Natural Resources Canada | Ressources naturelles Canada

Monitoring Canada's dynamic water resources using SAR

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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

SAR and Water

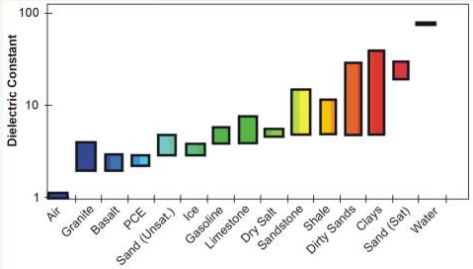
Well suited for surface water and flood mapping (cloud cover, heavy rains, etc.)

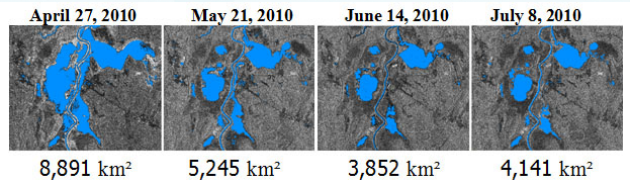
Excellent water/land separation

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





SAR Surface Scattering

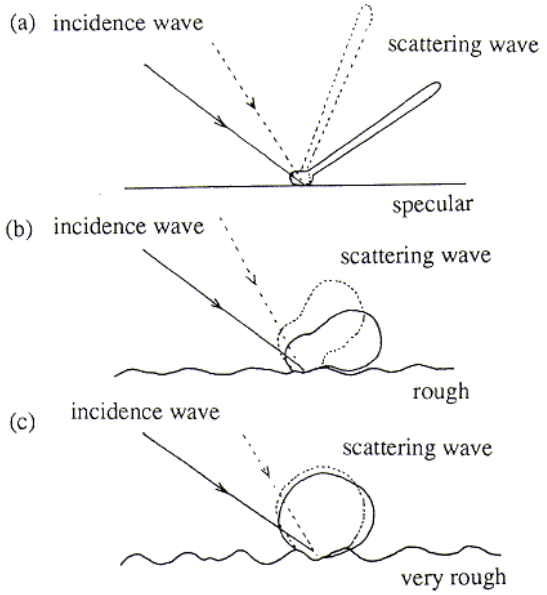
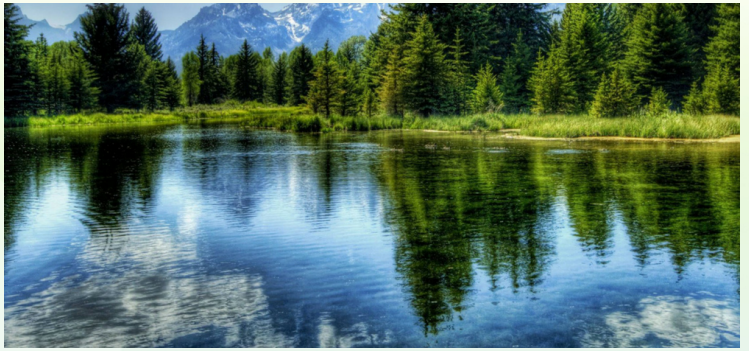


Figure 3.4.1 Surface scattering pattern with different surface roughness



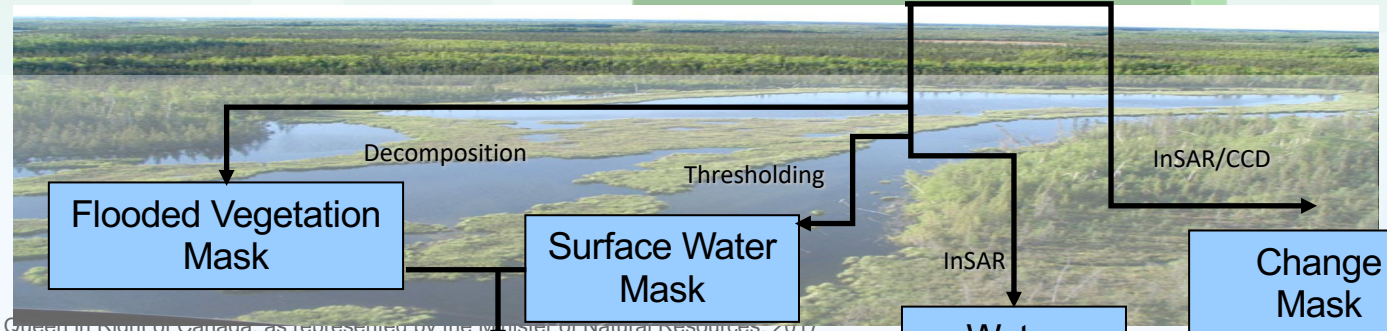
SAR Dynamic Surface Water Monitoring

- RCM Compact Polarimetry
- Other EO data

- DEMs
- GIS Layers
- In-Situ data

Pre-Processing
- Radiometric
- Geometric
- Ortho-rectification

Product Generation
(GIS Ready Output)



Flooded Vegetation Mask

Surface Water Mask

Wetland Extent

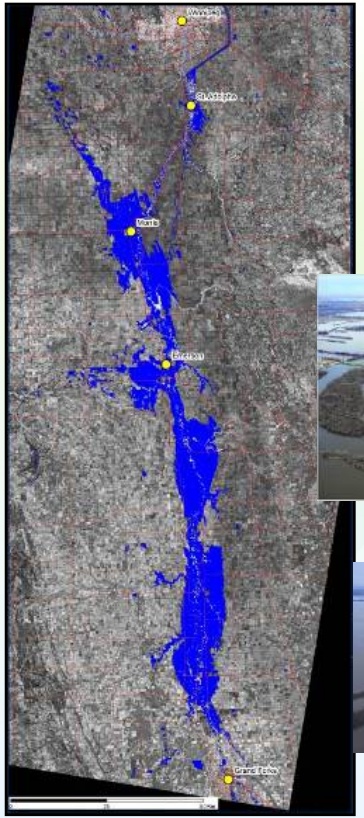
Water Level

Change Mask

2011 Flood Products

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

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

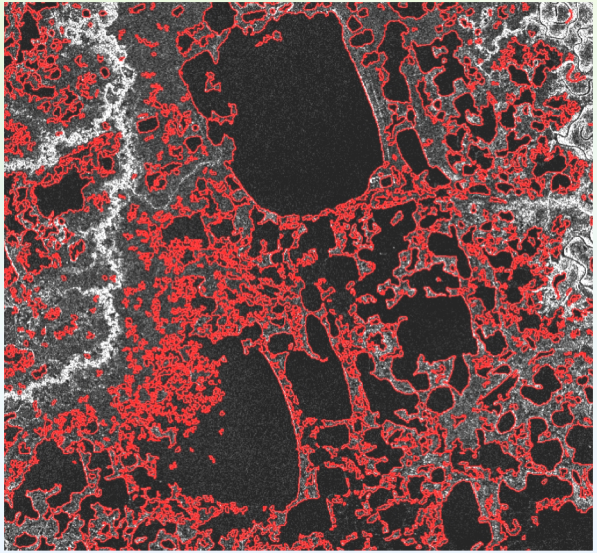


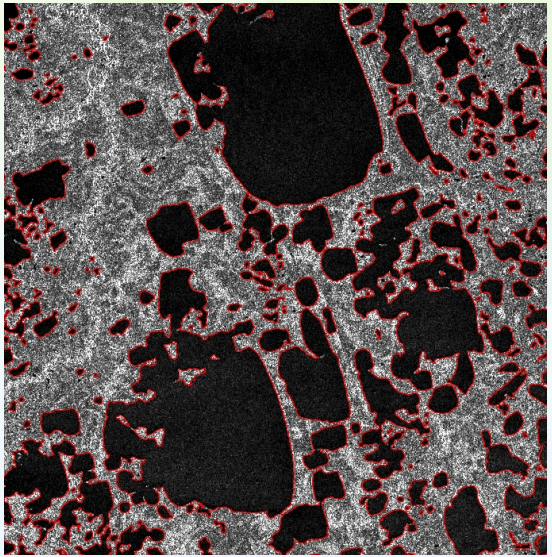
SAR and Surface Water Extent

- 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



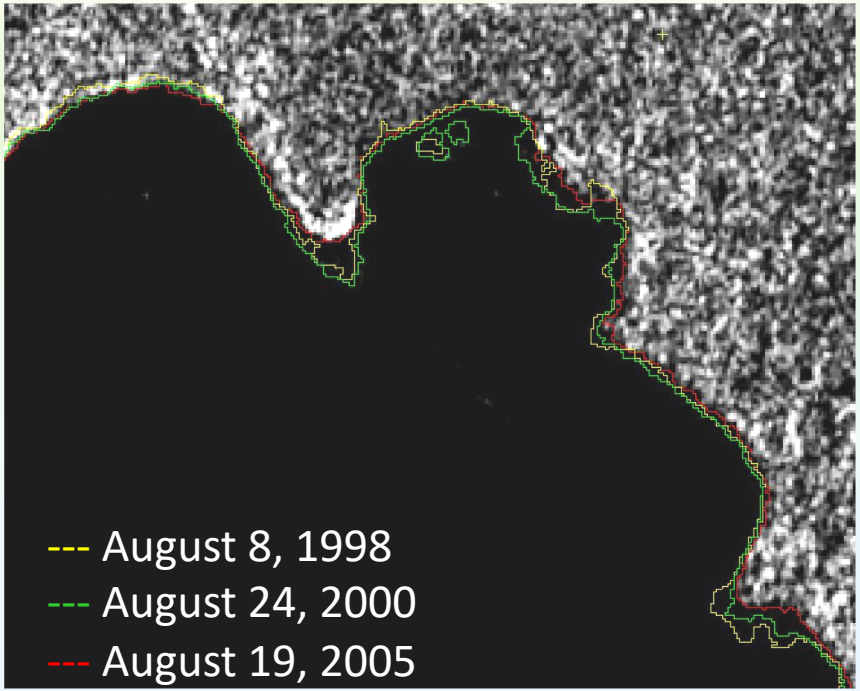


Summer -- Lower water levels

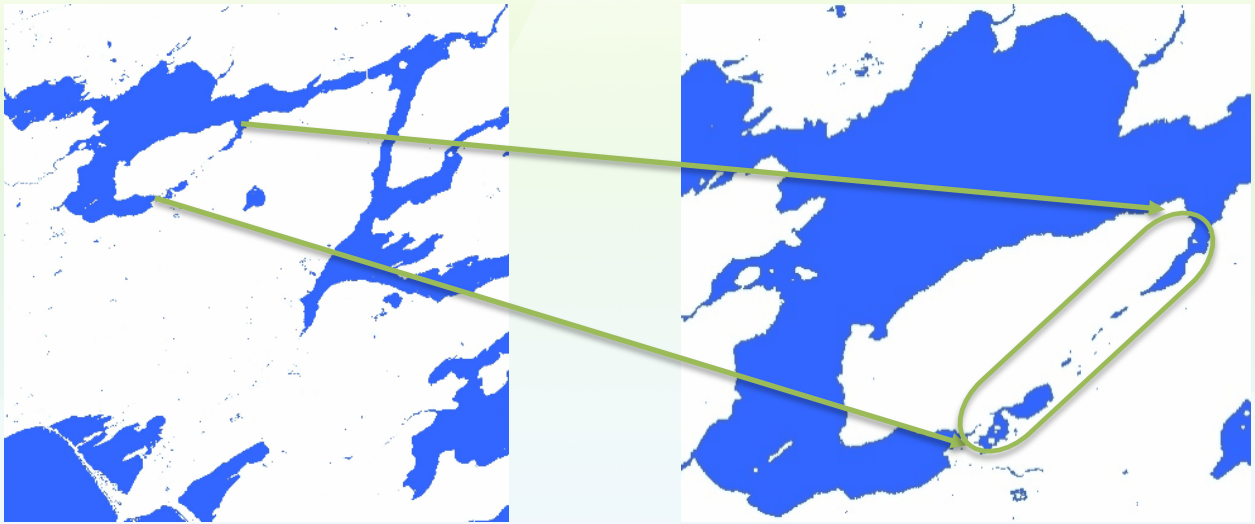
McClelland Lake, Fort Mackay, AB

Inter-annual variability in lake extent

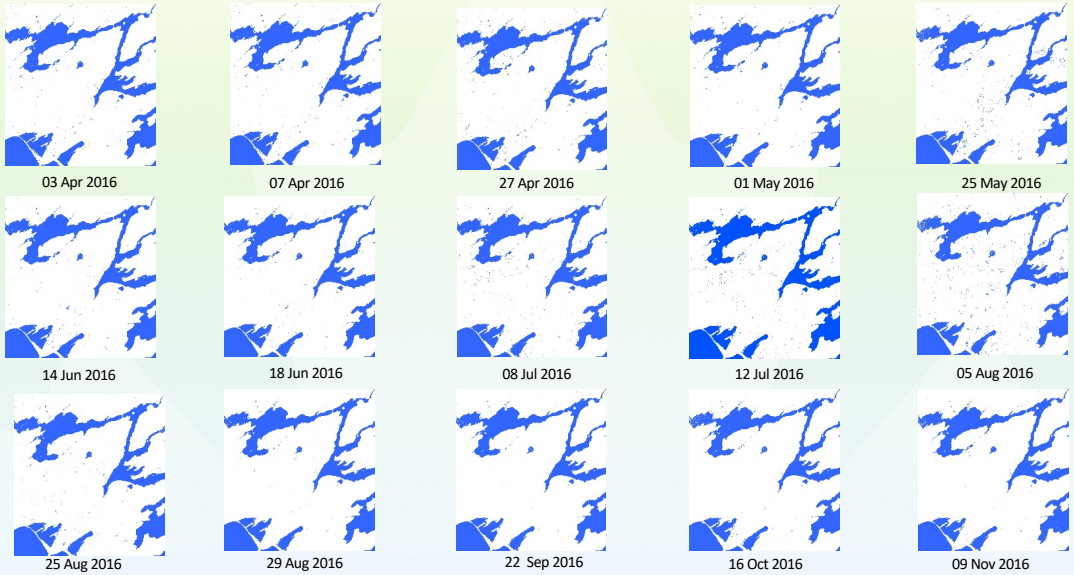
Background image is August 19, 2005



Bay of Quinte open water animation (2016)



Open water of Bay of Quinte

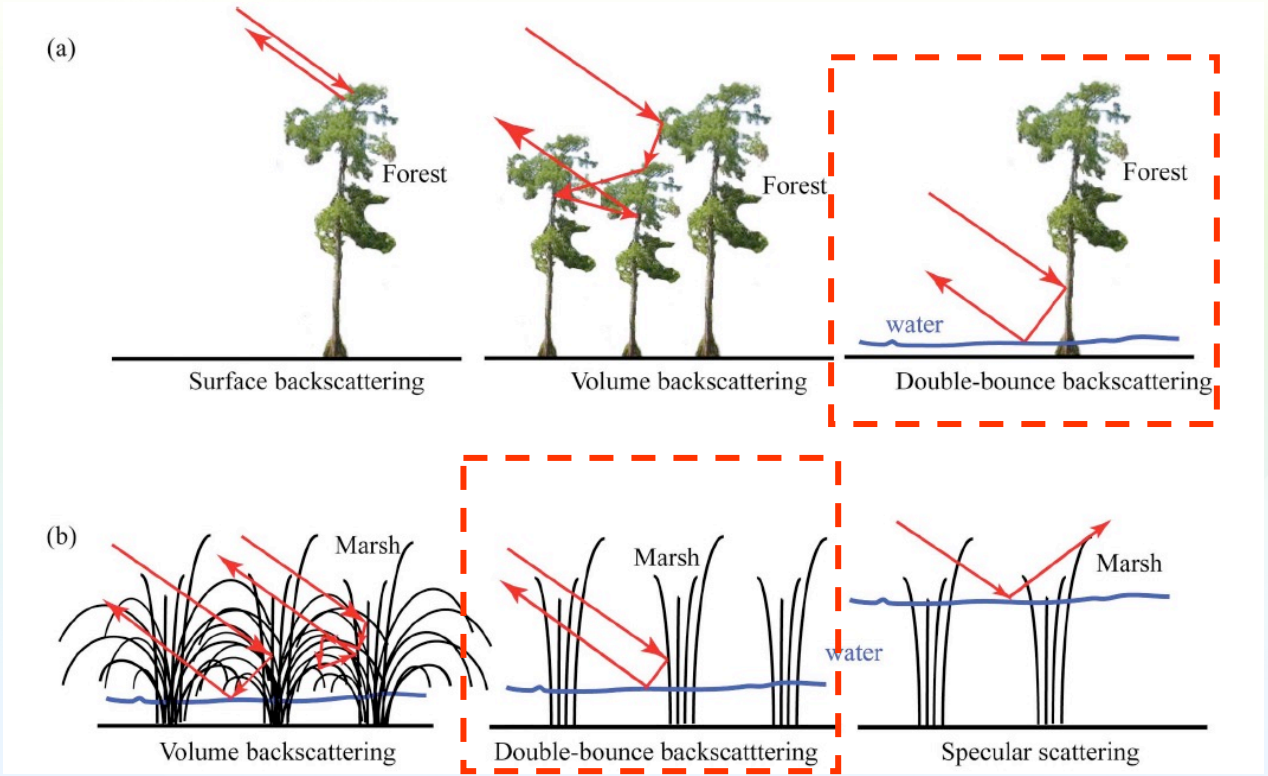


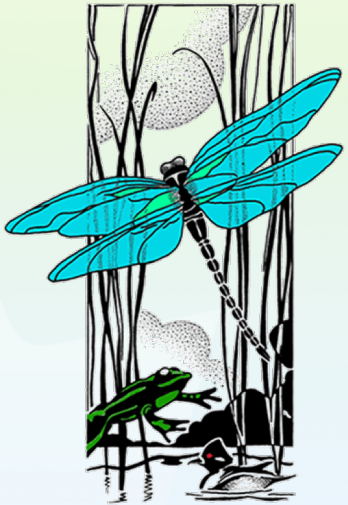
Current Research Thrusts

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

Flooded Vegetation Mapping

Scattering Mechanisms





Polarimetry provides...

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

Scattering matrix
(complex)

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

5 independent measures

3 Backscatter coefficients σ°

e amplitudes: *Svv, Shh, Shv*

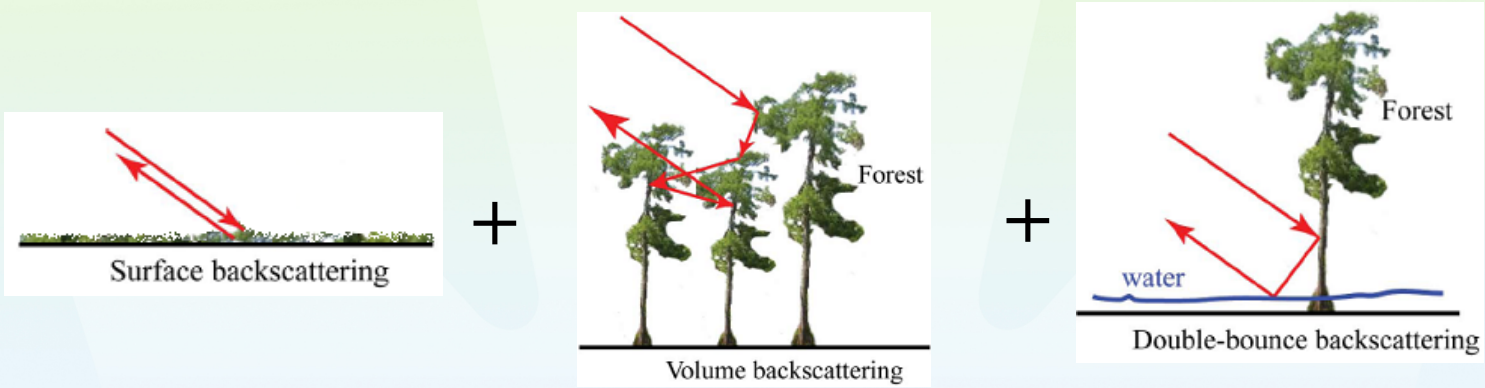
2 Phases differences $\Delta\phi$

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

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

Freeman-Durden Decomposition

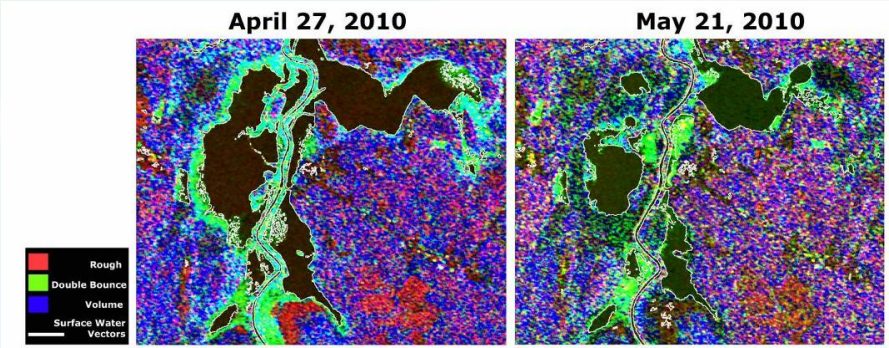
$$|S_{HH}|^2 + |S_{HV}|^2 + |S_{VH}|^2 + |S_{VV}|^2 =$$



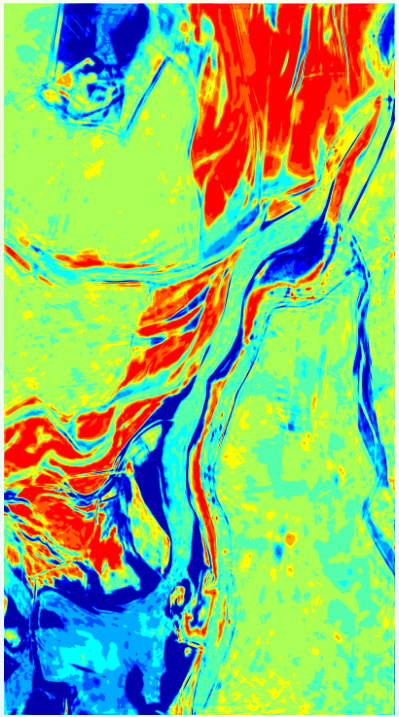
= Total Intensity

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

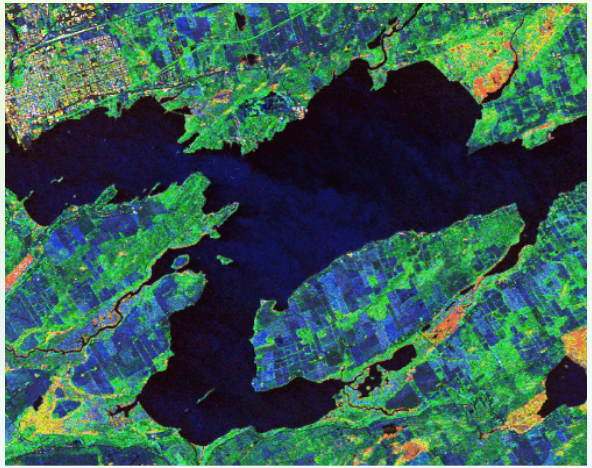


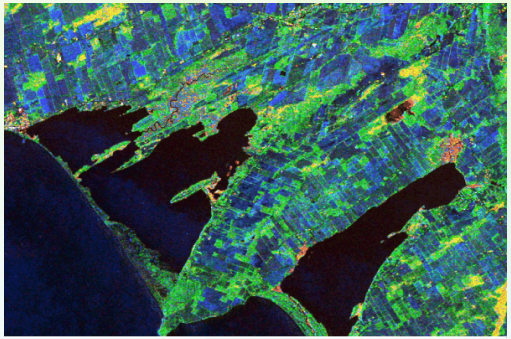
SAR and Flooded Vegetation



Dong Ting Lake
Δ Double Bounce

Bay of Quinte wetland FDD animation (2016)

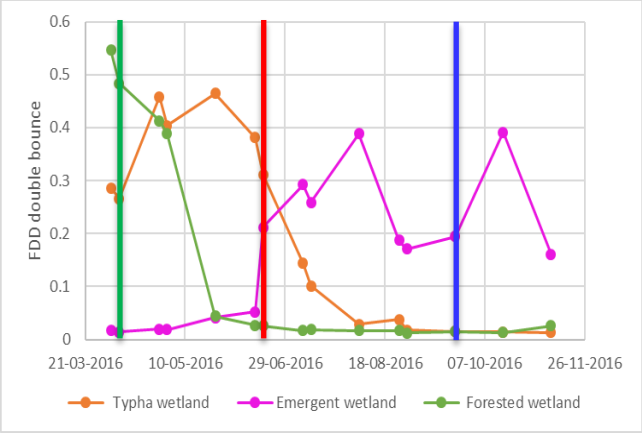


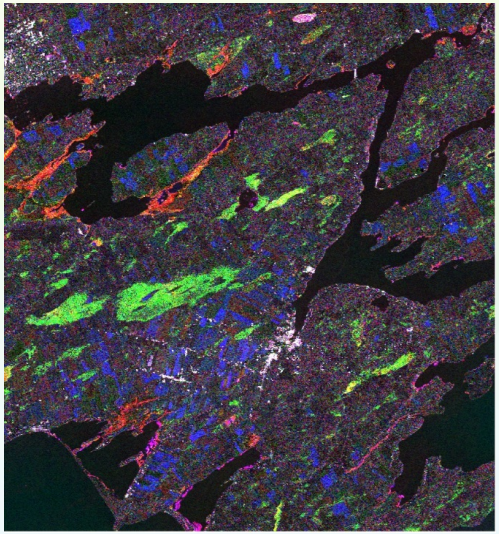


Freeman Durden Decomposition

R: Double bounce, G: Volume scattering, B: Rough surface

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

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

Flooded Vegetation Research Thrusts

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

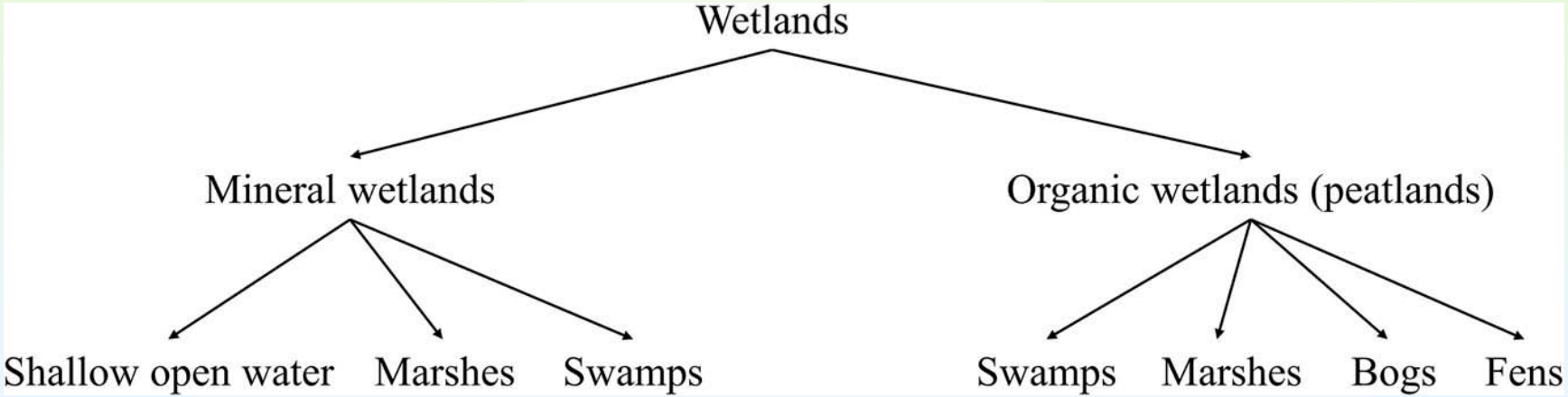
Wetland Classification

Wetland Classification SOA

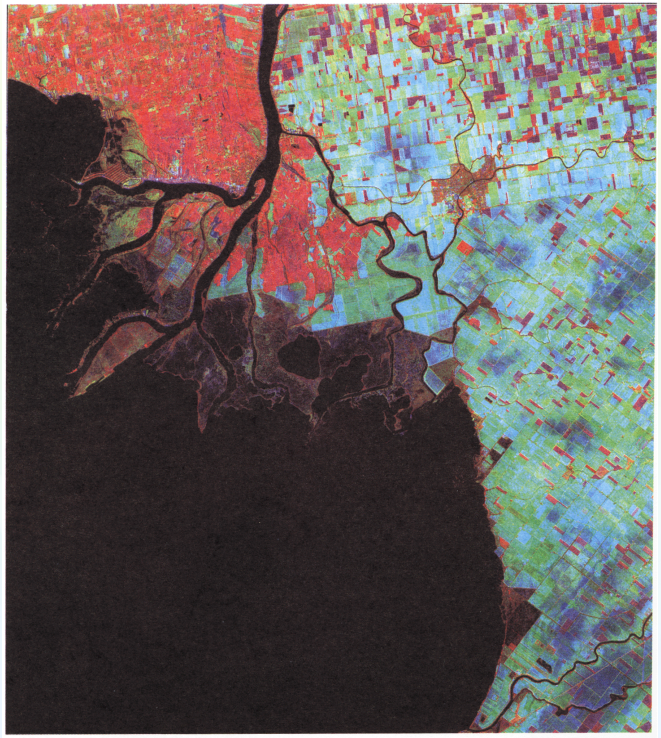
- Object based classification
- Optical, SAR, and DEM layers
- Multi-temporal (Spring and summer)
- Machine Learning algorithms
- Big Data processing capabilities

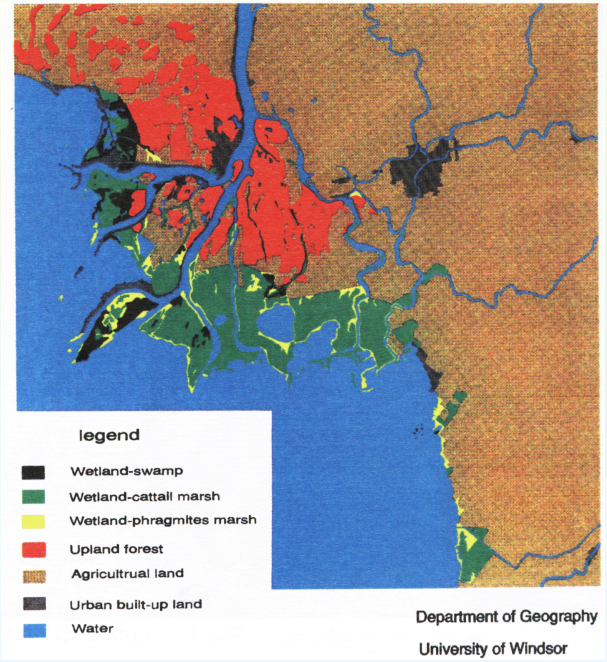
CWCS

Canadian Wetland Classification System



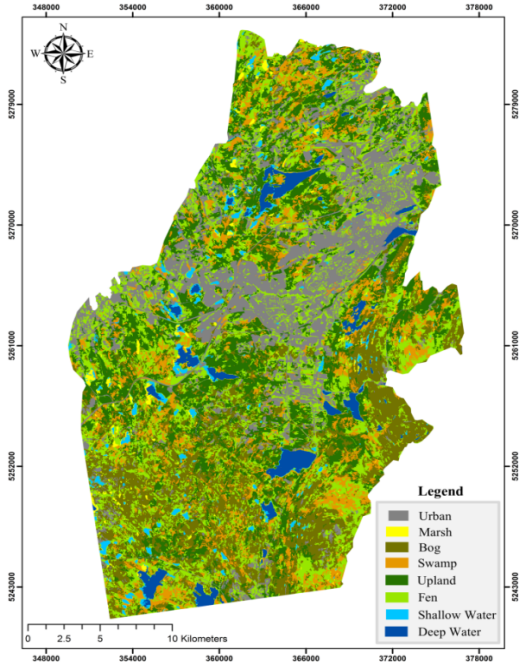
Wetland Mapping





Lake St. Clair ERS-1/TM PCA

Avalon Peninsula SAR



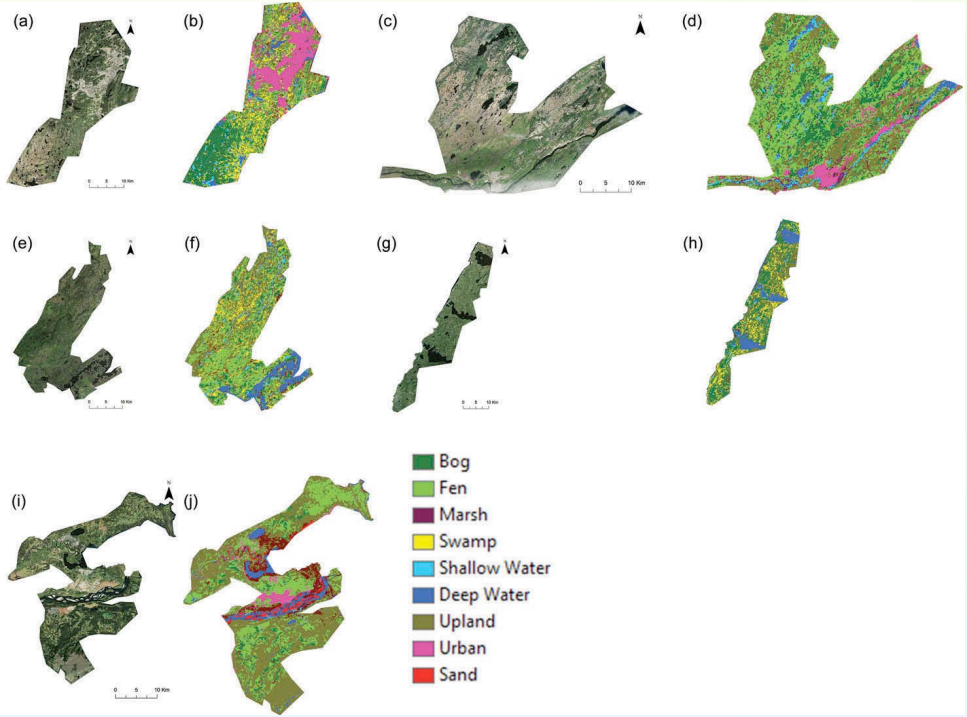
Sensor	Time interval	# of images	Image mode	Inc. angle (°)	Resolution (m)	Polarization	Direction
ALOS-1	Feb 2007 to November 2010	7	FBS	38.7	10	HH	Ascending
		10	FBD	38.7	20	HH-HV	Ascending
RADARSAT-2	April to August 2016	5	U16W2	42.13	2.5	HH	Descending
		4	FQ22	42	8	Quad-pol	Ascending
		3	FQ30	48	7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

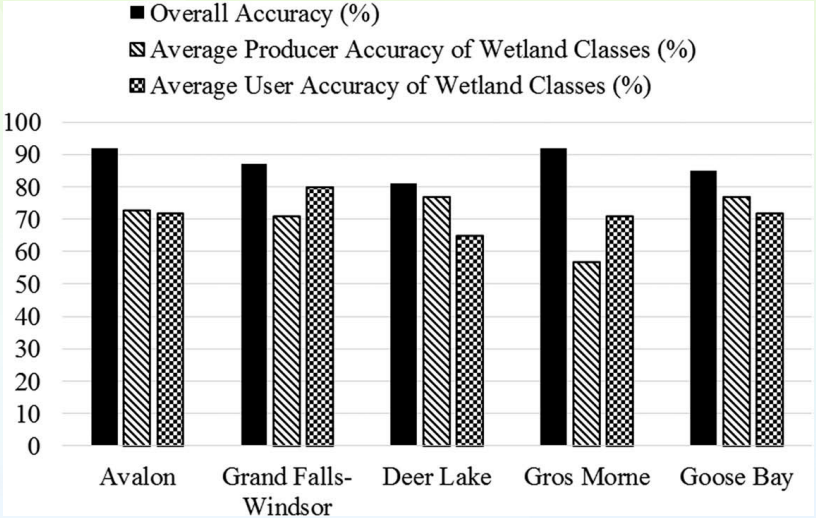
SVM classification

85 % accuracy

Kappa 0.82

Newfoundland Sites SAR/Optical





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

Canadian Wetland Inventory

Classification scheme in GEE

Google Earth Engine

c·core

Sentinel-1&2 Imagery

Pre-processing

Feature Extraction

SNIC Superpixel Segmentation

Random Forest Classification

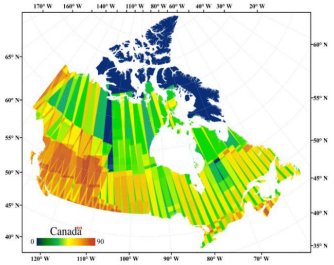
Wetland Inventory Map

5

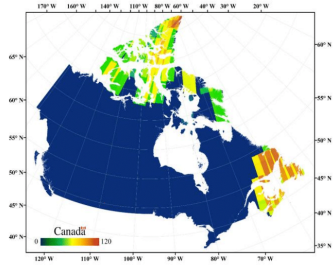
Sentinel 1&2

The coverage of three-year summer composite

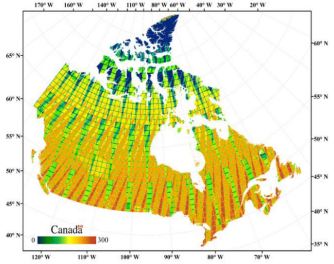
S1: VV/VH



S1: HH/HV



S2

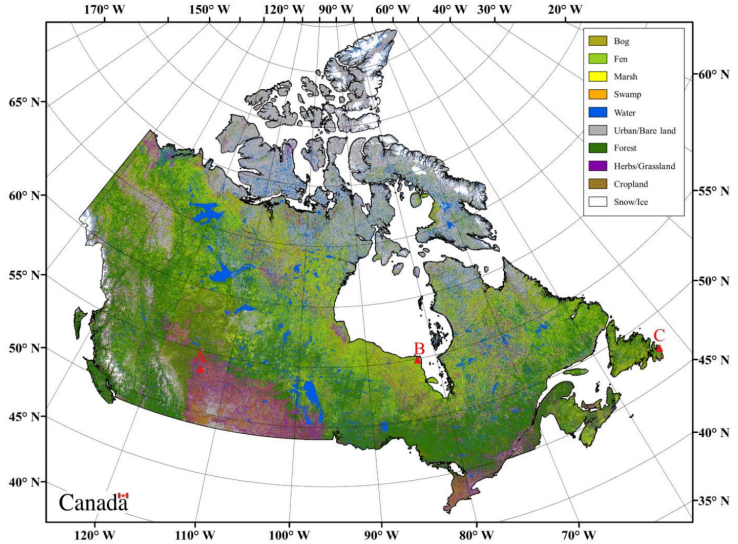


c·core

6

CWI Map

The first Canadian wetland inventory map at a spatial resolution of 10 m



Wetland Classification Research Thrusts

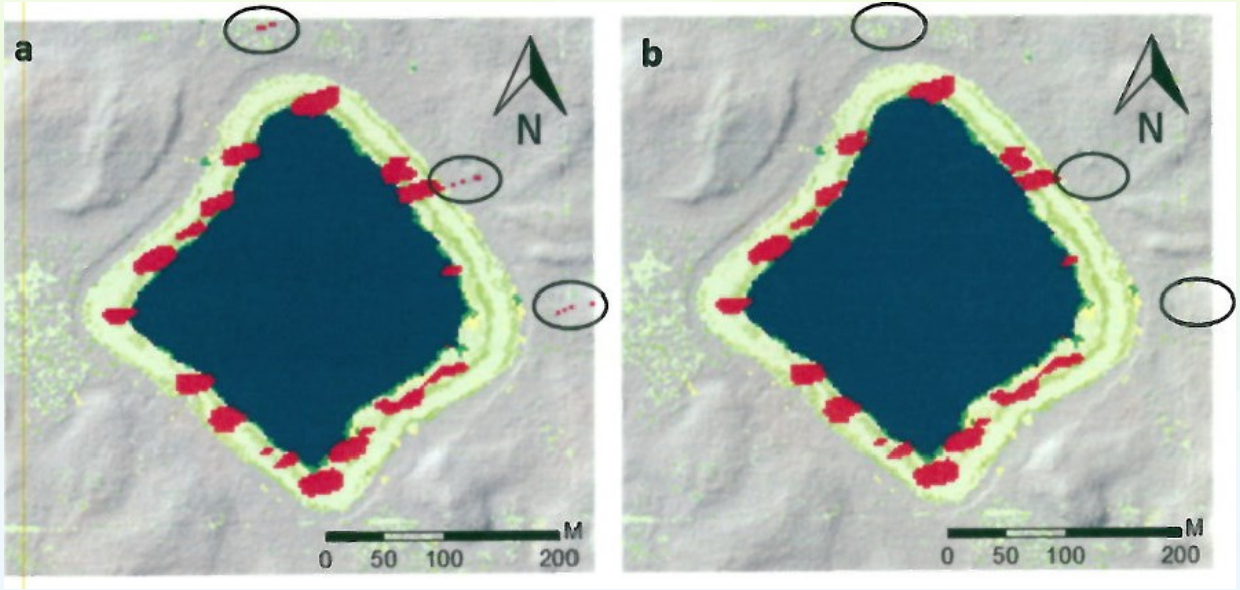
- Higher resolution in time and space
- Multi-source – L-band coming
- Machine Learning classification strategies
- Big Data analytics

SAR/Lidar Fusion

SAR/Lidar Fusion

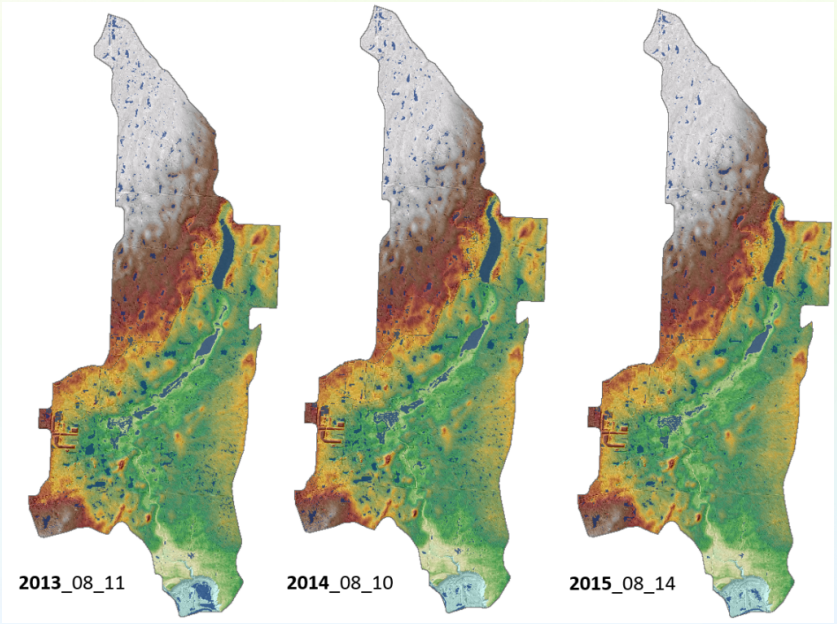
- Lidar or other high resolution DEM and multi-temporal SAR for hydro-period determination
- Periodic Lidar and derivatives for fixing errors of omission and commission using simple logic
  - Roads and human footprints not water
  - Pasture and bare ground above water level not water
  - Vegetation too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

Example Error Correction



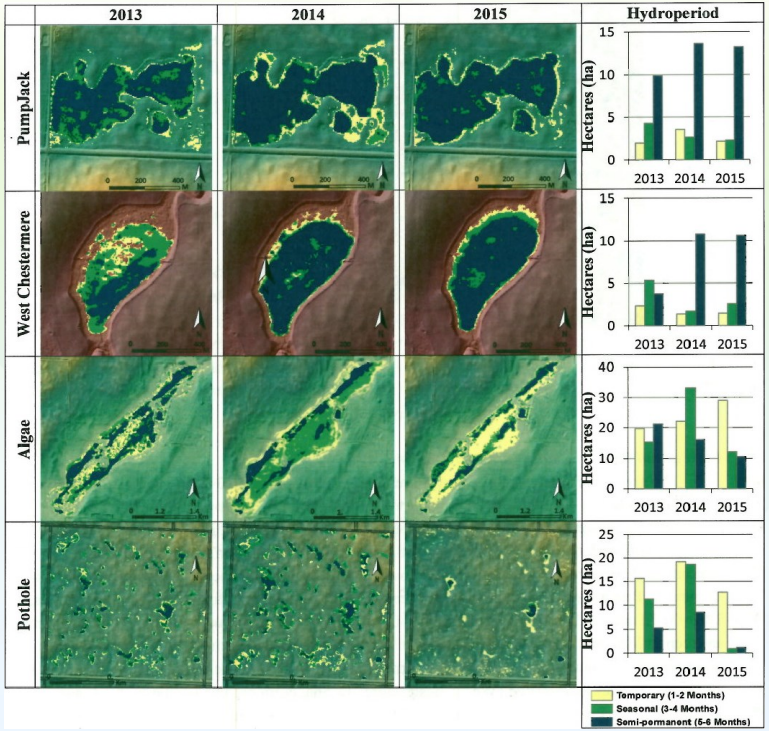
SAR/LiDAR Sheppard Slough

- 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

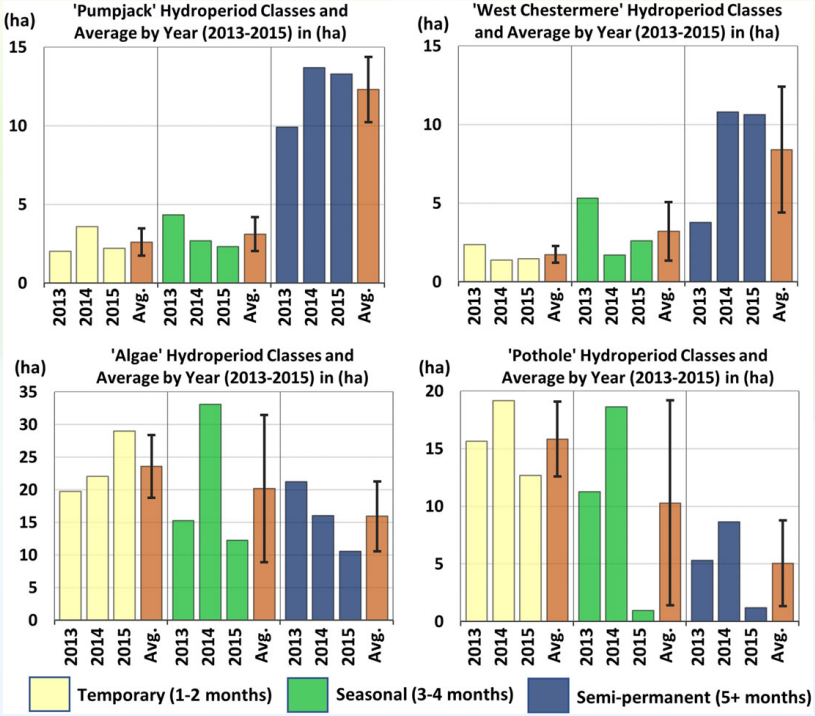


SAR/LiDAR Fusion – Sheppard Slough Calgary

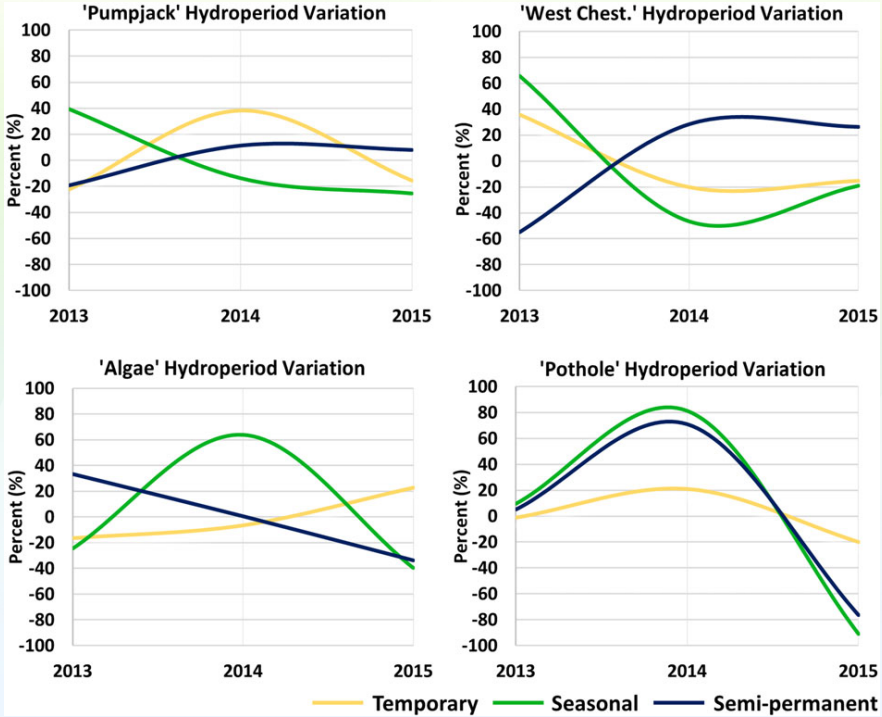
Hydro-period Determination



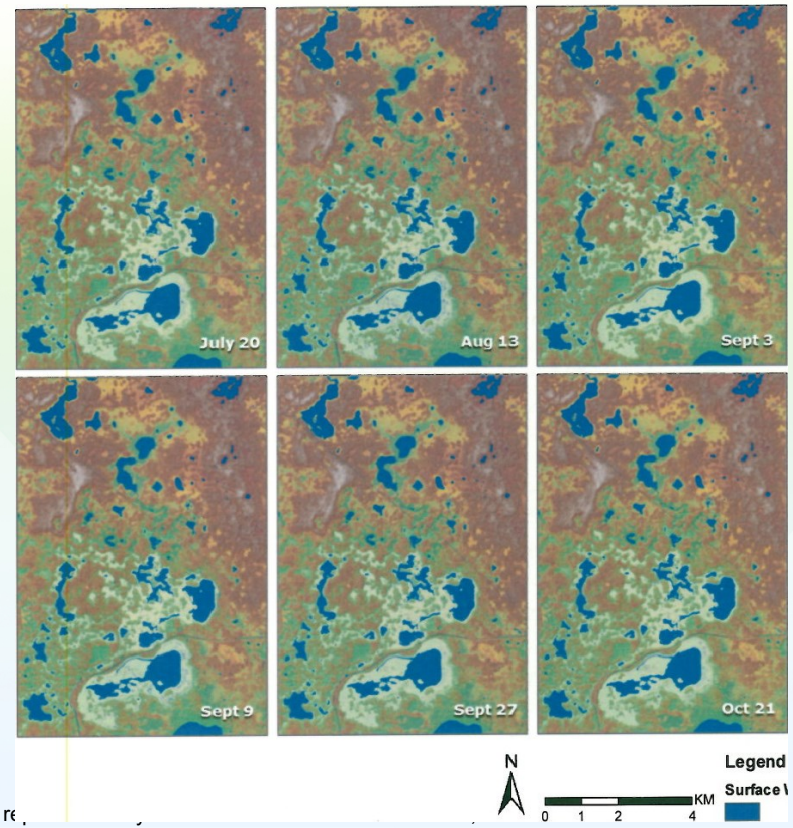
Hydroperiod classes



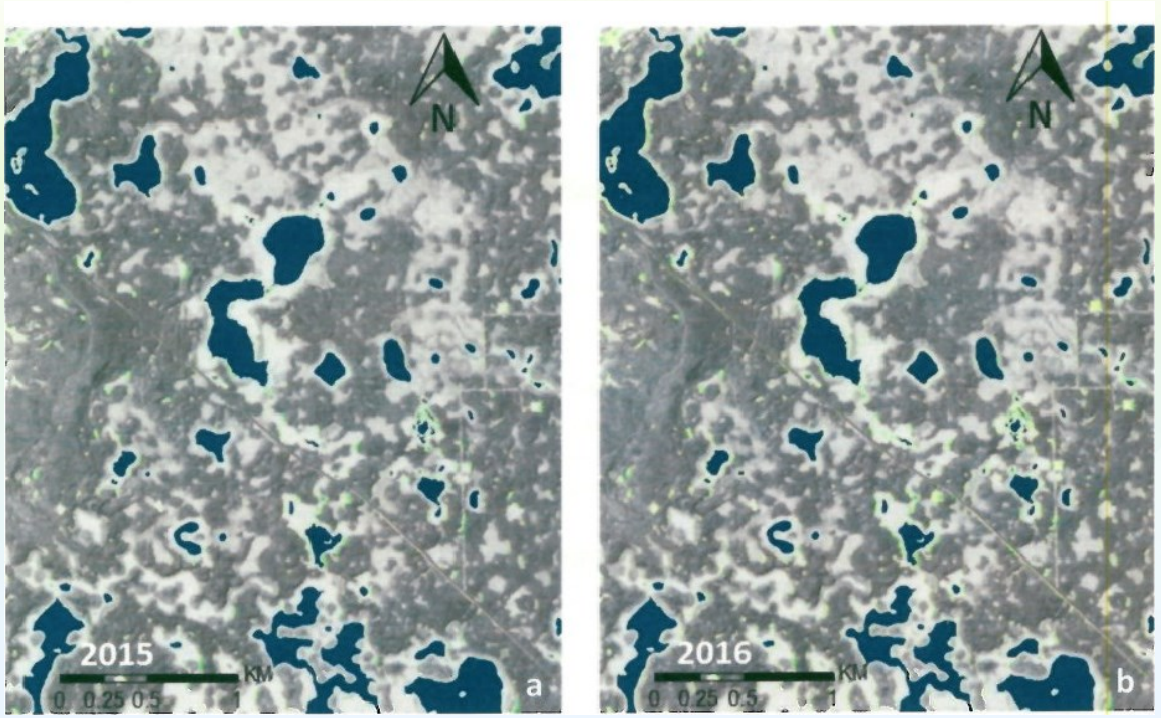
Interannual variation wetland hydroperiod class



SAR Derived Water Masks URSA

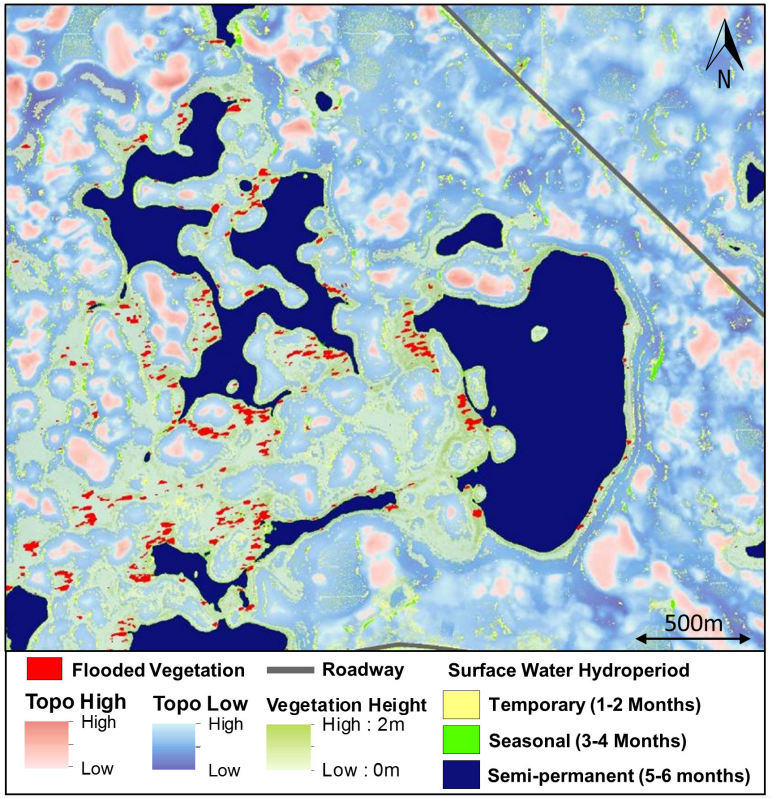


URSA Hydroperiod



Yellow – temporary
Green – seasonal
Blue - permanent

URSA Hydro-period



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

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

SAR Coherence for Wetland Mapping and Monitoring

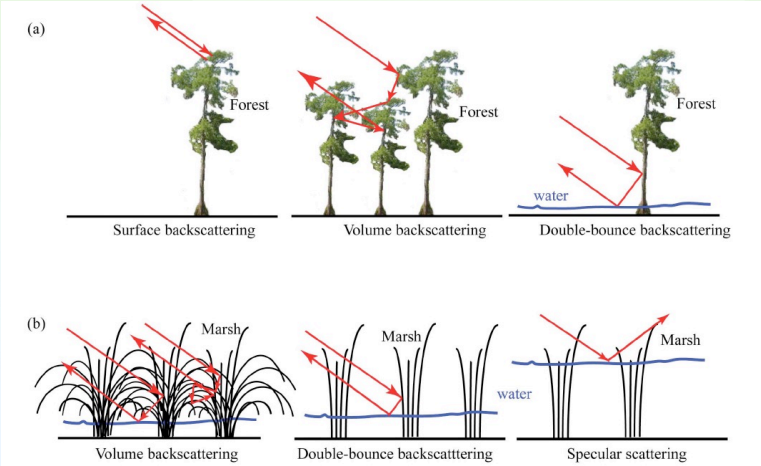
SAR COHERENCE

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

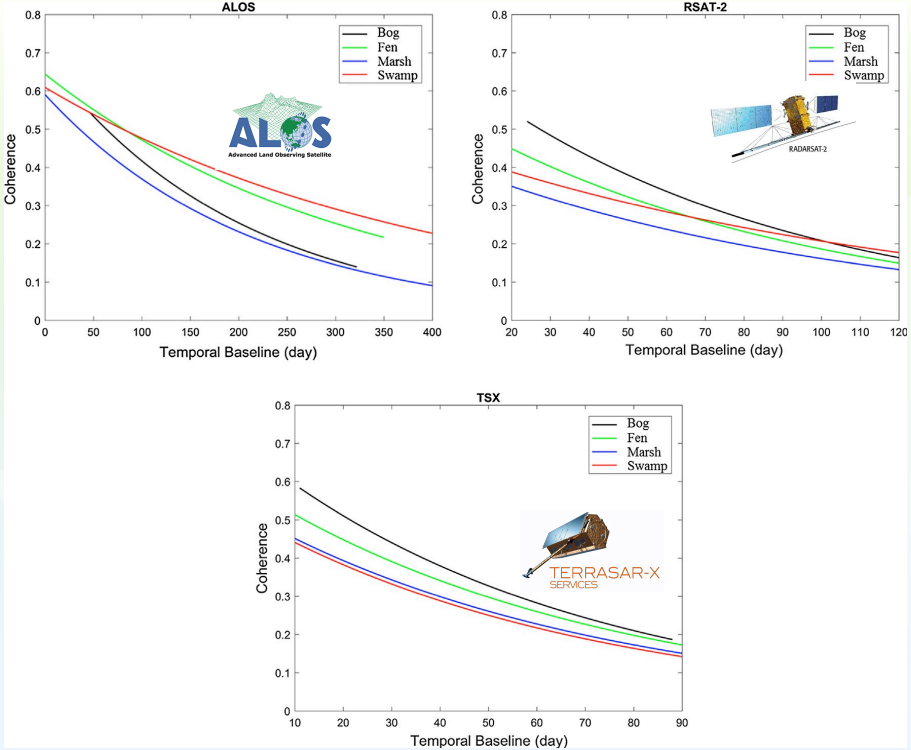
Low coherence → usually water (unusable)

Moderate coherence → growing or moving veg (sometimes usable)

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



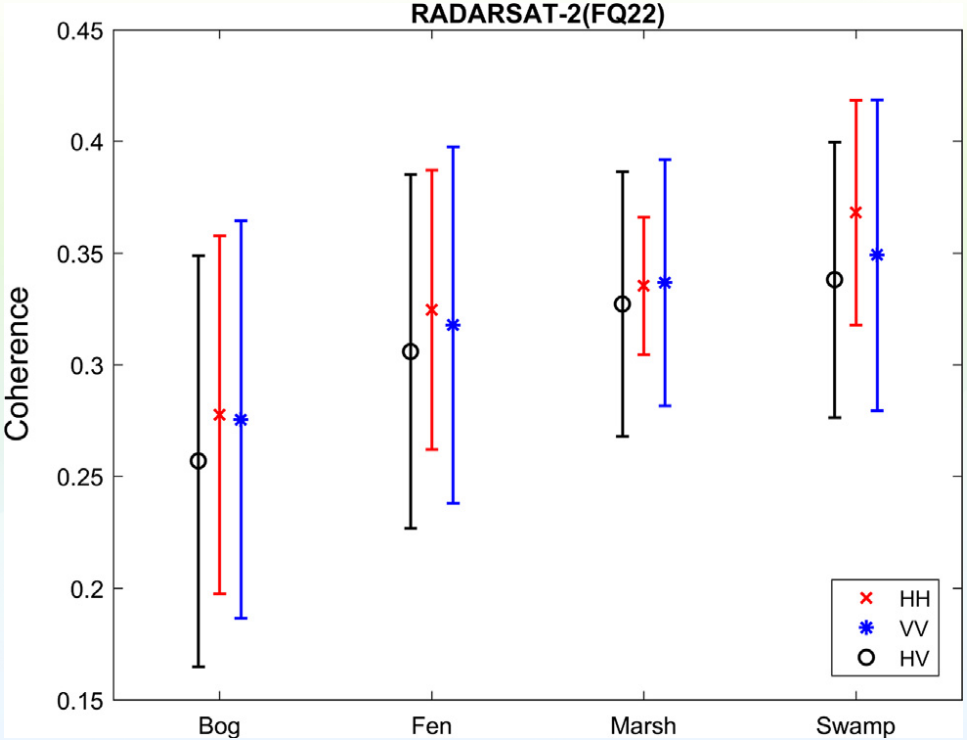
Wetland Coherence vs Temporal Baseline



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

SAR Coherence vs Polarization



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

Coherence Change Detection

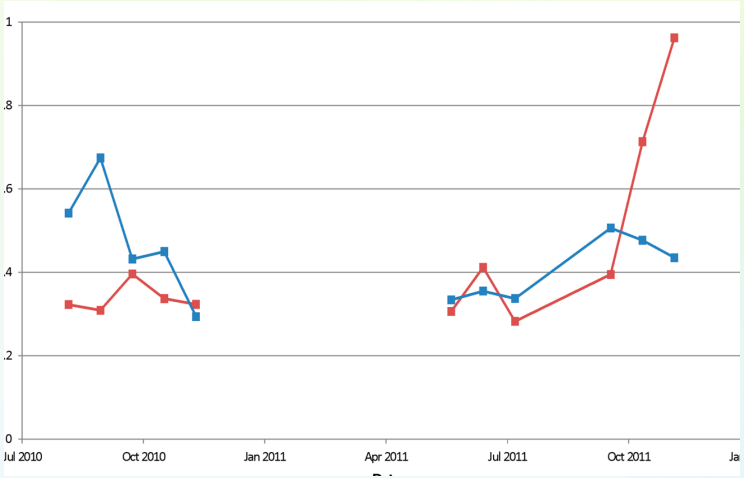
High Coherence both dates – flooded vegetation

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

High Coherence but sudden drop – drainage or vegetation change

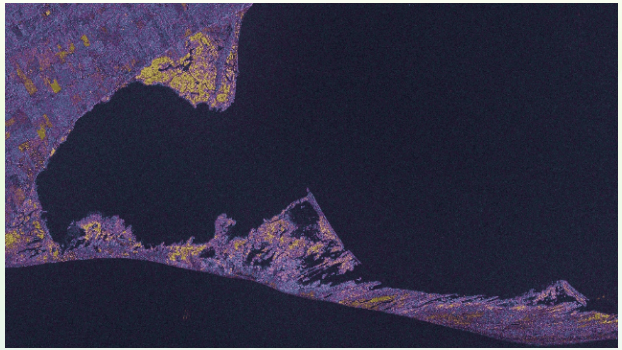
Med to Low Coherence then increasing - water level increase

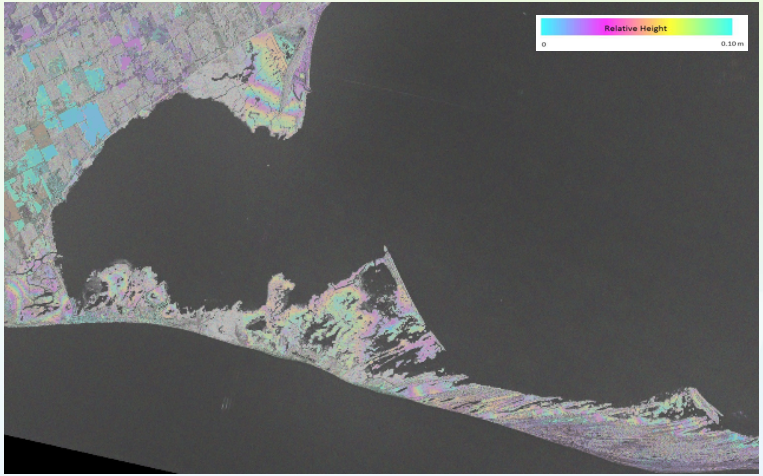
Low to High Coherence – recently flooded



Brisco et al., 2017, Remote Sensing

Coherence/Water level animation (2016)





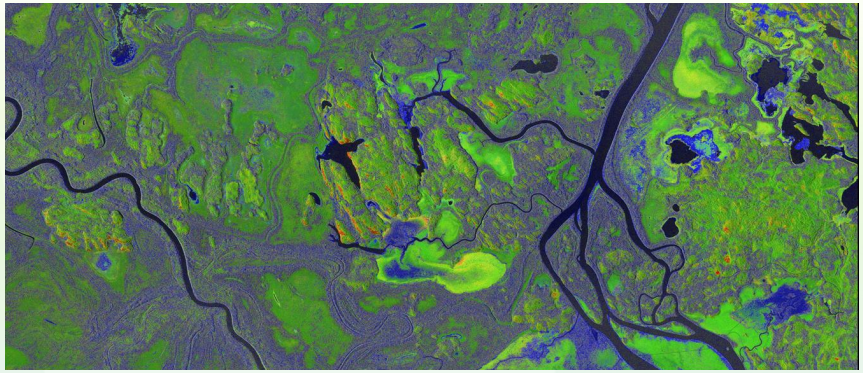
Long Point, Ontario – RADARSAT-2

Methodology Raster Temporal Coherence

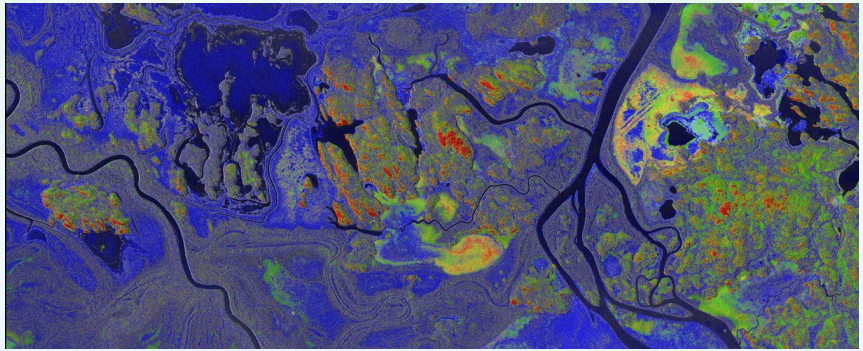
- Ice-off season (May 15-Oct 15)
- 6-9 Co-registered Intensity Images
- 5-8 24 day interval coherence estimates
- Statistical Analysis per pixel
  - Mean
  - Standard Deviation – normalization
- Visualization

Raster Temporal Statistics PAD

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

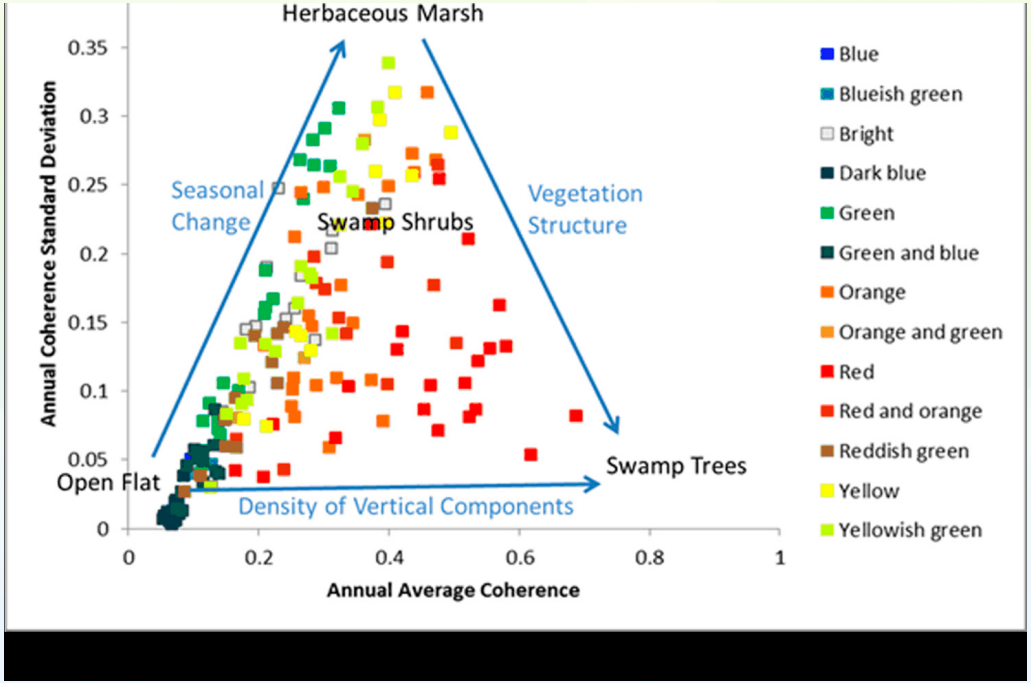


2013



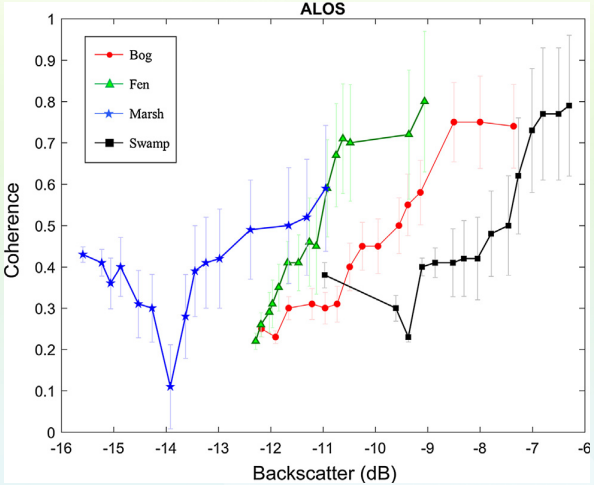
2014

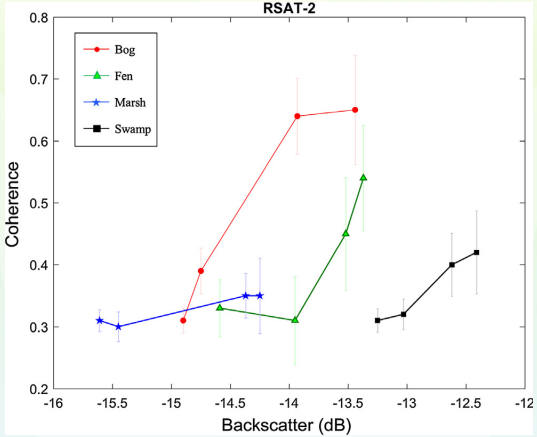
Annual Coherence for Wetland Monitoring

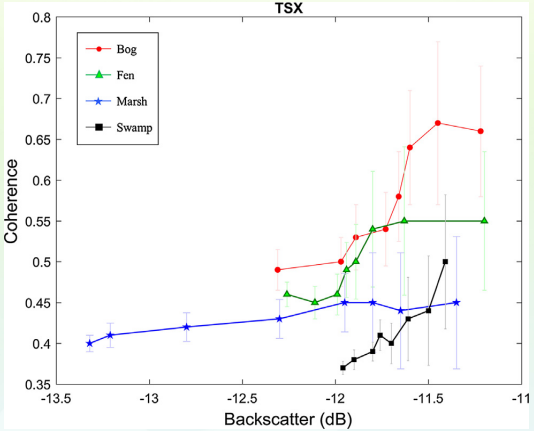


Brisco et al., 2017, Remote Sensing

Coherence and Intensity Wetland Classification





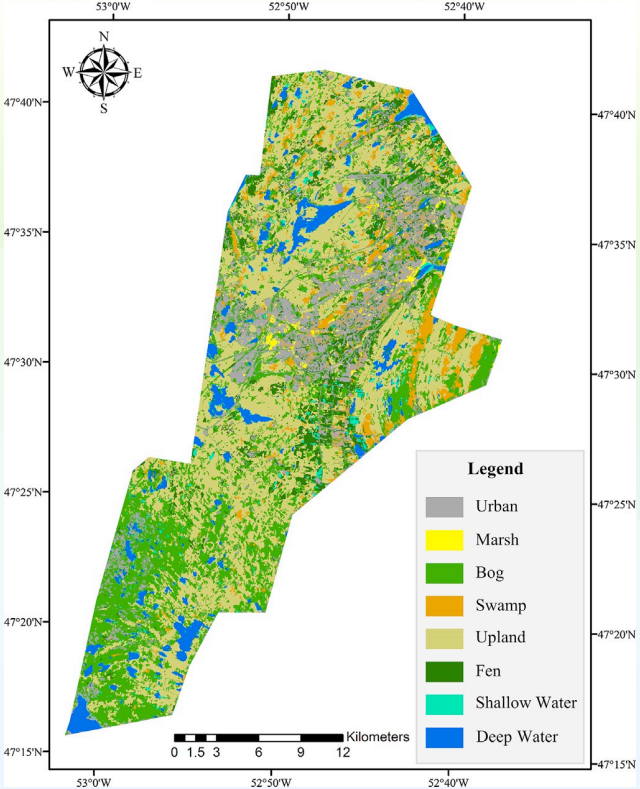


Mohammadimanesh et al., 2018, ISPRS Journal Photogrammetry and Remote Sensing

Classification Map – RADARSAT-2

Avalon Peninsula
Nfld/Labrador

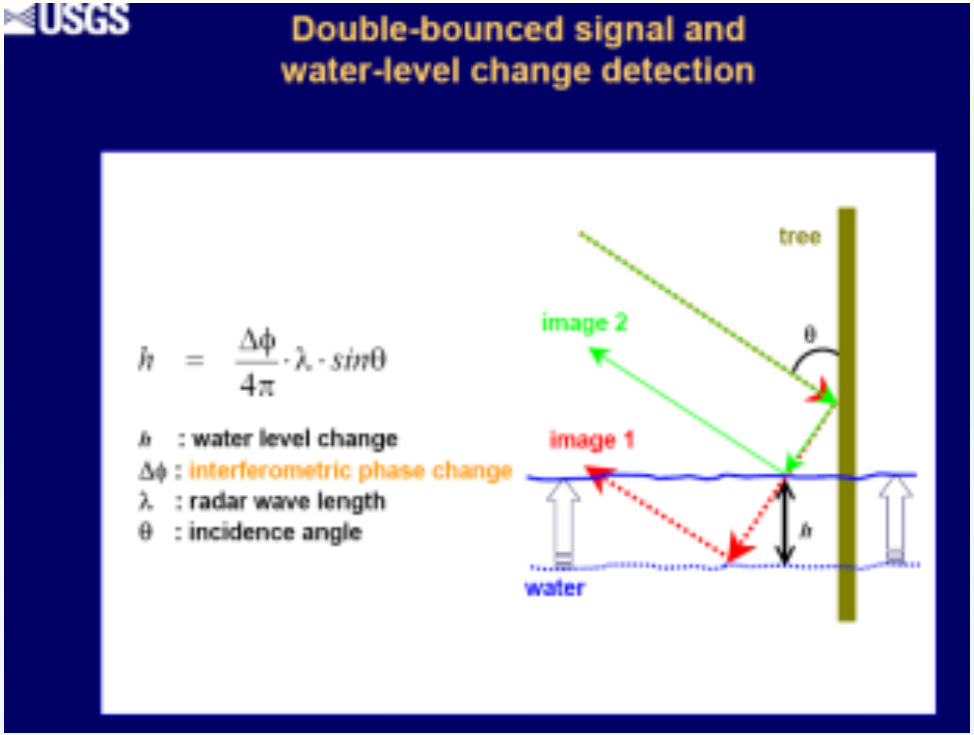
overall accuracy of 74.33% and a Kappa coefficient of 0.66 were obtained.



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

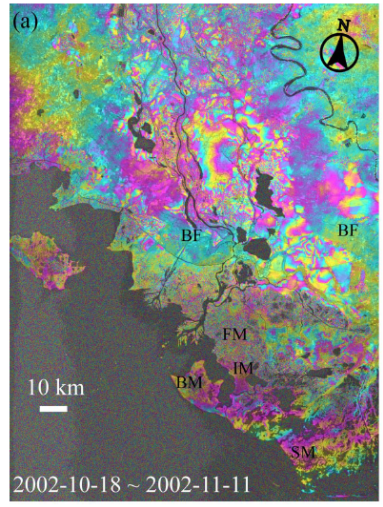
InSAR Water Level

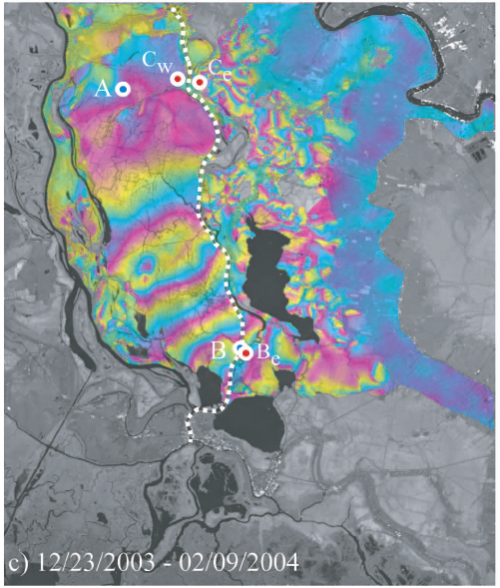
InSAR for water level



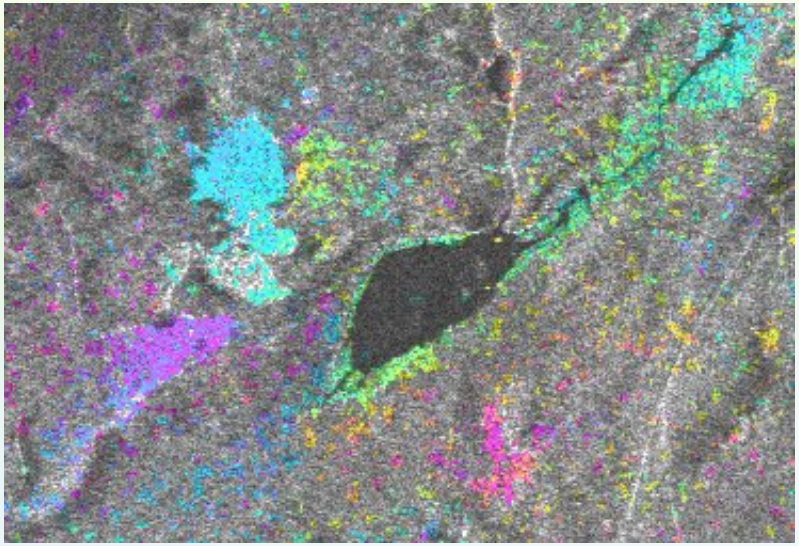
INSAR for Wetlands

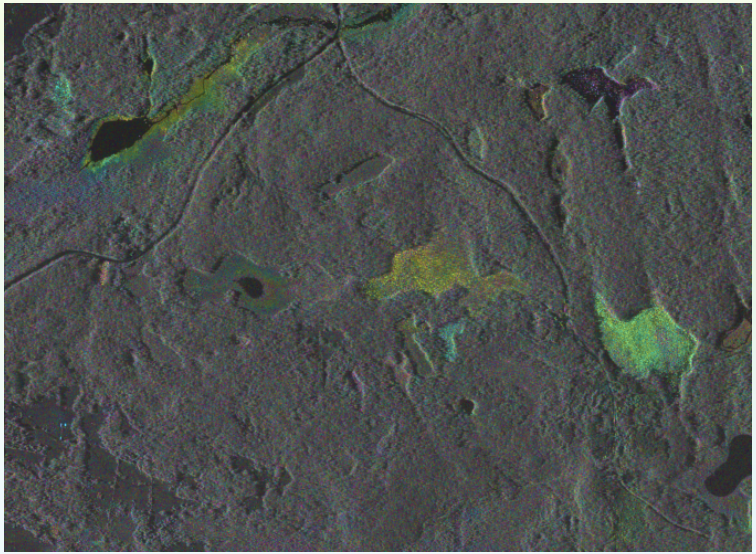
- Wetland coherence allows interferogram generation
- Water level changes can then be determined from interferograms





Radarsat-2 Spotlight Interferograms





Relative Phase

2π

InSAR Water Level Approach

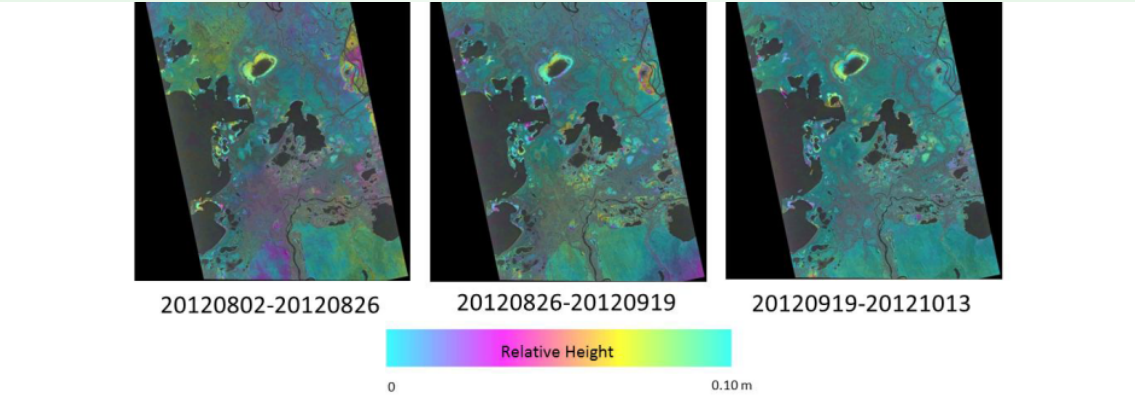
- Satellite Acquisitions
- Fieldwork – Install Instruments
  - Radar reflectors
  - Water Gauges
- InSAR stack processing

InSAR water level

- Can use interferometric SAR processing in flooded vegetation to monitor water level changes at the mm scale

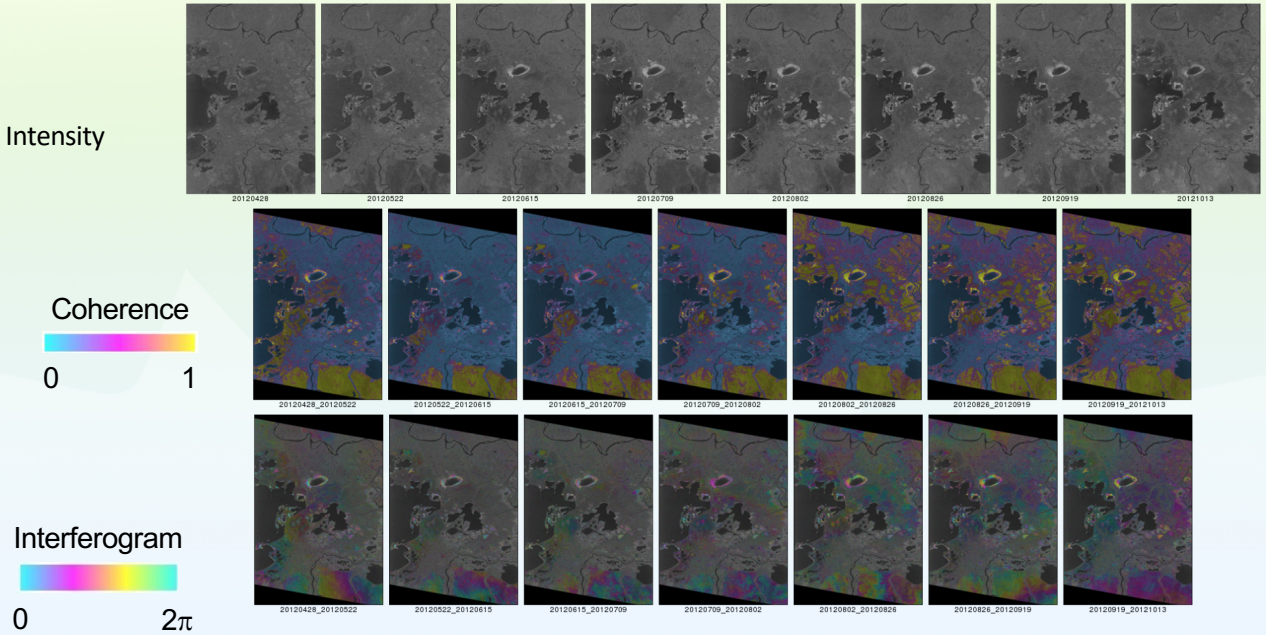
- Improved water volume for hydrologic modelling, weather forecasting, and ecological applications

Water level change

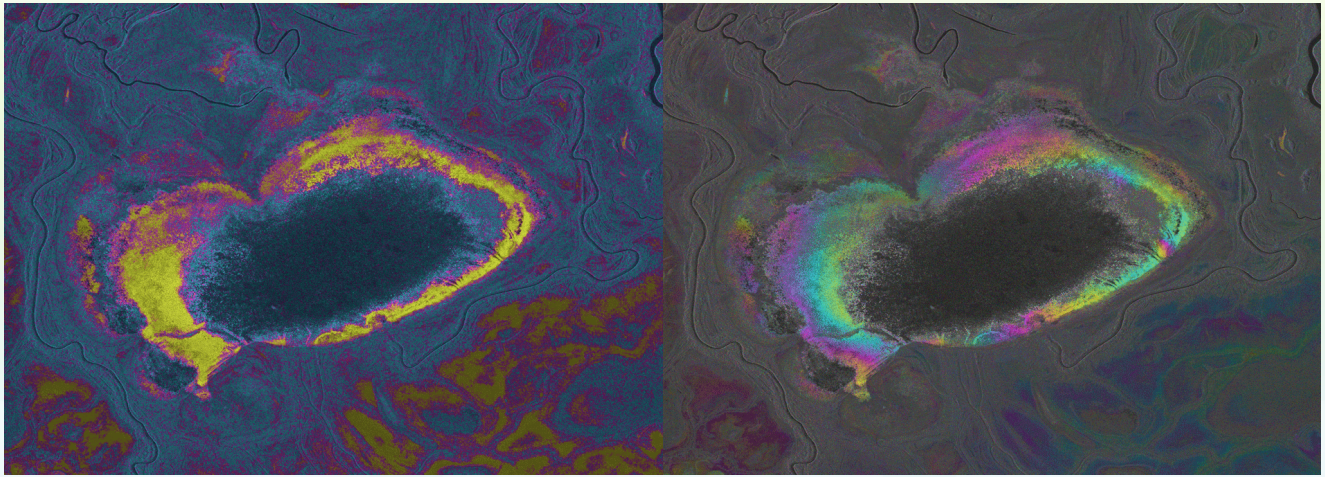


PAD 2012 InSAR

April – October 2012



PAD – Barril Lake 2012 Animation



Coherence

Interferogram

InSAR Water Level Research Thrusts

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

Thanks for your attention!