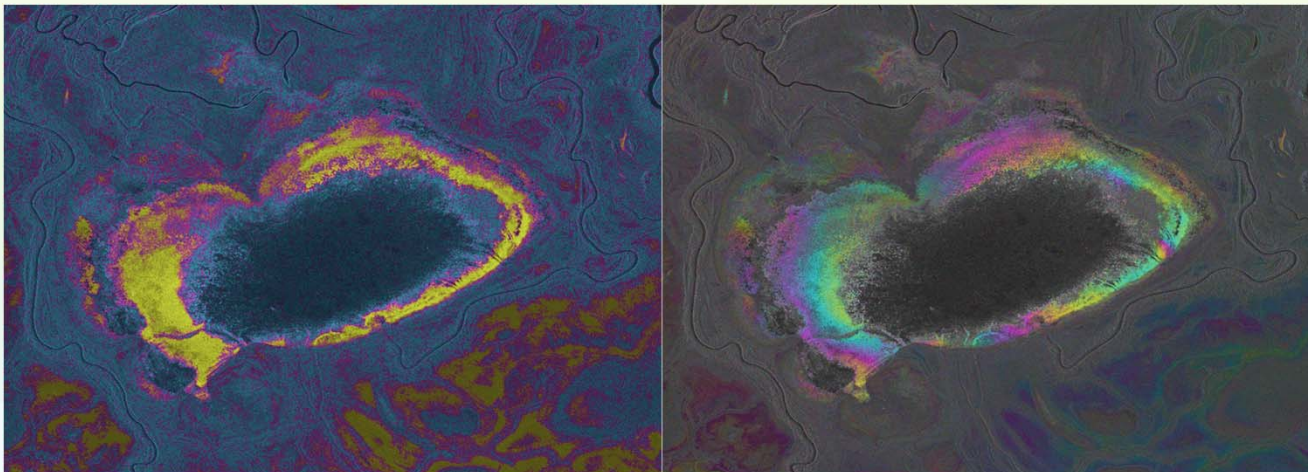


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PAD – Barril Lake 2012 Animation



Coherence

Interferogram

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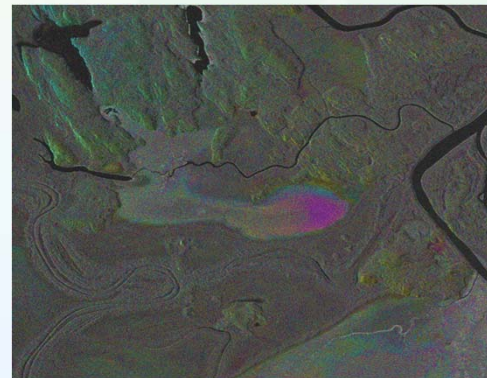
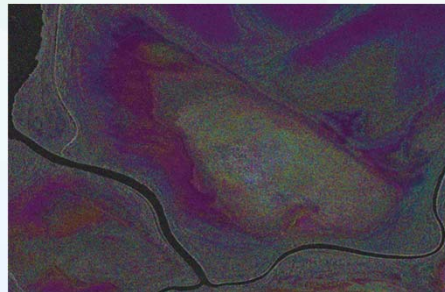
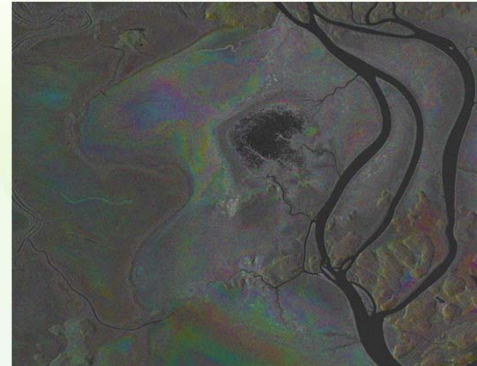
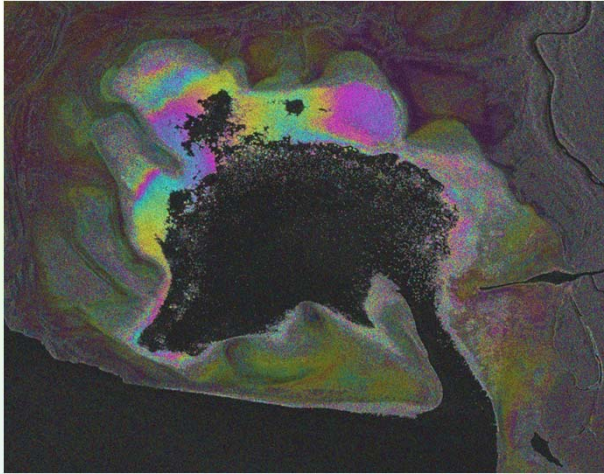


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PAD Remaining Sites Interferogram Animation



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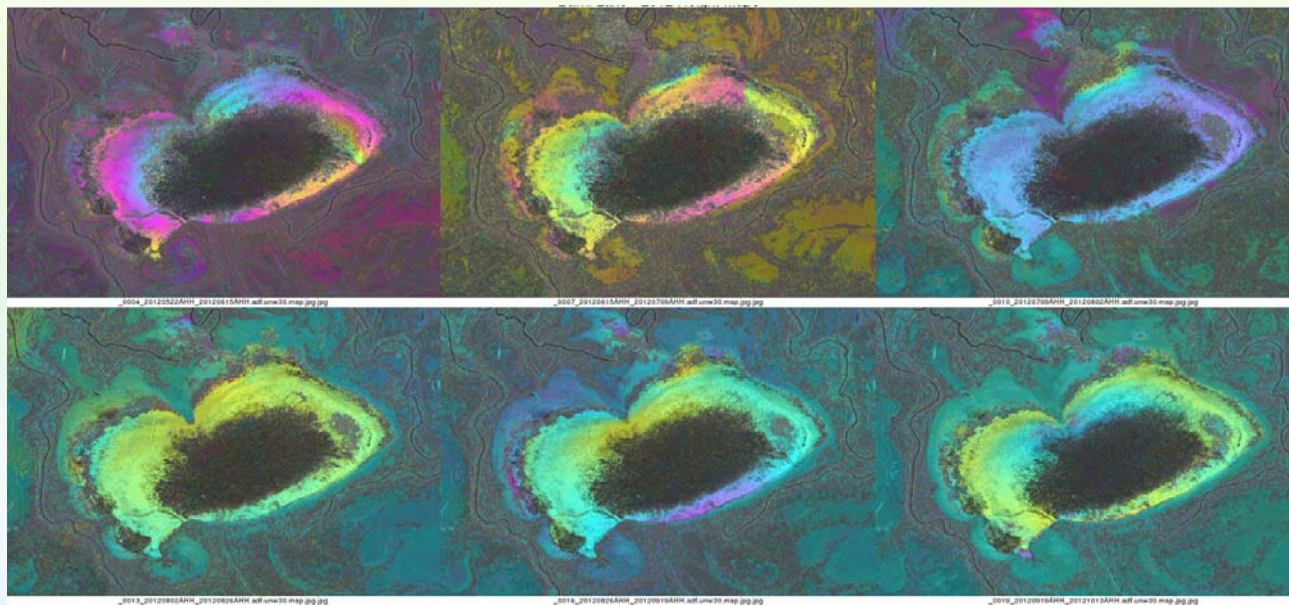


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Water Level Monitoring



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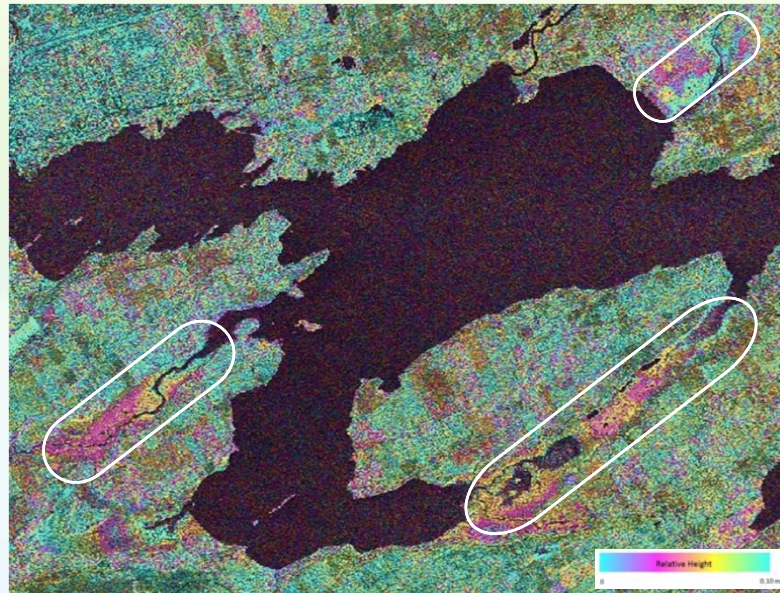


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Bay of Quinte relative water level change animation (2016)



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InSAR Water Level Research Thrusts

- Higher resolution in time and space
- Multi-frequency to solve phase ambiguity
- Small satellite design considerations

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