Investigation of Polarimetric L-band ALOS and C-band Radarsat2 for peatland subsurface water flow monitoring

R. Touzi[1], G. Gosselin[1], and R. Brooks[2]

[1]Canada Centre for Remote Sensing

[2] University of Saskatchewan

Acknowledgment

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Shimada and JAXA for ALOS

Data + Summer acquisitions

Background

- Wetland in Canada: 148 millions ha (25% of the World)
- Peatlands globally cover 3% of the land, they store 30% of the terrestrial carbon (11.3 Gtonnes)
- Maintain peatlands => reduce greenhouse gases
- Wetland are **under threat** ⇨ **Canadian Wetland Inventory (CWI)**

☛ EO CWI in collaboration with **Env. Canada**

☛ **Park Canada**: park integrity monitoring and CC effect

- Wapusk National Park: Polar bear habitat

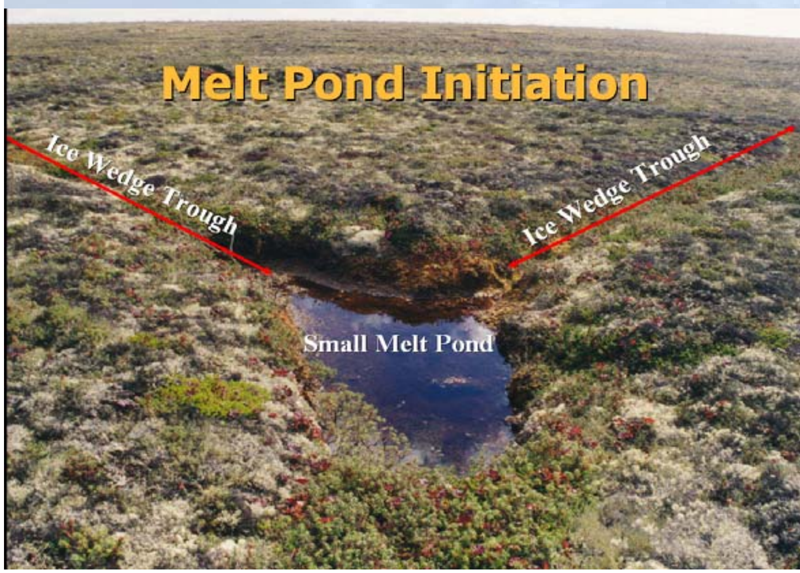
☛ **Alberta ESDR**: Boreal peatland change monitoring and identification of the source of stress (CC or oil sand exploration)

Subarctic Peatland Under Threat ✹!!!
Wapusk National Park

Climate Change effect:

- ✹ **Bogs** transformed to **Fen**
- ➩ Affect **polar bear denning habitat** which is entirely within bogs with thick peat deposits

☛ALOS => Peatland monitoring



Why **Polarimetric** SAR for Subarctic wetland monitoring?

- HH-Radarsat-1 of Limited Capability for vegetation-type discrimination
  - **Radarsat-1 combined with clear-sky-dependent Landsat for wetland classification**
  - ➪ **Radarsat/Landsat approach not suitable for wetland monitoring**
- Polarimetric SAR ➪ Scattering mechanisms and target structure ➪ Enhanced vegetation discrimination
- **Touzi decomposition** using polarimetric C-band Convair SAR:
  - **Enhanced wetland classification**
  - **Scattering phase <u>sensitive</u> to peatland subsurface water flow ➪ discrimination of poor fen and bogs**
- Cost effective => ALOS, Radarsat2, TerraSAR

OUTLINE

- Touzi Decomposition for High-resolution and roll invariant incoherent target scattering decomposition
  - **Complex** entity **(α_s, $\Phi_{\alpha s}$)** for unambiguous description of target scattering type
  - **High-resolution scattering classification** in contrast to conventional methods: Cloude-Pottier α|H, Freeman , Yamagushi and Van Zyl ➪ **coarse resolution** classif.
- Results obtained with polarimetric Convair580 SAR
  - Enhanced wetland classification
  - Scattering phase sensitive to peatland subsurface water flow discrimination of poor fen and bogs
- Polarimetric ALOS & Radarsat2 for peatland subsurface water flow monitoring

Touzi Decomposition for High Resolution Characterization of Wetland Scattering

TGRS Jan. 2007

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 45, NO. 1, JANUARY 2007 73

Target Scattering Decomposition in Terms of Roll-Invariant Target Parameters

Ridha Touzi, *Member, IEEE*

Abstract—The Kennaugh–Huynen scattering matrix con-diagonalization is projected into the Pauli basis to derive a new scattering vector model for the representation of coherent target scattering. This model permits a polarization basis invariant representation of coherent target scattering in terms of five independent target parameters, the magnitude and phase of the symmetric scattering type introduced in this paper, and the maxim… ization parameters (orientation, helicity, and maximu… The new scattering vector model served for the ass… the Cloude–Pottier incoherent target decomposition. W… Cloude–Pottier scattering type α and entropy H are … ant, β and the so-called target-phase parameters do dep… target orientation angle for asymmetric scattering. The … vector model is then used as the basis for the devel… new coherent and incoherent target decompositions i… unique and roll-invariant target parameters. It is shown … the phase and magnitude of the symmetric scattering t… be used for an unambiguous description of symme… scattering. Target helicity is required for the assessm… symmetry–asymmetry nature of target scattering. The … scattering type phase is shown to be very promising f… classification in particular, using polarimetric Convai… thetic aperture radar data collected over the Ramsar … wetland site to the east of Ottawa, ON, Canada.

Index Terms—Characteristic decomposition, … coherent, diagonalization, eigenvalues, eigenvectors, e… coherent, polarimetry, speckle, synthetic aperture radar (SAR), wetlands.

Nomenclature and Abbreviations

α–β model	Model introduced by Cloude and Pottier for parameterization of the coherency eigenvector.
CTD	Coherent target decomposition.
ICTD	Incoherent target decomposition.
SSCM	Symmetric scattering characterization method introduced by Touzi and Charbonneau for optimum characterization of the maximized target symmetric scattering.
LOS	Radar line of sight.
$[S]$	Scattering matrix.
μ_1 and μ_2	Scattering matrix coneigenvalues.
k	Target scattering vector introduced by Cloude.
α	Scattering type parameter introduced by Cloude and Pottier.
β	Orientation angle introduced by Cloude and Pottier.
α_s^c	Symmetric scattering type introduced in this paper as a complex entity.
α_s	Symmetric scattering type magnitude.

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The author is with the Canada Centre for Remote Sensing, Natural Resources Canada, Ottawa, ON K1A 0Y7, Canada.

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TGRS Sep. 2009

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Phase of Target Scattering for Wetland Characterization Using Polarimetric C-Band SAR

Ridha Touzi, *Member, IEEE*, Alice Deschamps, and G. Rother

Abstract—Wetlands continue to be under threat, and there is a major need for mapping and monitoring wetlands for better …

I. Introduction

RADAR polarimetry, which has been an active area of … than 50 years [2]–[6], has started … recent launch of polarimetric satellite … (SARs), namely, L-band ALOS- … TerraSAR [8], and, most recently, C-band … RADARSAT-2 is the first satellite that will … use of polarimetric information at mul- … at 9-m (fine-mode) and 24-m (standard- … should permit a deeper exploration … and enhanced extraction of target … The Canada Centre for Remote … been investigating C-band polarimetric … more than 20 years using the Convair- … metric capability was added in 1988 [10]. … of the RADARSAT-2 project in 1998, … investigating key applications that promote … T-2 fully polarimetric capabilities. Ship … [11], [12], agricultural crop charac- … forest-type classification [14] were shown … applications that can benefit greatly from … Rs. Recently, a preliminary study using … spring data acquisition over Mer Bleue … C-band SAR could be promising for … [15]. This investigation has continued, … data collected in the fall season per- … demonstration of the promising potential … and for detection of their seasonal … will be presented in this paper. … weather capabilities and sensitivity to … characteristics, RADARSAT-1 has been … data source for characterization of … [16]–[18]. Unfortunately, the limited ca- … AT-1's single-polarization C-band SAR … discrimination makes the use of clear-sky- … infrared satellite data necessary for wet- … [17], [19], [20]. Recently, we have shown … information significantly improves the po- … for forest-type discrimination [14]. The … RADARSAT-2's polarimetric and all-weather … provide unique information for operational … monitoring. … been published on the investigation of … wetland class characterization [21]–[25]. … have shown that the phase difference

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Wetland characterization using polarimetric RADARSAT-2 capability

R. Touzi, A. Deschamps, and G. Rother

Abstract. The use of single-polarization (HH) RADARSAT-1 synthetic aperture radar (SAR) data has been shown to be important for wetland water extent characterization. However, the limited capability of the RADARSAT-1 single-polarization C-band SAR in vegetation type discrimination makes the use of clear-sky-dependent visible near-infrared (VNIR) satellite data necessary for wetland mapping. In this paper, the potential of polarimetric RADARSAT-2 data for wetland characterization is investigated. The Touzi incoherent decomposition is applied for the roll-invariant decomposition of wetland scattering. In contrast with the Cloude–Pottier decomposition that characterizes target scattering type with a real entity, α, the Touzi decomposition uses a complex entity, the symmetric scattering type, for unambiguous characterization of wetland target scattering. It is shown that, like the Cloude α scattering type, the magnitude α_s of the symmetric scattering is not effective for vegetation type discrimination. The phase ϕ_{α_s} of the symmetric scattering type has to be used for better characterization of wetland vegetation species. The unique information provided by ϕ_{α_s} for an improved wetland class discrimination is demonstrated using Convair-580 polarimetric C-band SAR data collected over the Mer Bleue wetland in the east of Ottawa, Canada. The use of ϕ_{α_s} makes possible the discrimination of shrub bog from sedge fen and even permits the discrimination between conifer-dominated treed bog and upland deciduous forest under leafy conditions.

Résumé. L'utilisation des données radar à synthèse d'ouverture (RSO) de RADARSAT-1 en polarisation unique (HH) a déjà fait ses preuves pour la caractérisation de l'étendue d'eau en milieu humide. Cependant, la capacité limitée du RSO en bande C de RADARSAT-1 en polarisation unique pour la détermination des types de végétation rend nécessaire l'utilisation …

The Touzi Decomposition for Roll invariant Incoherent Target Scattering Decomposition

☛ 50 years R&D (Kennaugh 51, Huynen 65, Cloude-Pottier 96)

$$[T] = \lambda_1 [T_1] + \lambda_2 [T_2] + \lambda_3 [T_3]$$

☛ New coherent Target Scattering Vector Model (TSVM):

$$\vec{e}^{\,SVM} = m \left| \vec{e}^{\,SVM} \right|_m \cdot e^{j\Phi_s} \cdot \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos 2\psi & -\sin 2\psi \\ 0 & \sin 2\psi & \cos 2\psi \end{bmatrix} \begin{bmatrix} \cos\alpha_s \cos 2\tau_m \\ \sin\alpha_s e^{j\Phi_{\alpha_s}} \\ -j\cos\alpha_s \sin 2\tau_m \end{bmatrix}$$

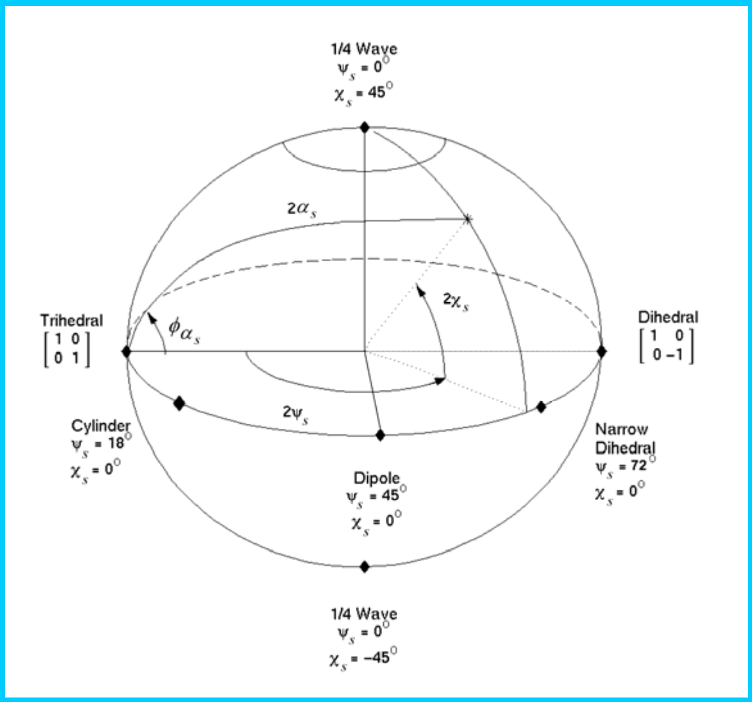
✷ **Solves for Cloude-Pottier target scattering type (α) ambiguities**

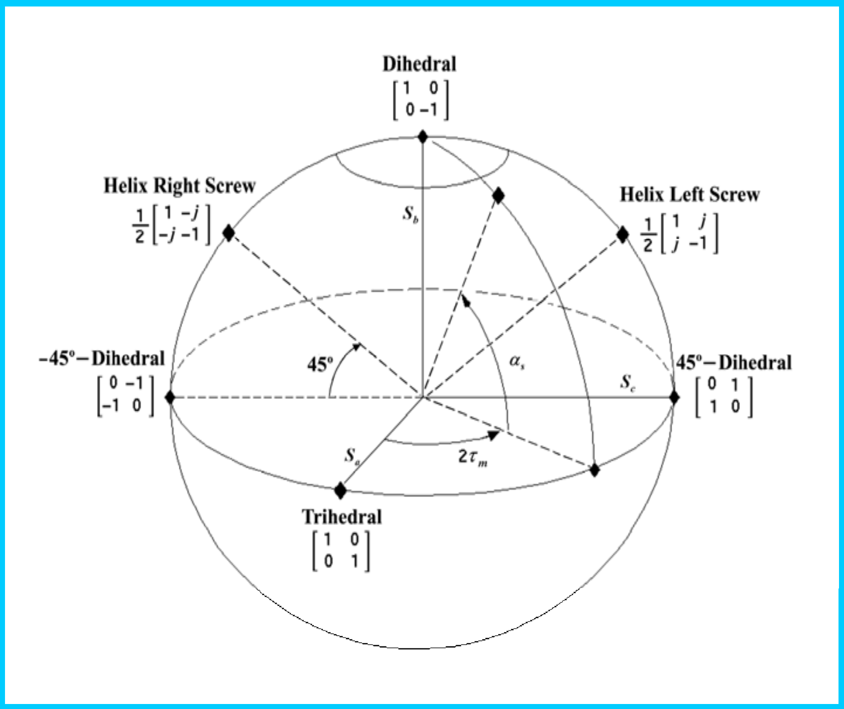
- ☛ **A complex entity (α_s, $\Phi_{\alpha s}$)**
- ☛ **Helicity (τ)** ⇨ Local asymmetry ➡ **Forest structure**

Two Poincarré spheres for representation of Single Scattering Parameters

- Scattering type (α_s, $\Phi_{\alpha s}$)
- HV=0 => $\Phi_{\alpha s}$ = Pauli phase

$$\tan(\alpha_s)e^{j\phi_{\alpha s}} = \frac{|\mu_1 - \mu_2|}{|\mu_1 + \mu_2|}$$



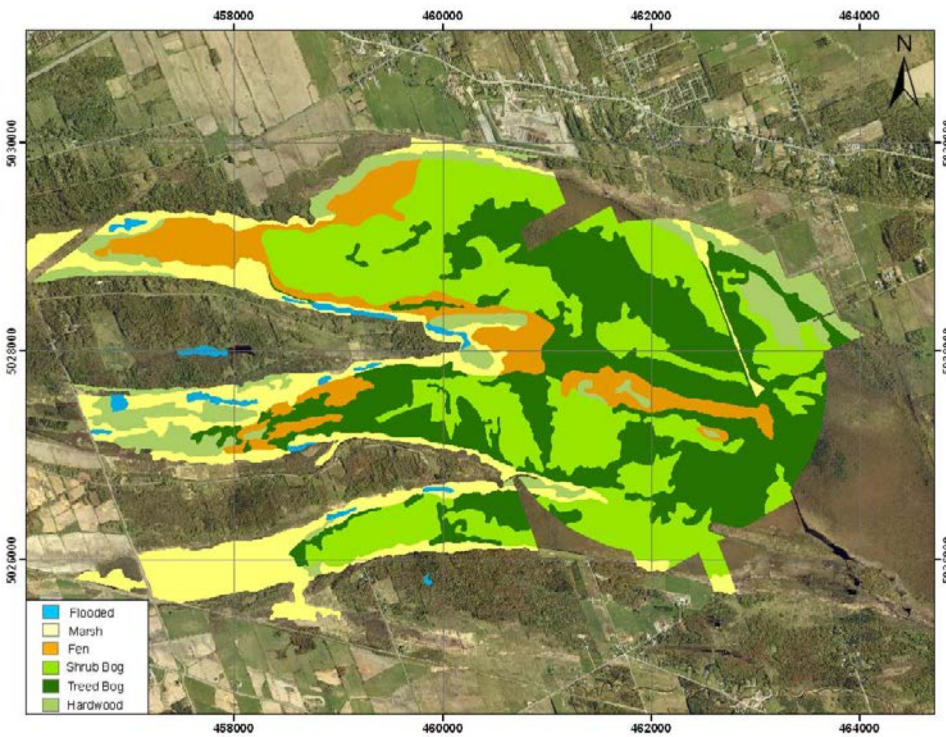


$$-\frac{\pi}{4} \le \tau \le \frac{\pi}{4}$$

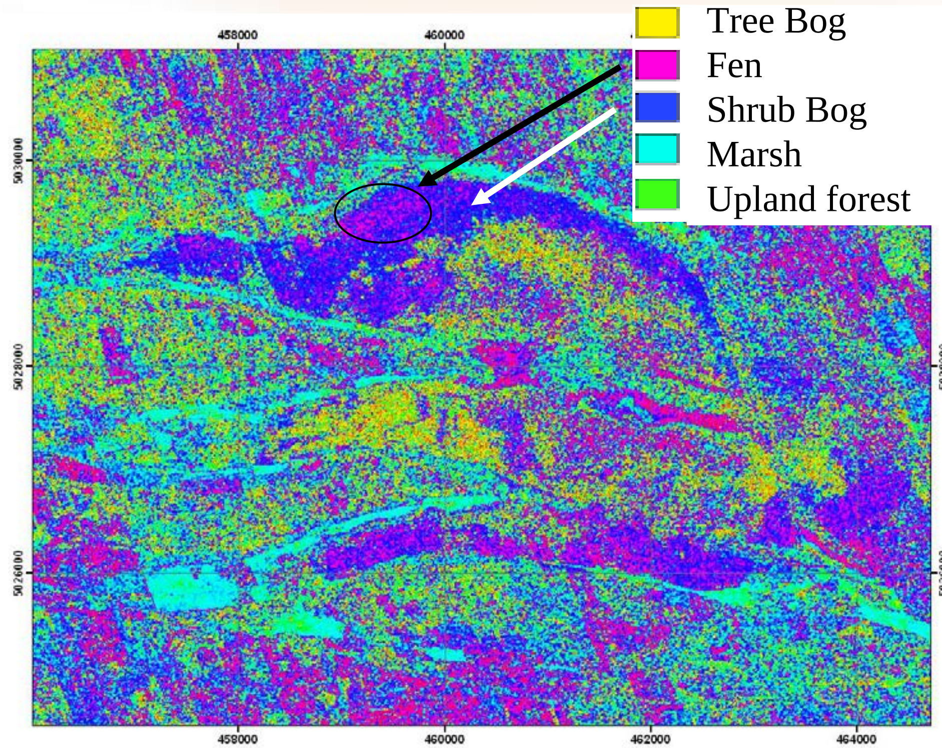
$$0 \le \alpha_s \le \frac{\pi}{2}$$

- (α_s, $\Phi_{\alpha s}$, τ) ➡ **unambiguous** description of **target scattering**

Dominant scattering Type Phase $\Phi_{\alpha s1}$ for Wetland Classification



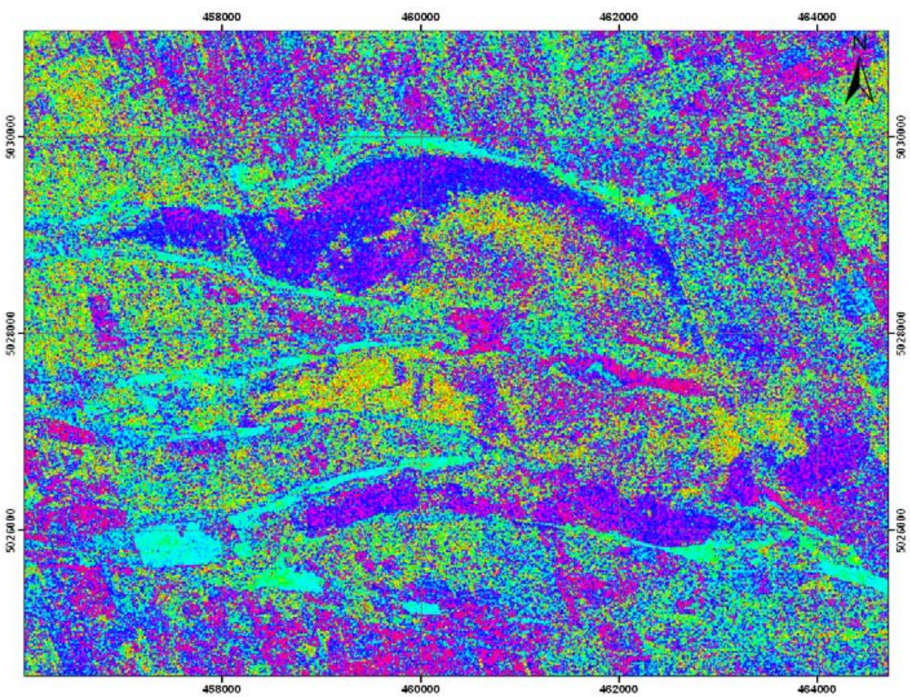
Color aerial photographs(2002) overlaid with a wetland classification based on the NCC the forest cover inventory.

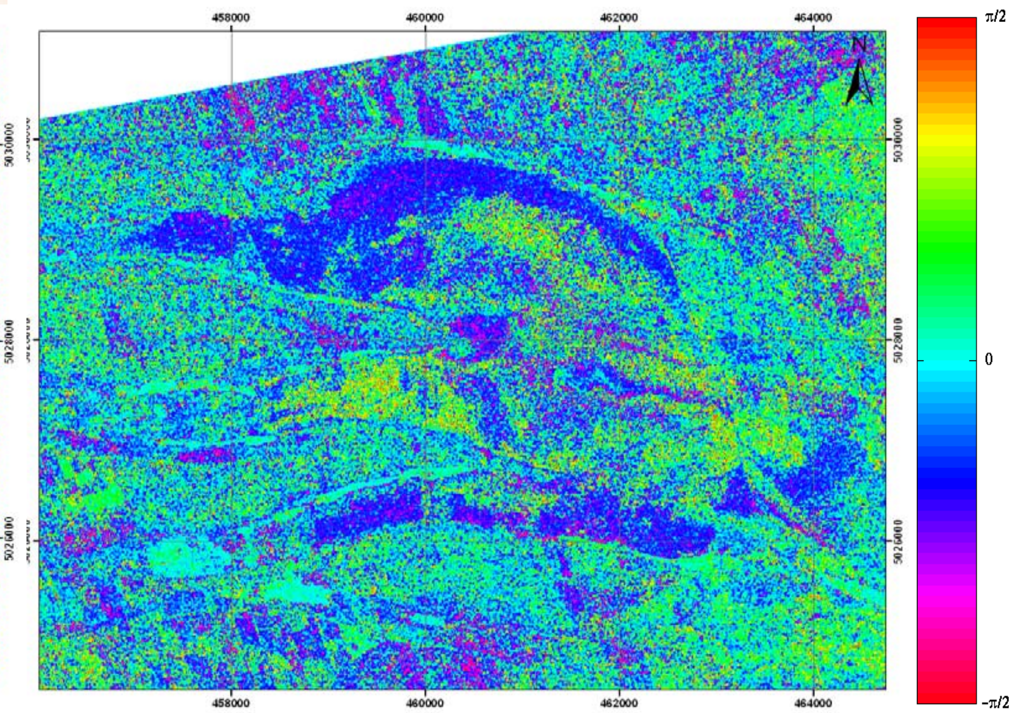


$\Phi_{\alpha s1}$ (June 95)

☛ Scattering Type Phase $\Phi_{\alpha s1}$ **Discriminates bog** from **fen**

$\Phi_{\alpha s1}$ For Wetland Seasonal Changes

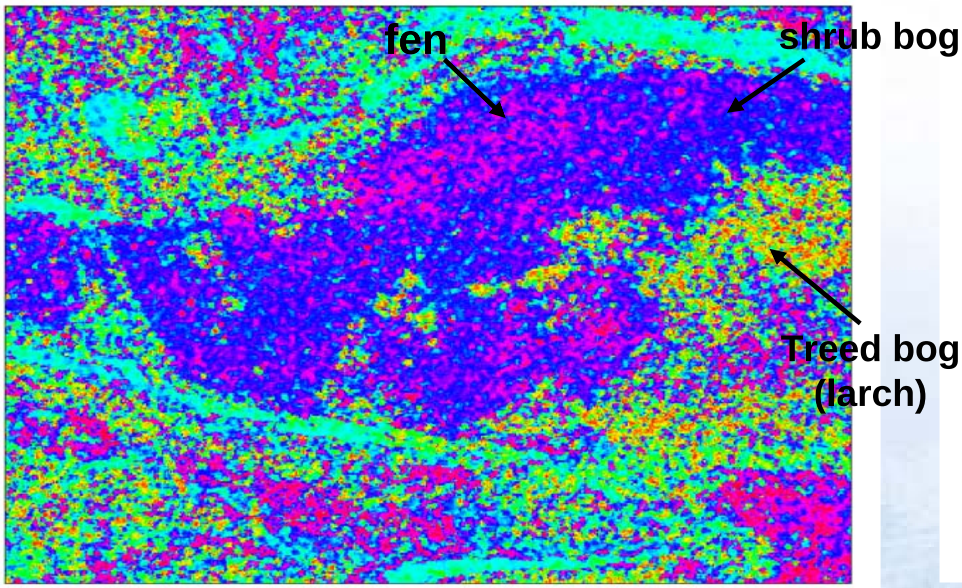




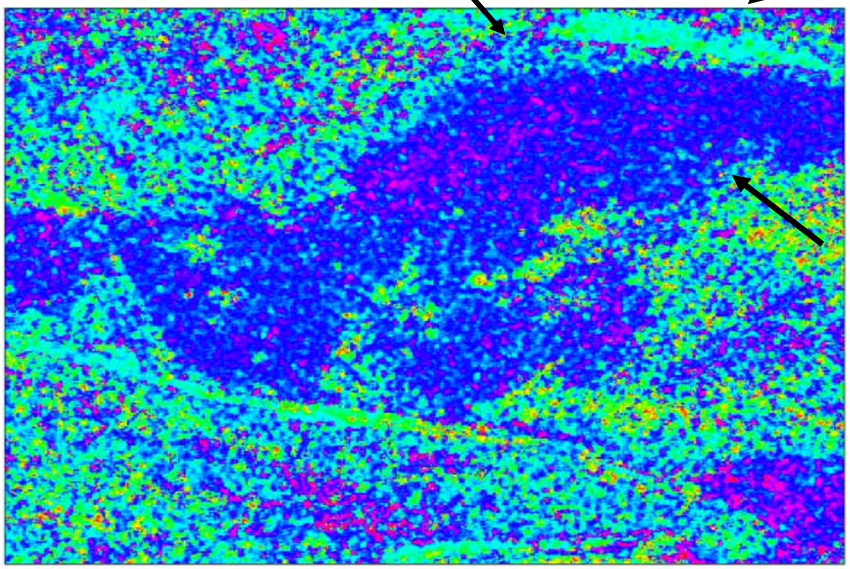
June95

Oct 95

Touzi phase sensitive to peatland subsurface water Flow



June 1995



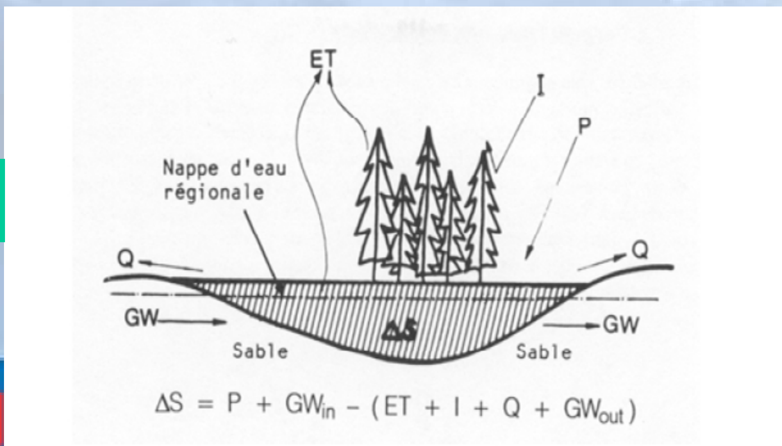
October 1995

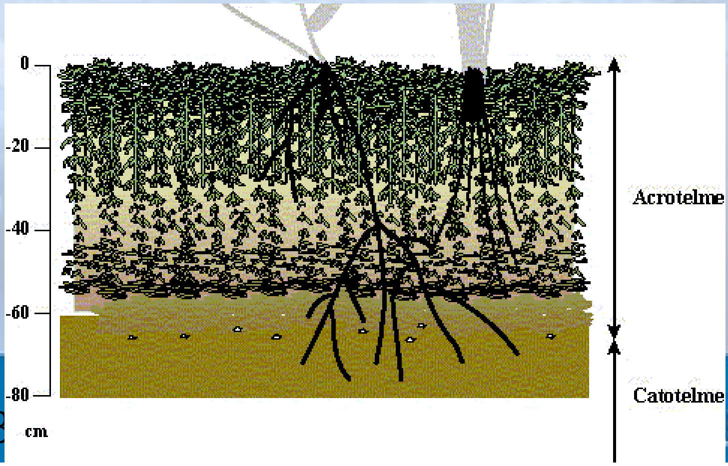
- **Sedge-dominated fens and shrub-bog well separated**
- **Treed bog: Larch seasonal needle loss detected**

Scattering Phase Sensitivity to Subsurface Water Flow

- **Two sublayers: Acrotelm (high hydraulic conductivity) and Catotelm (low hydraulic conductivity)**
  - **Fen: water level 20 cm below the peat surface**
  - **Bog: water level 50 cm below the peat surface**
- **Radiometry (HH, VV, VH, Cloude α) not sensitive to subsurface water**
- **$\phi_{\alpha s}$ detects fen run-off water**

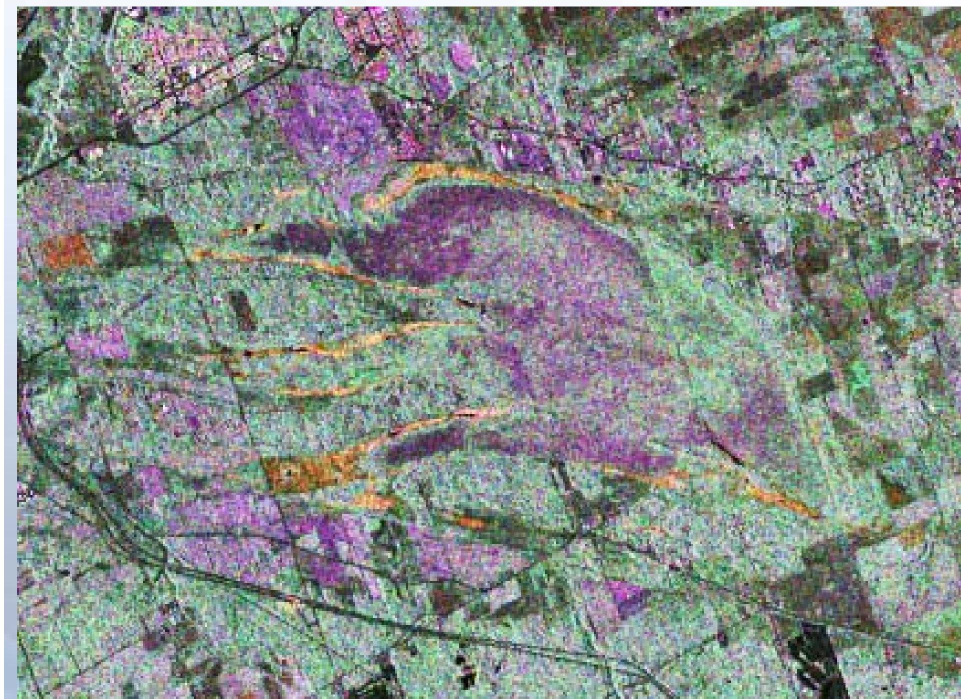
Fen



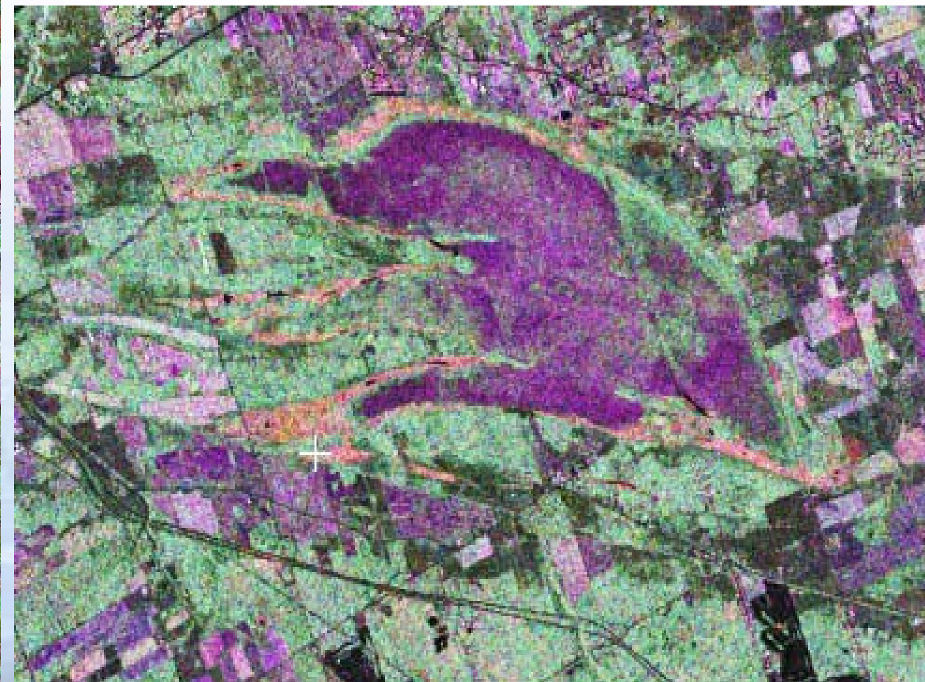


Bog

Mer Bleue Wetland seasonal change Detection Using Radarsat 2 (FQ12, HH-HV-VV in RGB)



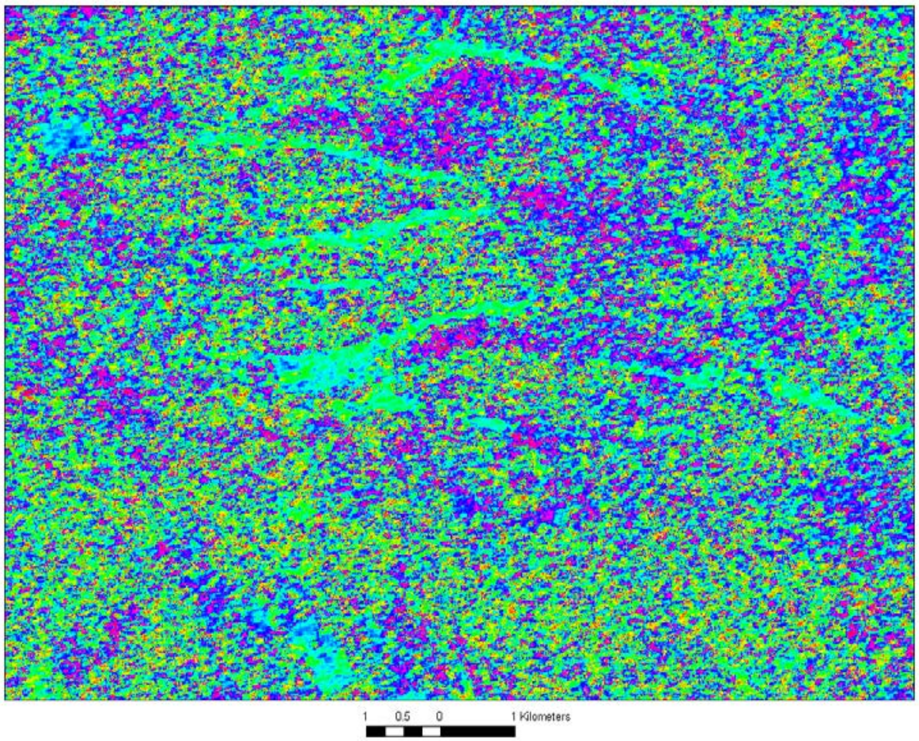
July08 (dry conditions)



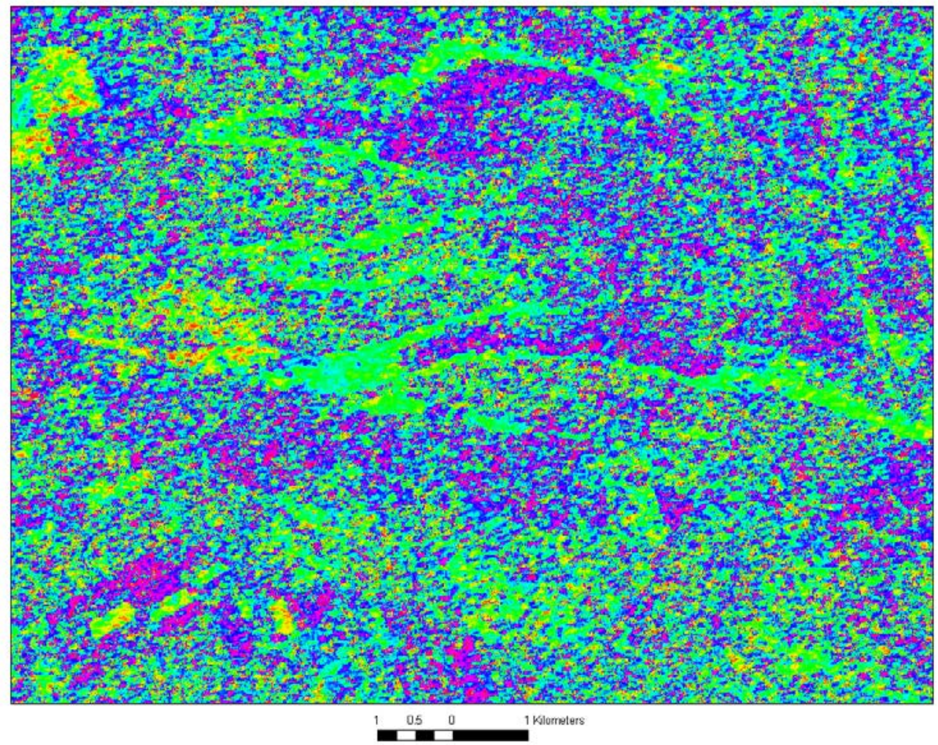
Oct 27, 08 (wet conditions)

Radarsat 2 Scattering Phase $\phi_{\alpha s}$

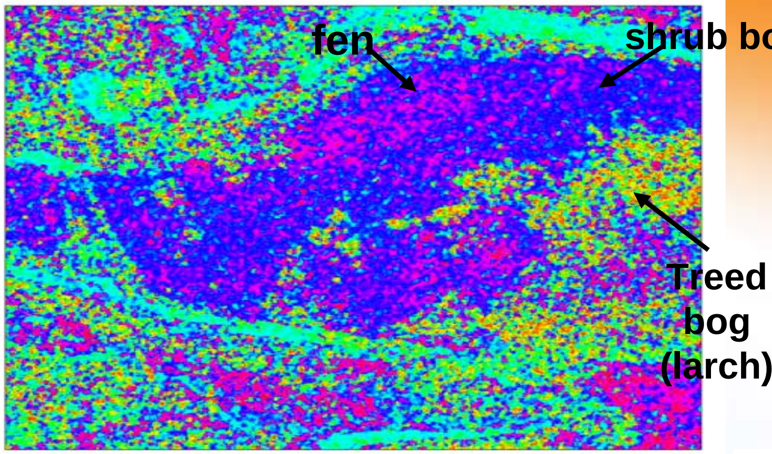
July 2008



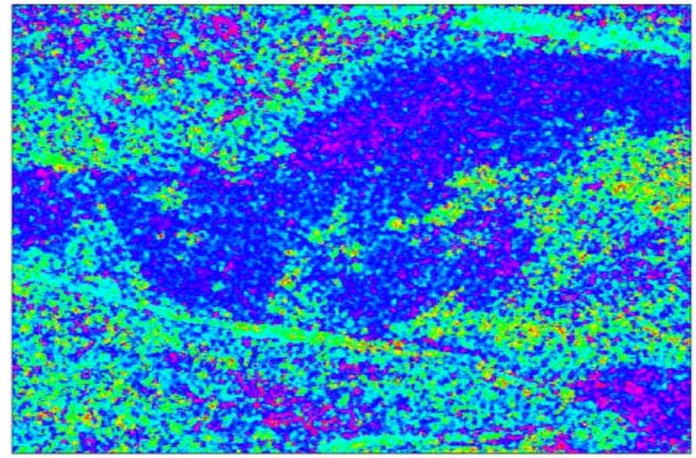
Oct 2008



☛ Scattering Phase Not Sensitive to peatland subsurface water flow Seasonal changes

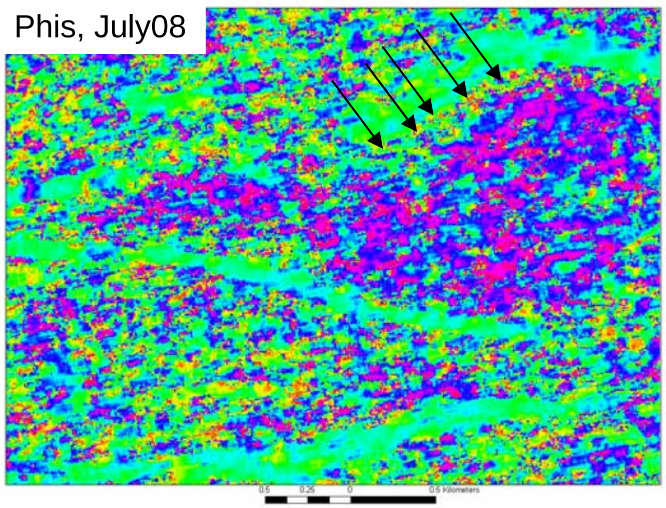


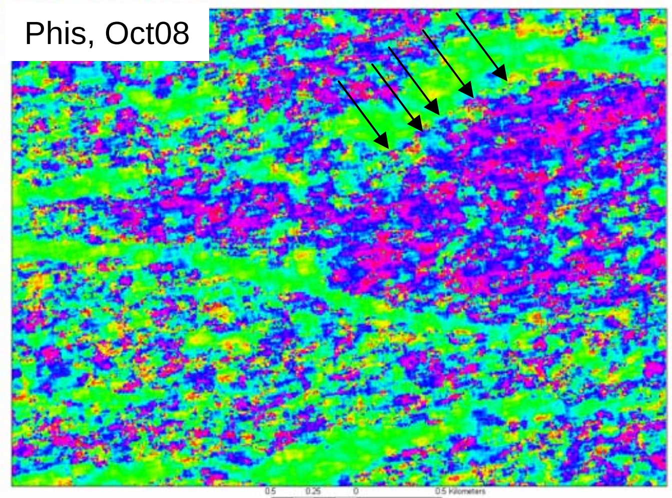
June 1995



Oct. 1995

CV-580

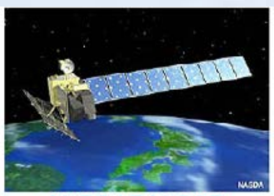




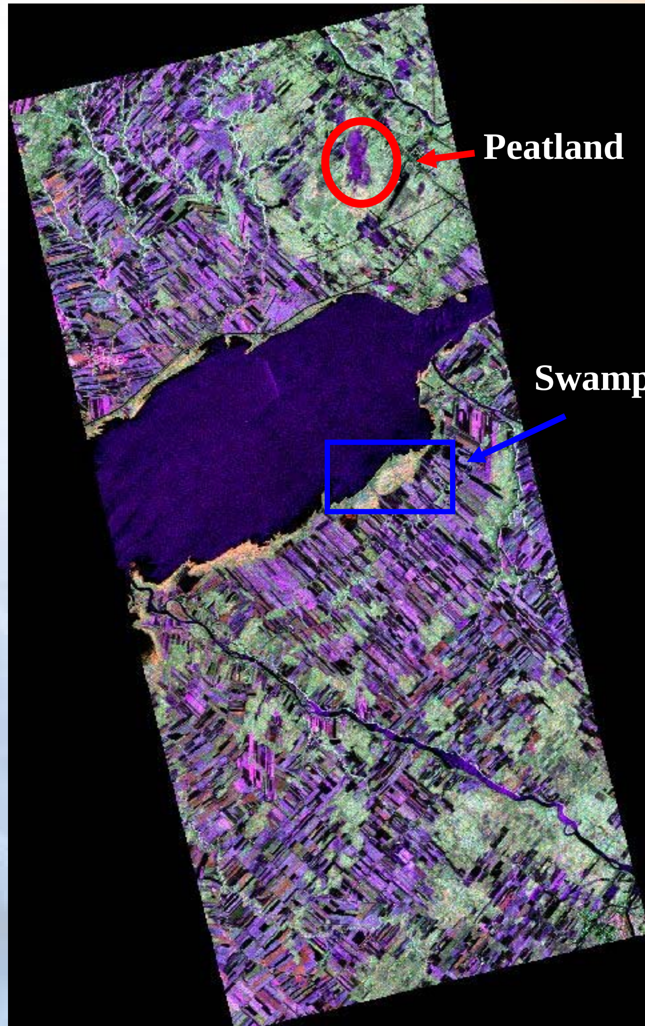
Radarsat-2

- RS2 Phase **not sensitive** to subsurface water
- Noise floor (-35 dB) **not** sufficiently **low** (CV580 : NESZ=-48 dB)

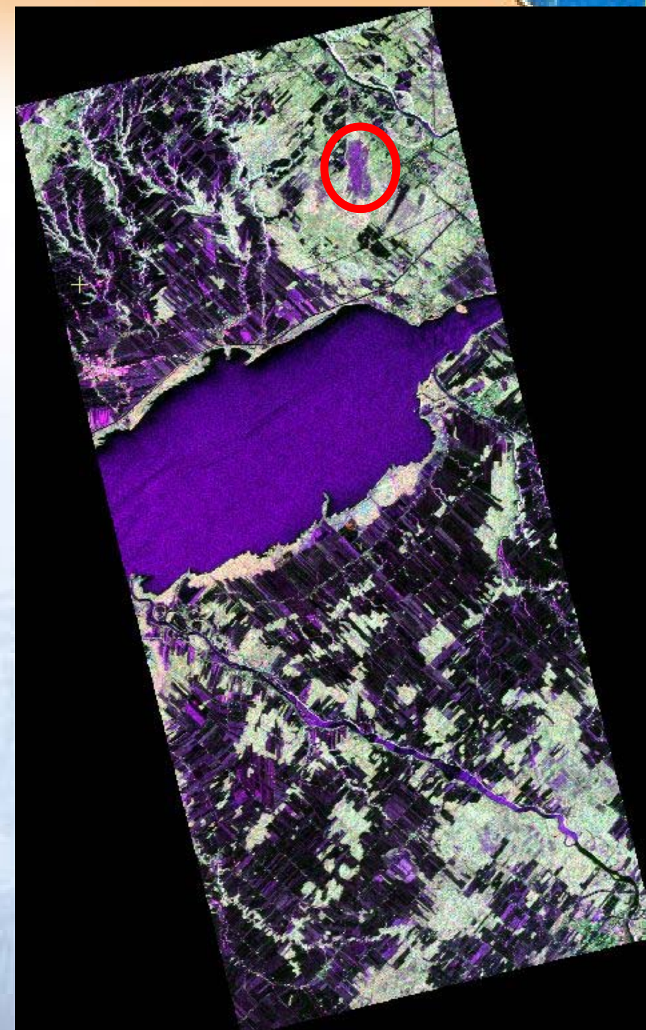
L-Band PALSAR for Wetland Characterization
Lac Saint Pierre (Canada)



ALOS / PALSAR
JAXA / JAROS (J)



PALSAR, Nov. 10, 2007



PALSAR, May 13, 2007

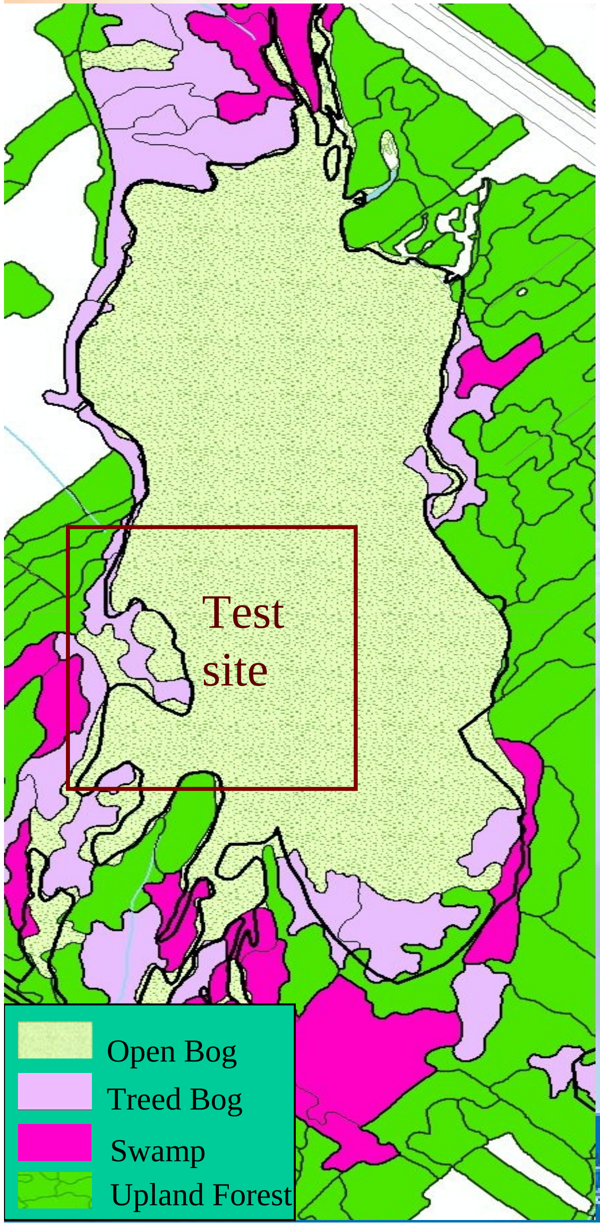
Lac St Pierre Peatland Characterization Using Polarimetric ALOS

Source : Google maps, 2009

Frasccatti,

Peatland: Poor fen + Bog

☛ Cannot be discriminated with Optic Sensors



- **Bog**:

➢ **Ombrotrophic**: . precipitations, fog and snow are the primary water sources

- **Poor Fen**:

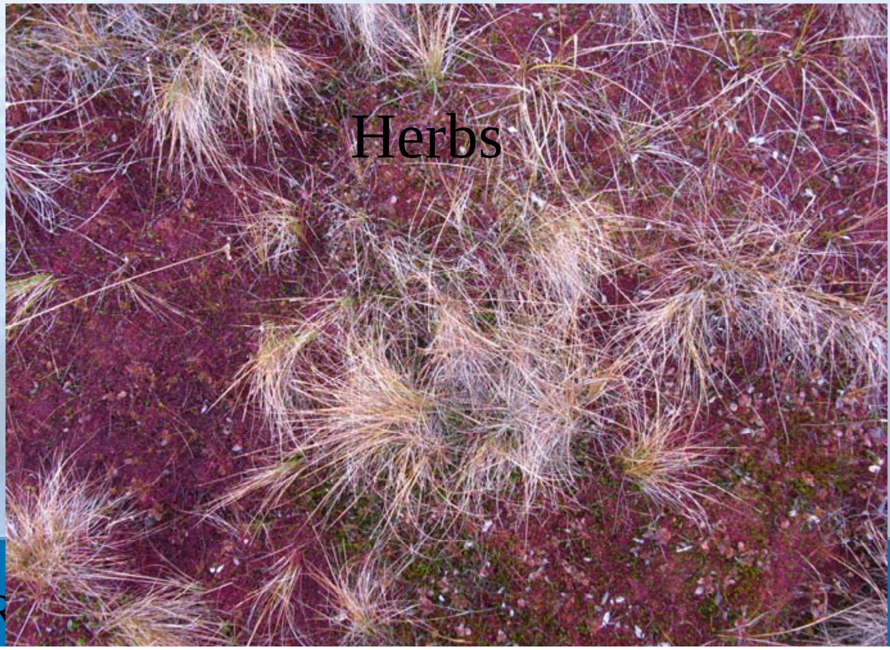
➢ **Minerotrophic**: fens are connected to small streams and may also receive water from surrounding uplands.

➢ As such, poor fens of high water retention are **continuously irrigated** with subsurface water even under no rainy conditions.

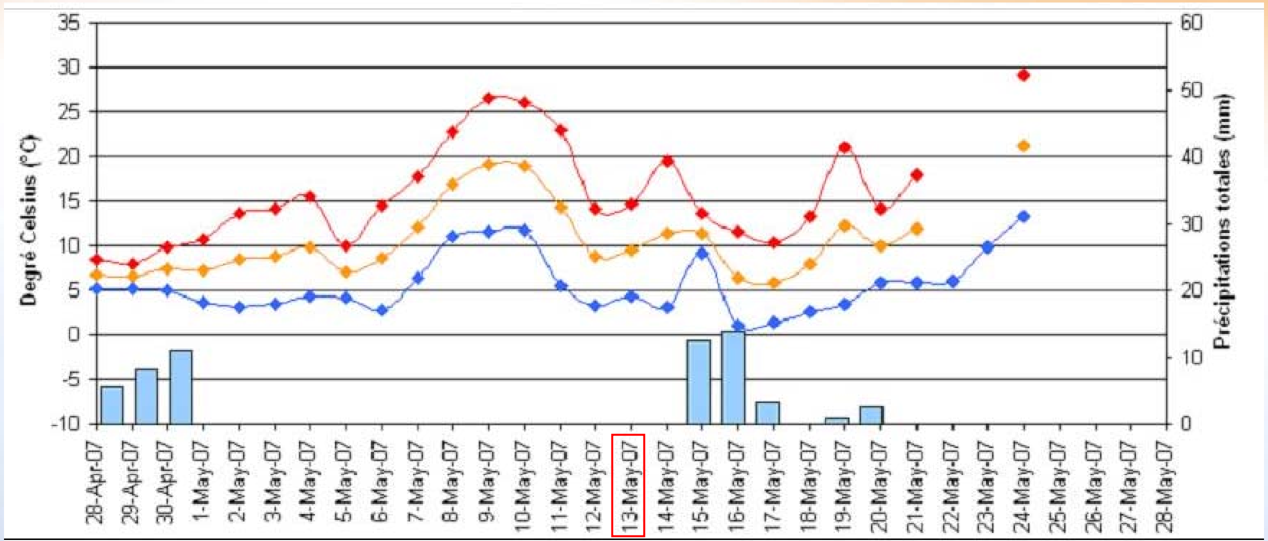
Shrub Bog

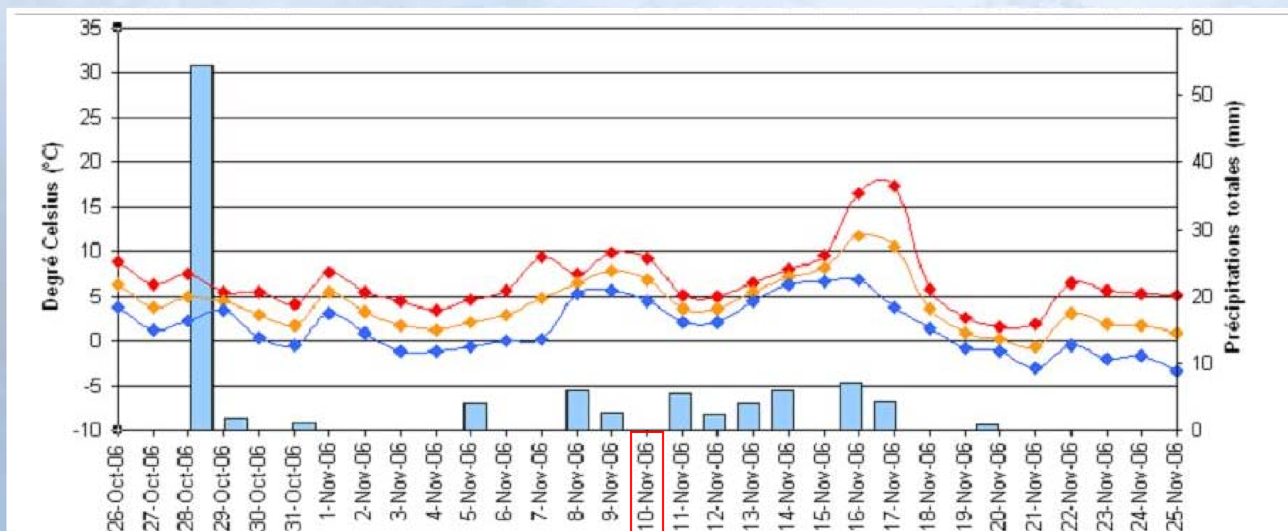
Peat Thinkness larger than 3m

Shrub Fen



Weather & Precipitations





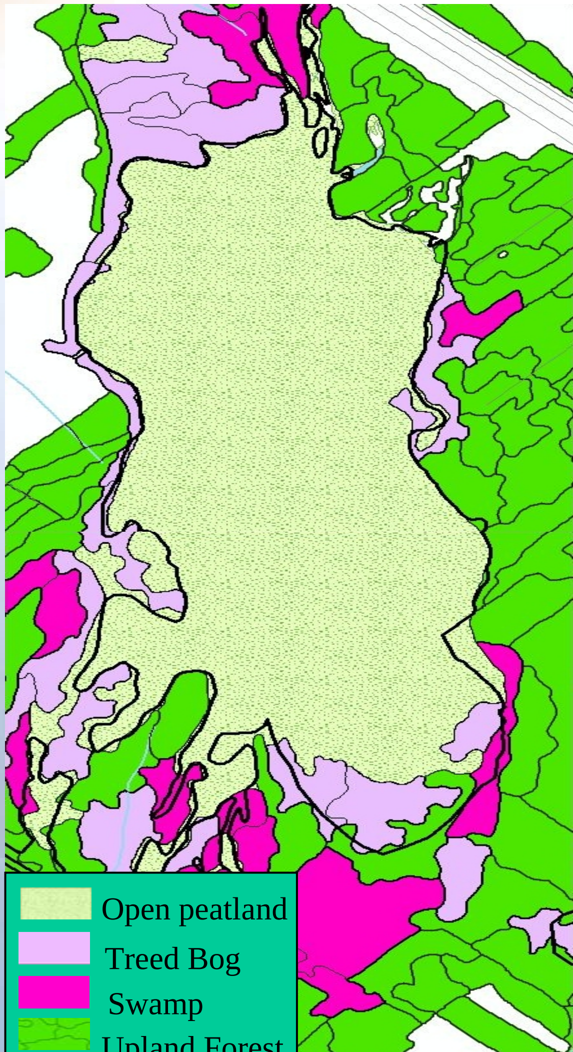
Precipitations (mm)

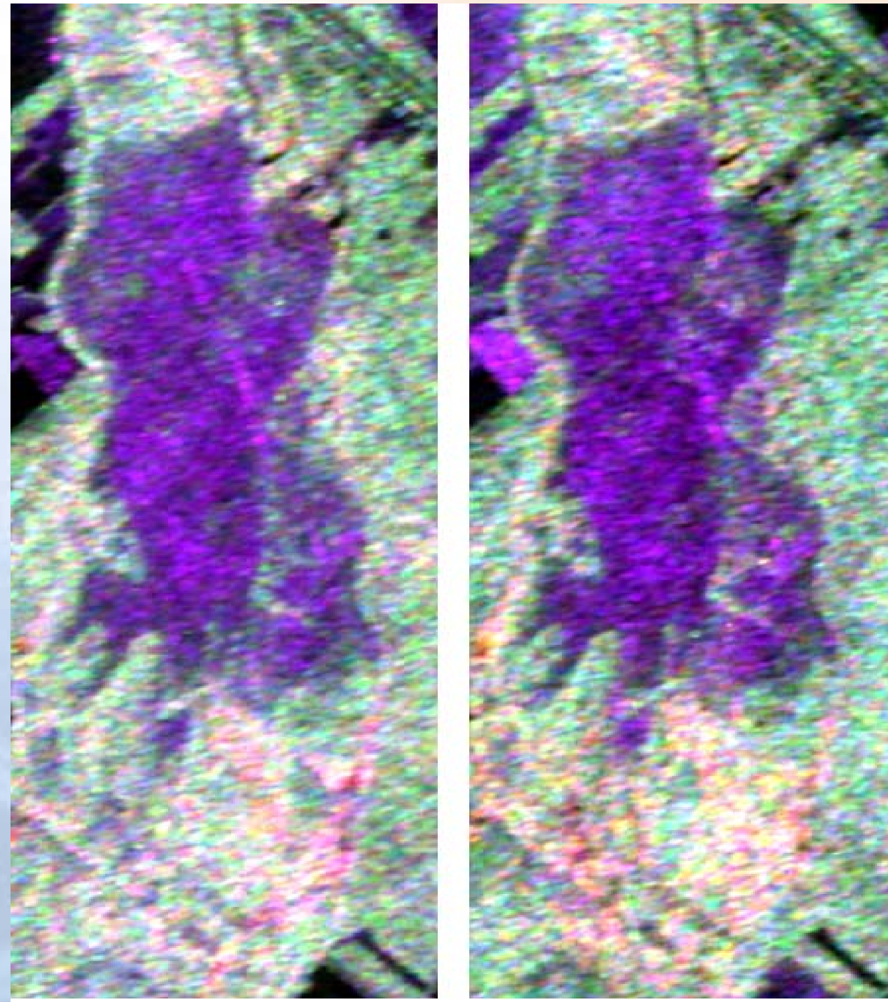
T. max (°C)

T. mean (°C)

T. min (°C)

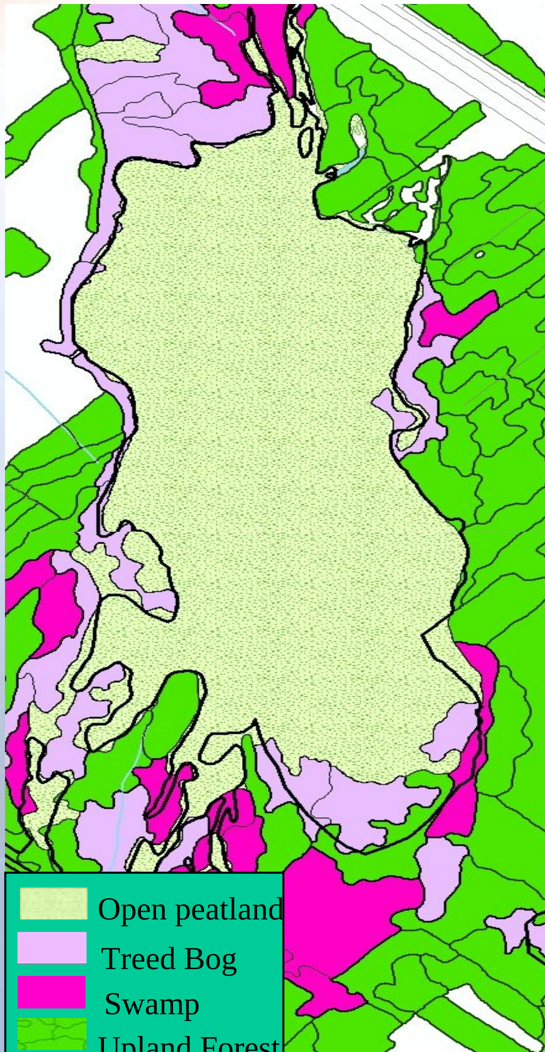
☛ HH-HV-VV not sensitive to water flow variations **beneath** the peat surface

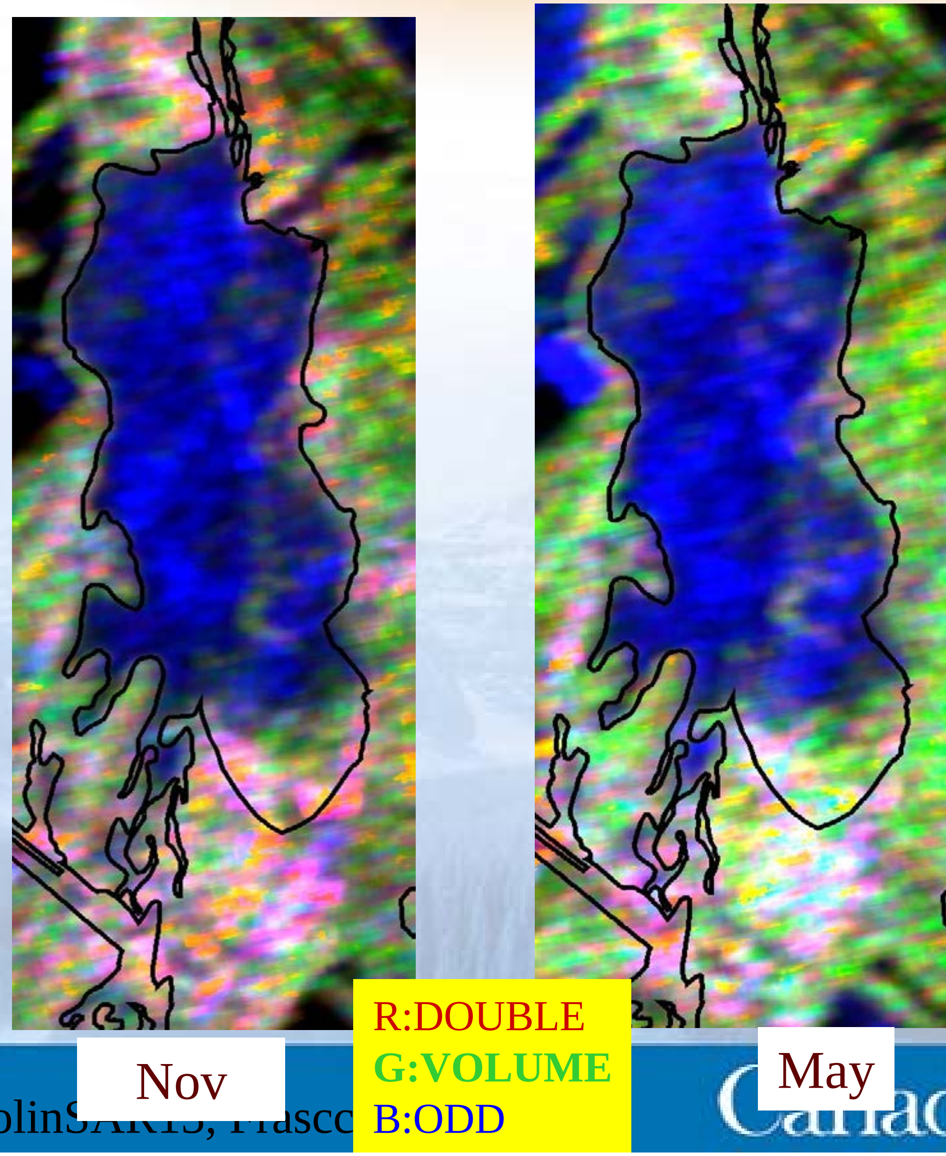




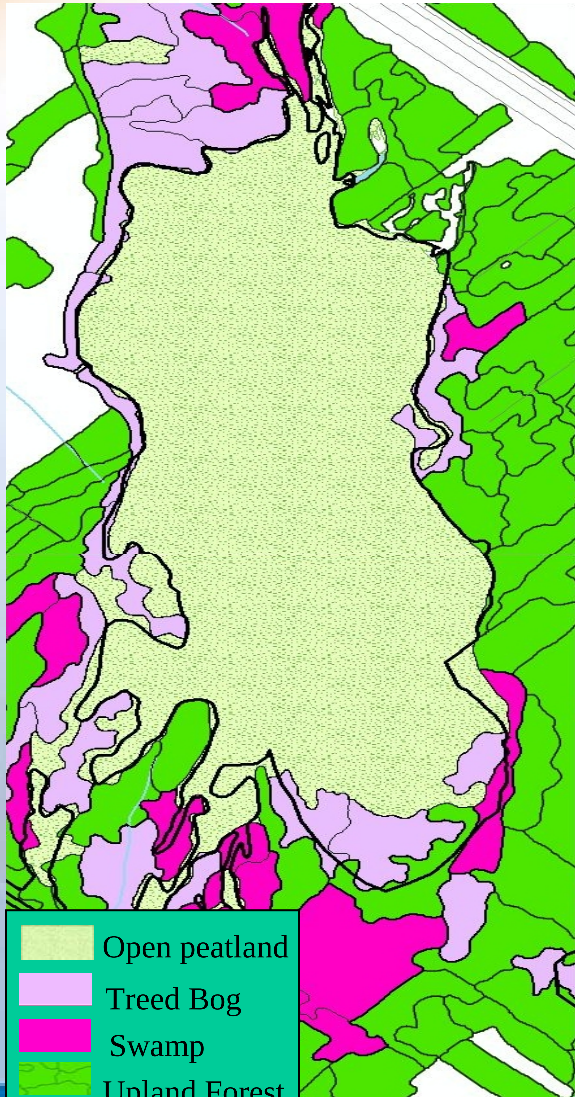
May June

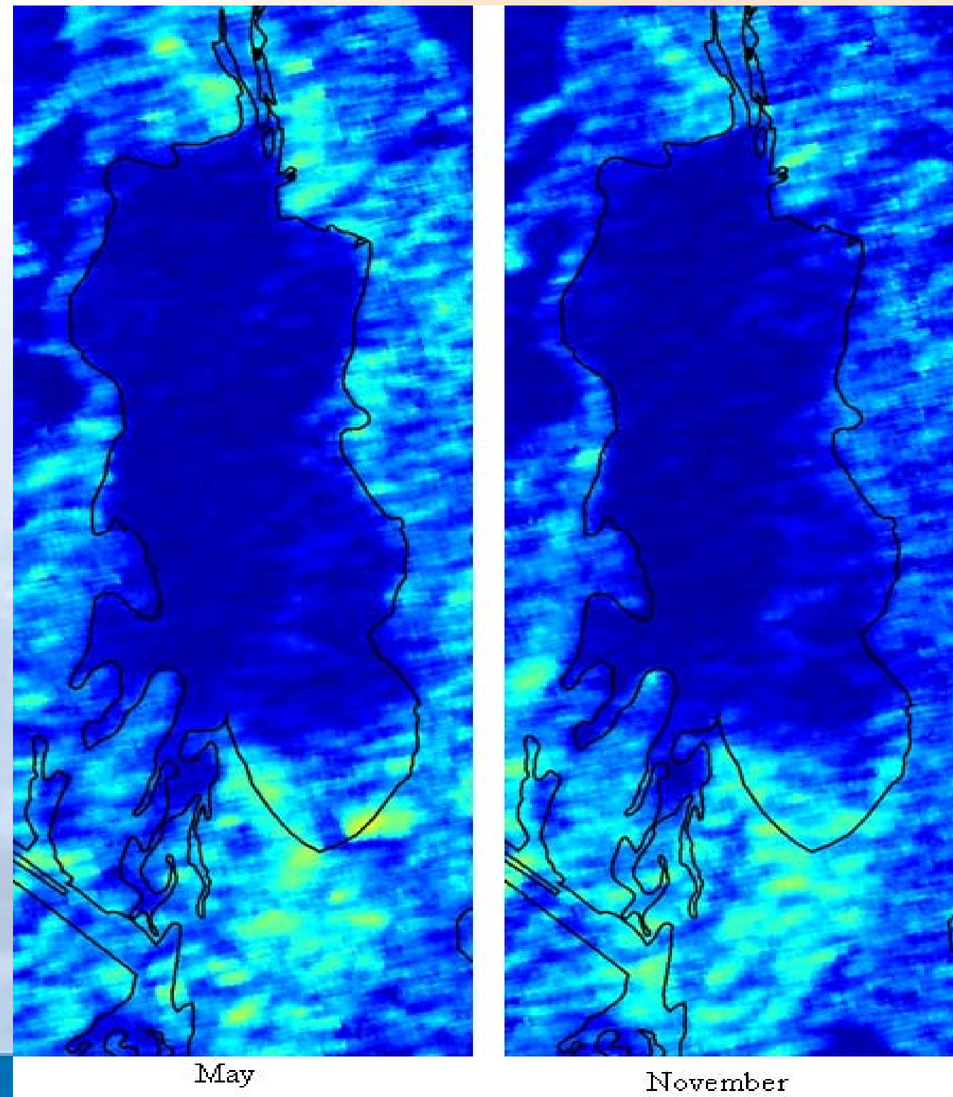
Freeman Coarse Scattering Classification not sensitive to water flow variations **beneath** the peat surface





☛ α_s (Cloude α) not sensitive to water flow variations **beneath** the peat surface

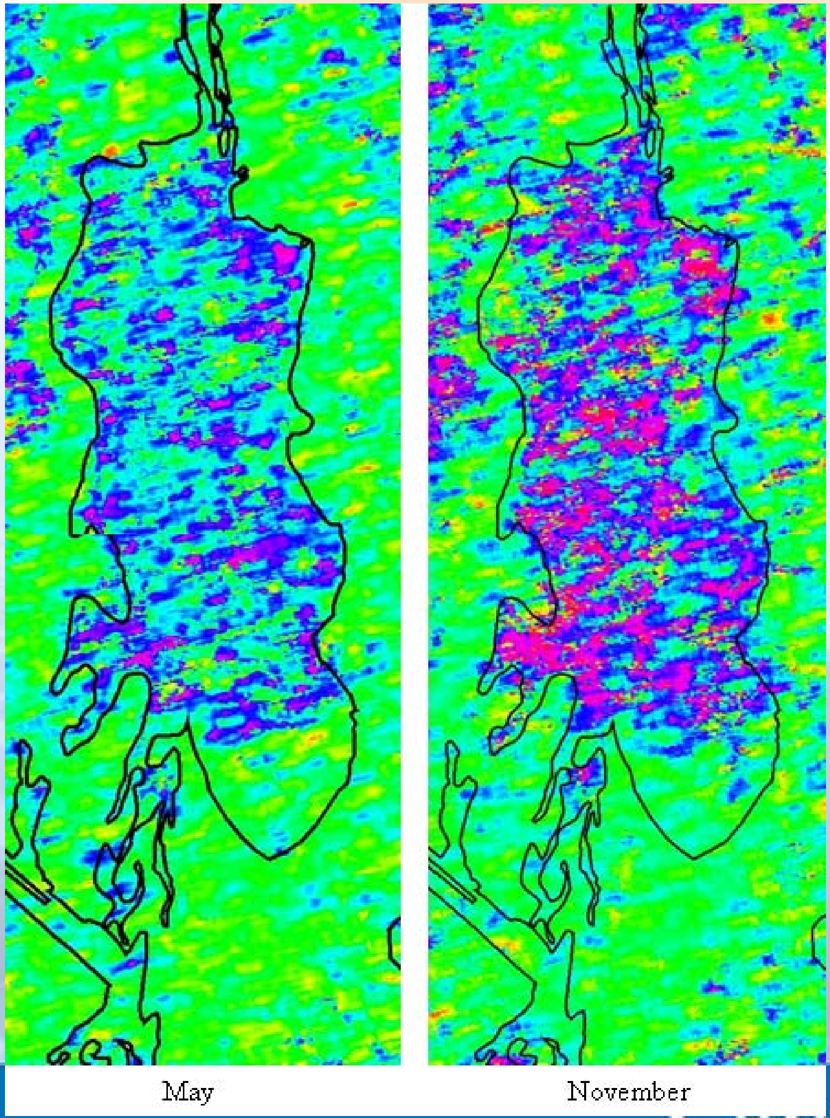




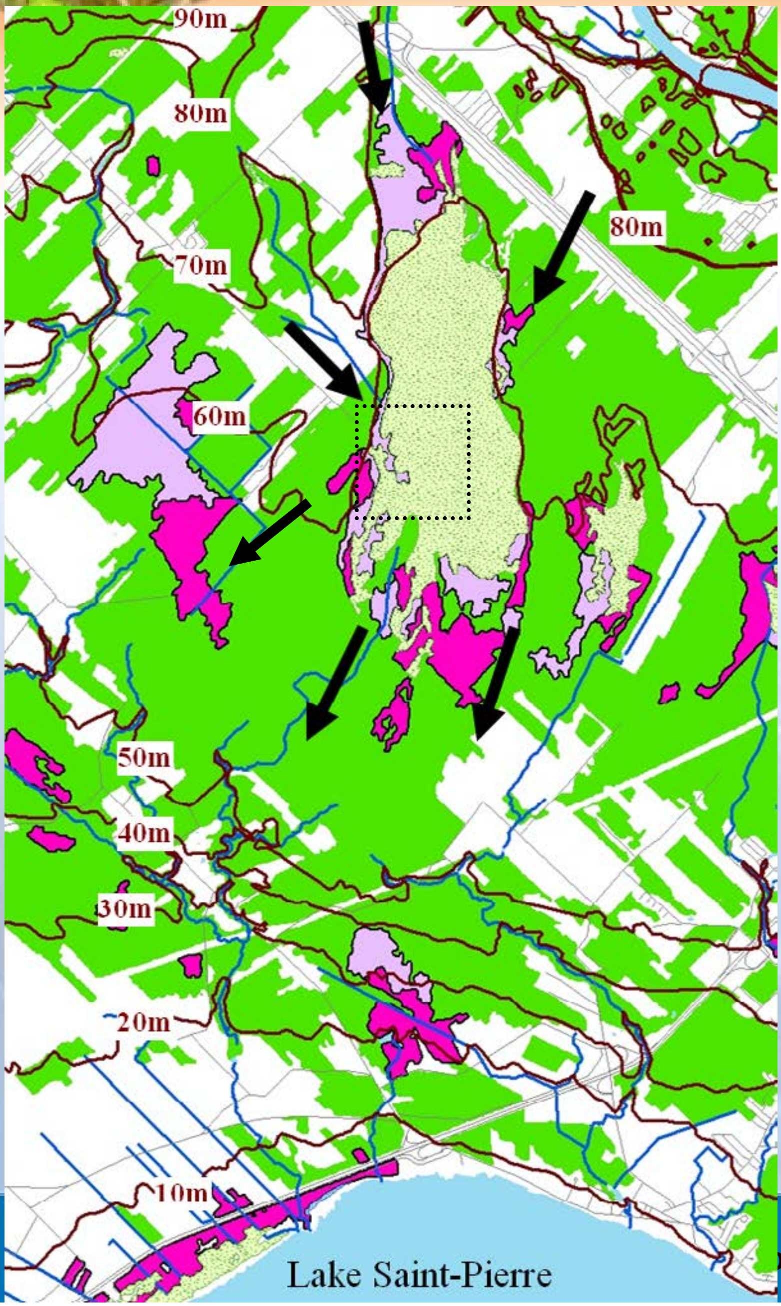
☛ Touzi phase **detects** water flow variations **beneath** the peat surface

- **Pink** ➪ subsurface water (less then 20 cm)
- ➪ Fen: subsurface run off water
- **Bleue** ➪ deep underground water
- Bog: water level at the catotelm (40-50 cm)

☛ **Essential** information for monitoring Bog-Fen Transformations in the North due to climate change stress

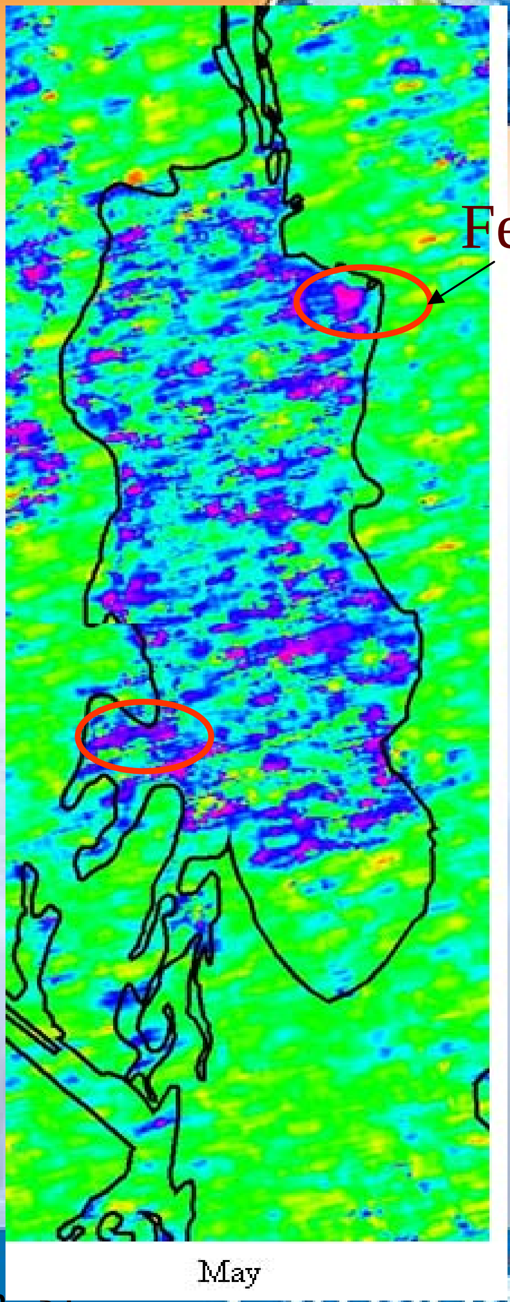


Detection of Poor fens in Open Bog

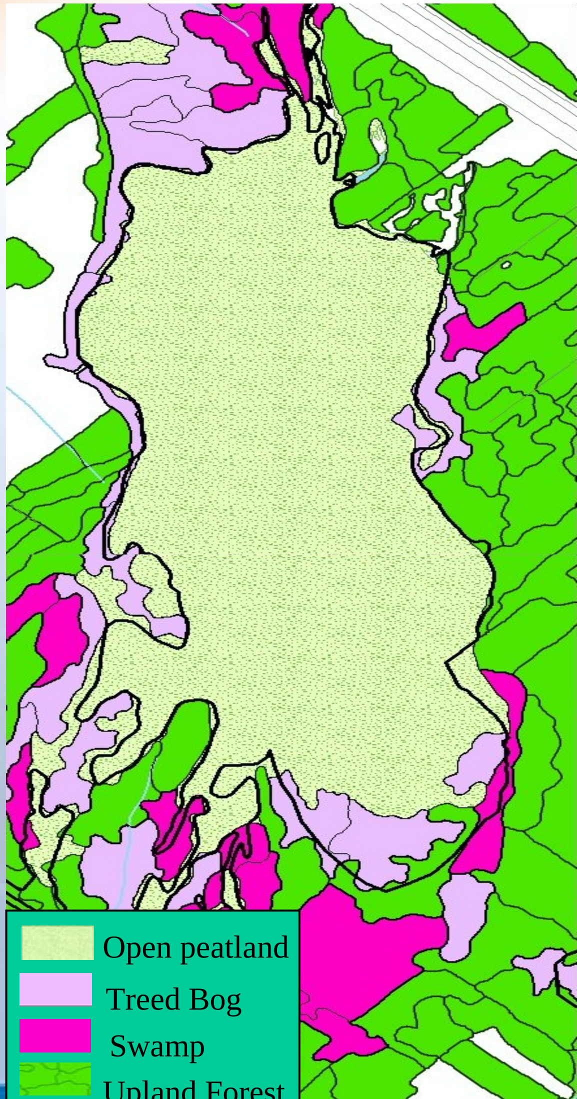


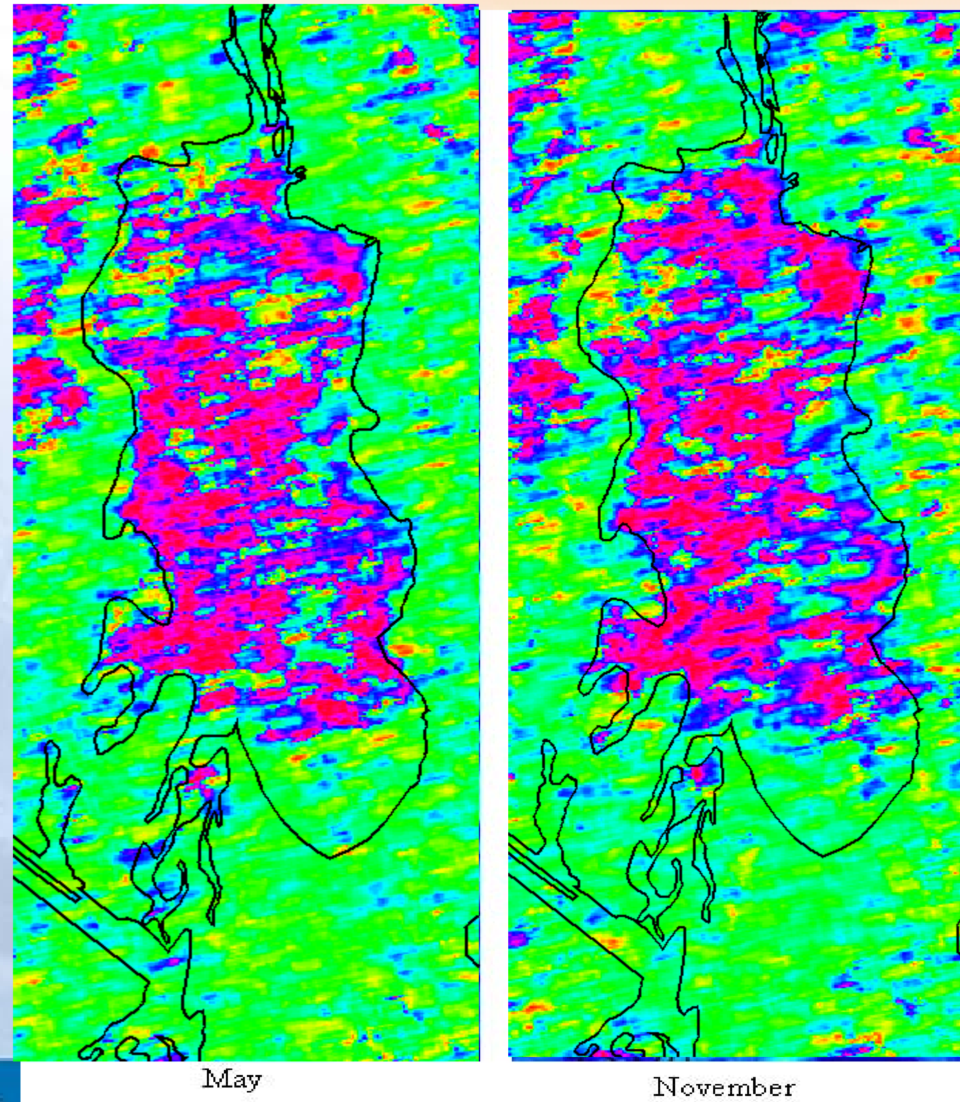
	Open Bog
	Treed Bog
	Swamp
	Upland Forest
	Water

→	Surface runoff direction
—	Stream
—	Elevation contour line (m)

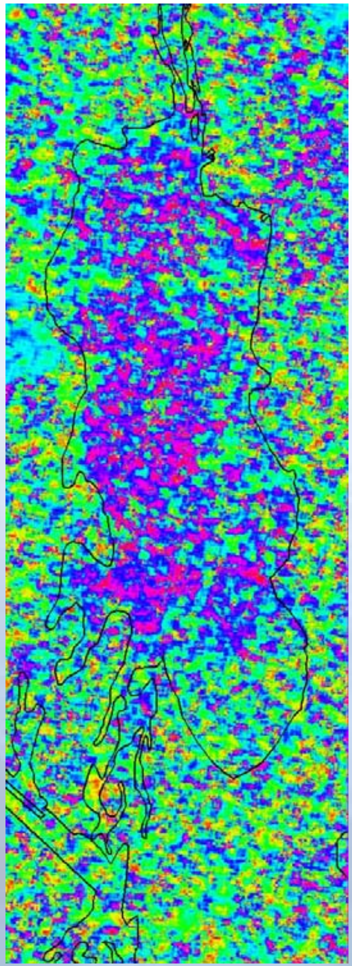


☛Pauli Phase arg(HH-VV,HH+VV) <u>not sensitive</u> to subsurface water flow variations

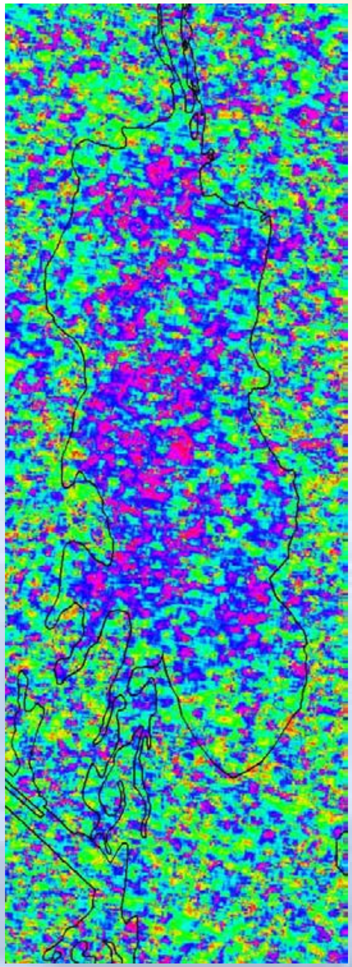




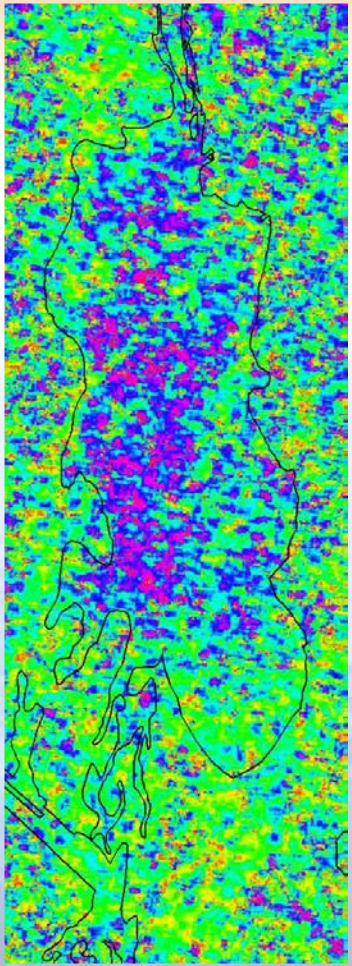
C-band-Radarsat2 not sensitive to peatland subsurface water flow (C-band + HV S/N not sufficiently low)



Jul-10

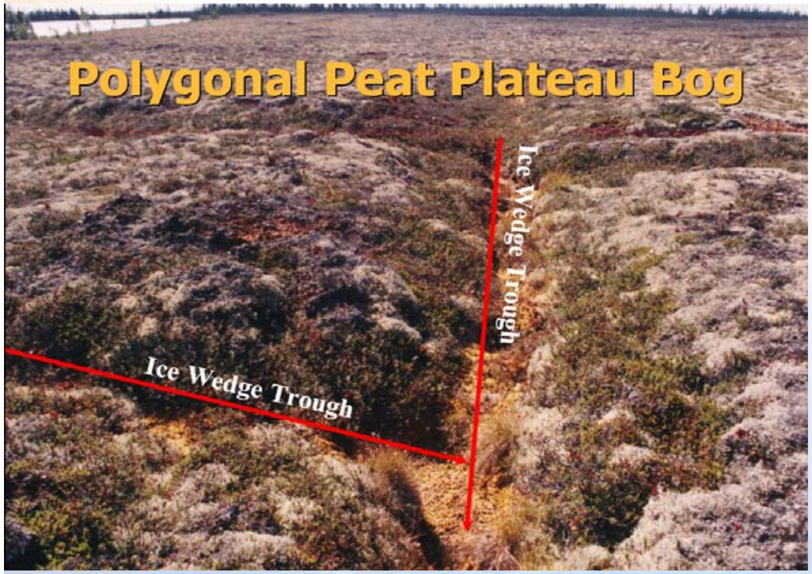


Aug-10



Nov-10

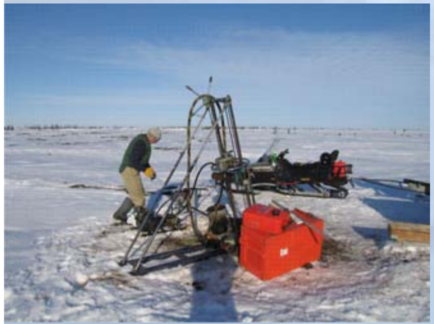
Polarimetric L-band PALSAR for Monitoring of peatland subsurface water flow
☛ Bog-fen transformations



Climate Change effect:

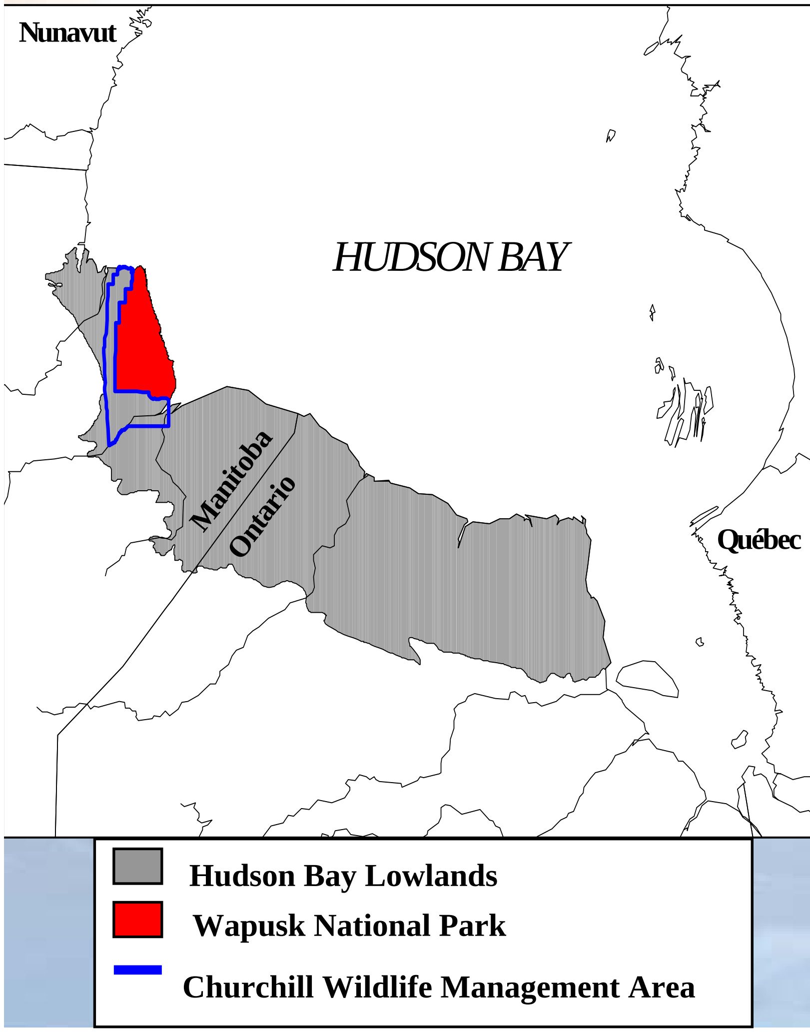
- ∗ Bogs transformed to Fen
  - ➢ Affect polar bear denning habitat which is entirely within bogs with thick peat deposits
  - ➢ Polar Bear under threat

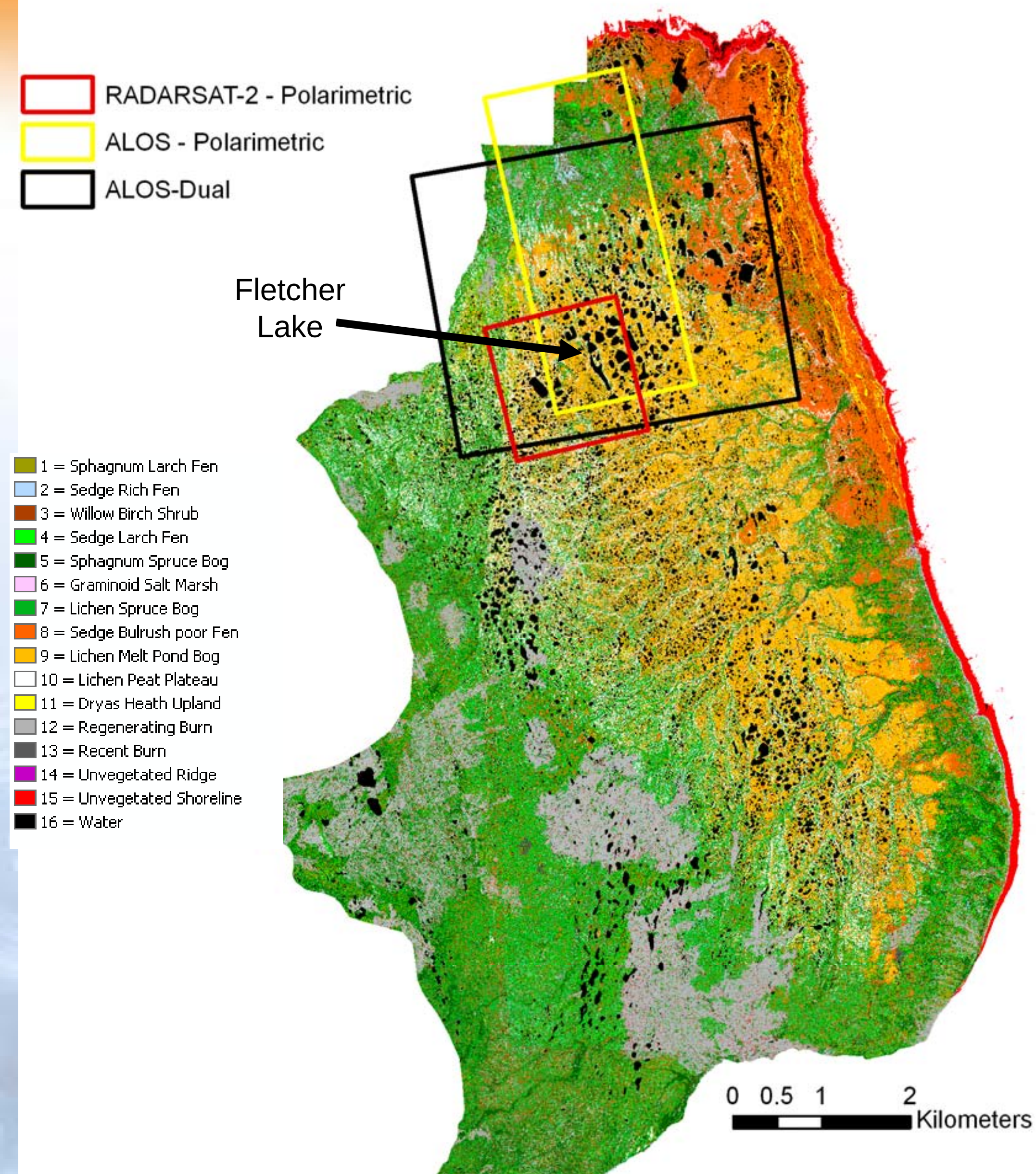
☛ Alos => Bog & Fen monitoring



Larry Dyke 2009 GSC

Wapusk National Park RADARSAT-2 and ALOS Acquisitions



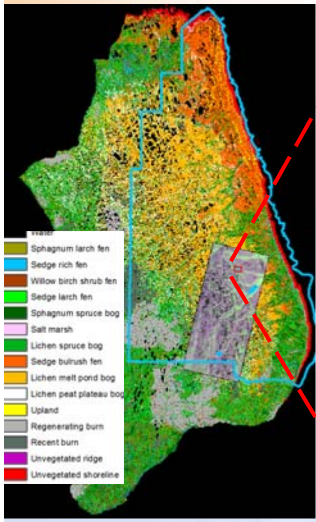


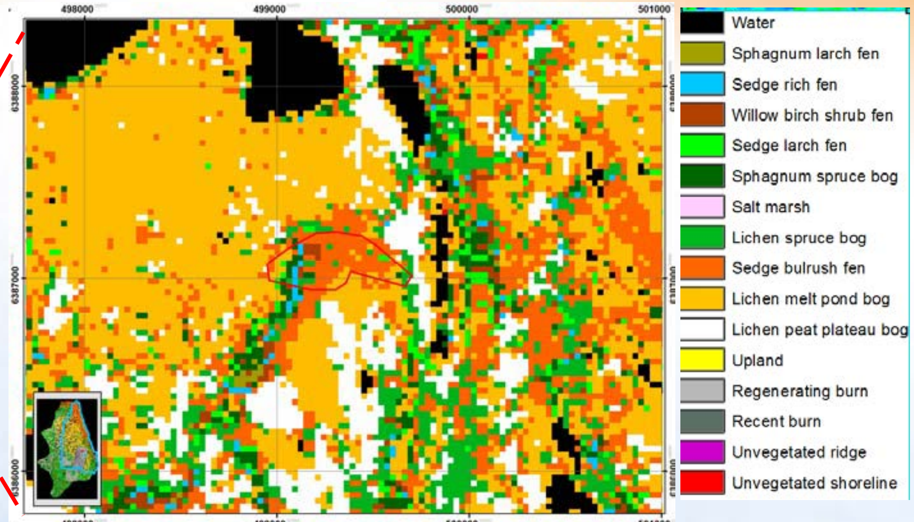
Ryan Brook's Classification
(Landsat-TM5, July, 27th, 1996)

Subsurface Water Flow Change
Sedge bulrush Fen & Litchen melt pond bog

Jun 8: Active layer 13 cm

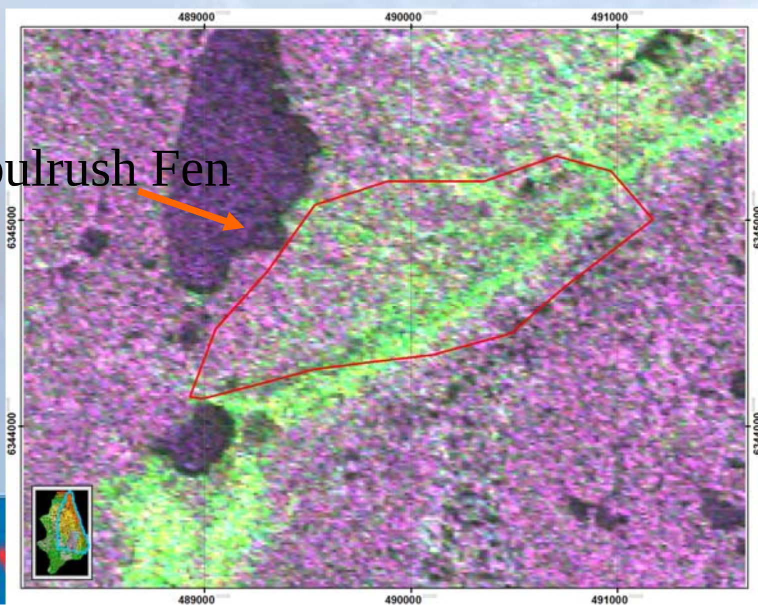
Jul 24: Active layer 27 cm



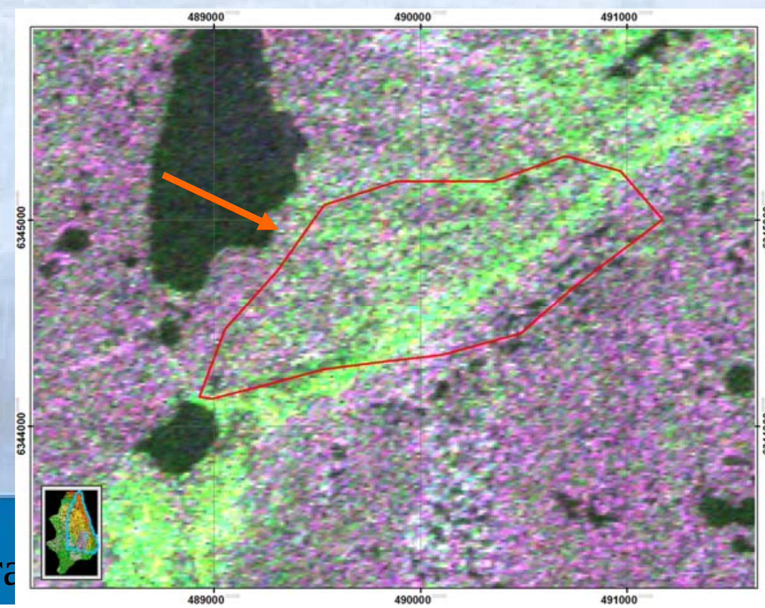


Sedge bulrush Fen

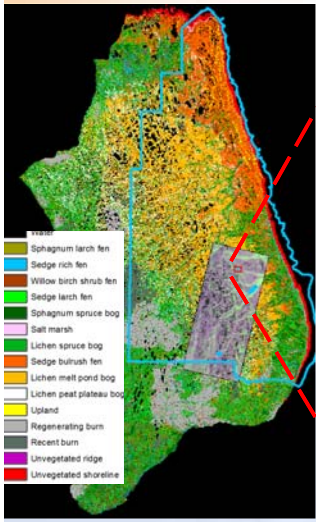
ALOS HH, HV, VV (Descending, Jun 8, 2010)

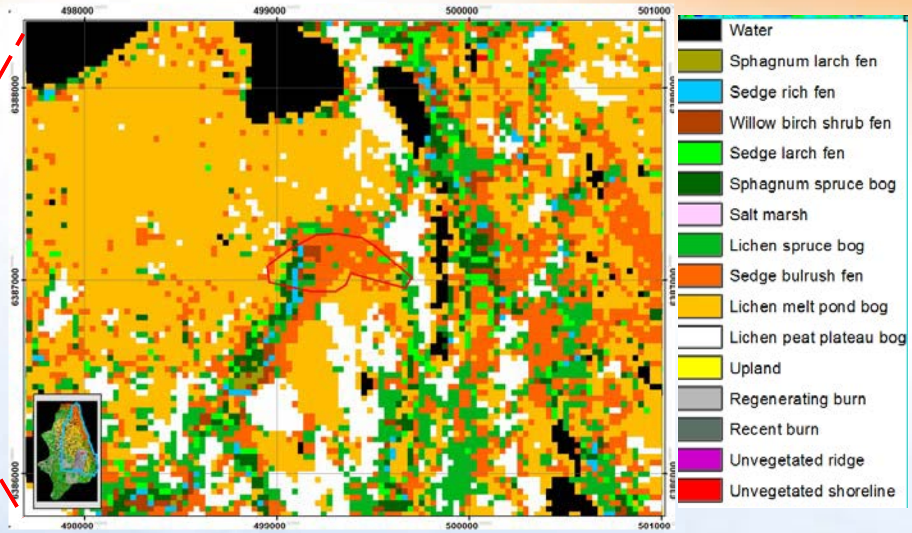


ALOS HH, HV, VV (Descending, Jul 24, 2010)



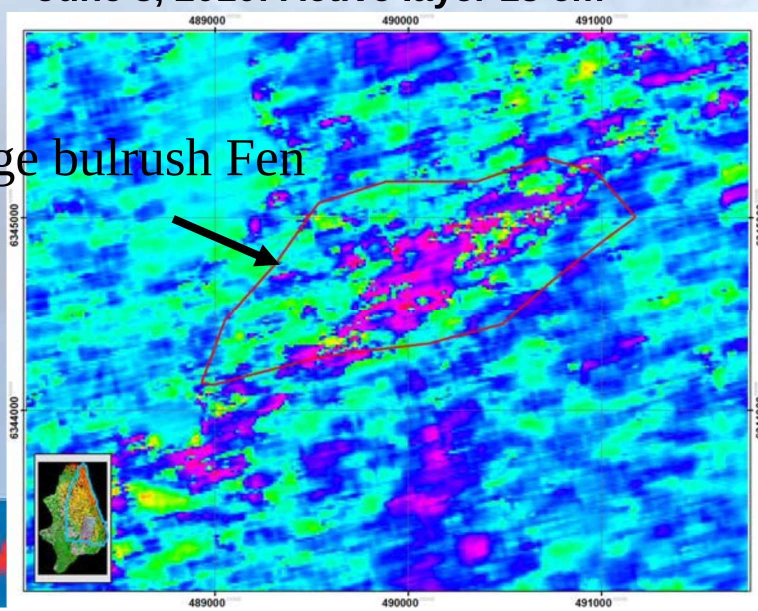
☛ Touzi scattering Phase Detects Subsurface Water Flow Change
Sedge bulrush Fen & Litchen melt pond bog



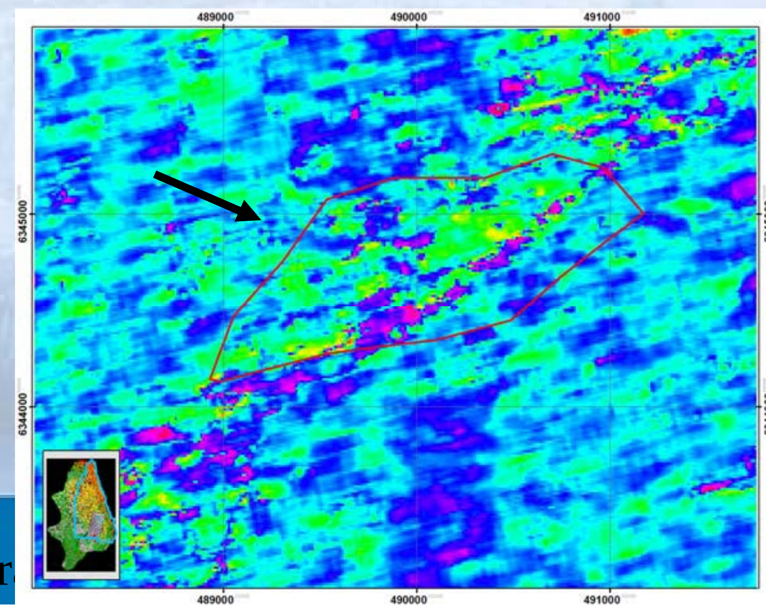


Sedge bulrush Fen

June 8, 2010: Active layer 13 cm



July 24, 2010: Active layer 30cm



Validated July 6, 2012

Litchen melt pond bog

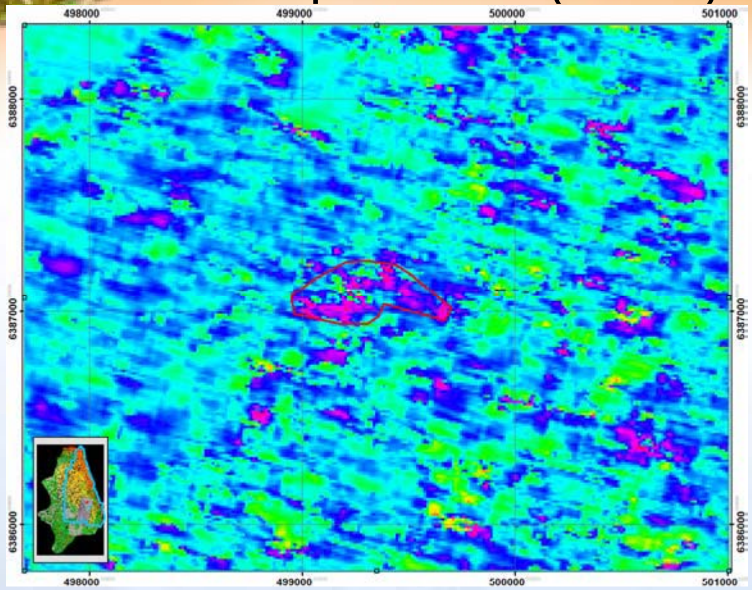
- No water under peat bog surface
- Active layer (20cm)

Sedge bulrush Fen

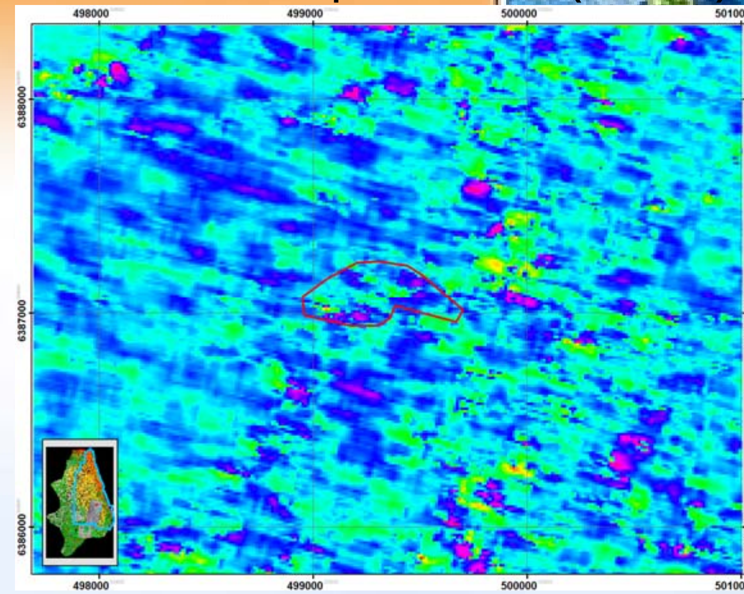
- Water 13 cm under peat fen surface
- Active layer thickness (20cm)

Radarsat2 Not sensitive to peatland subsurface water

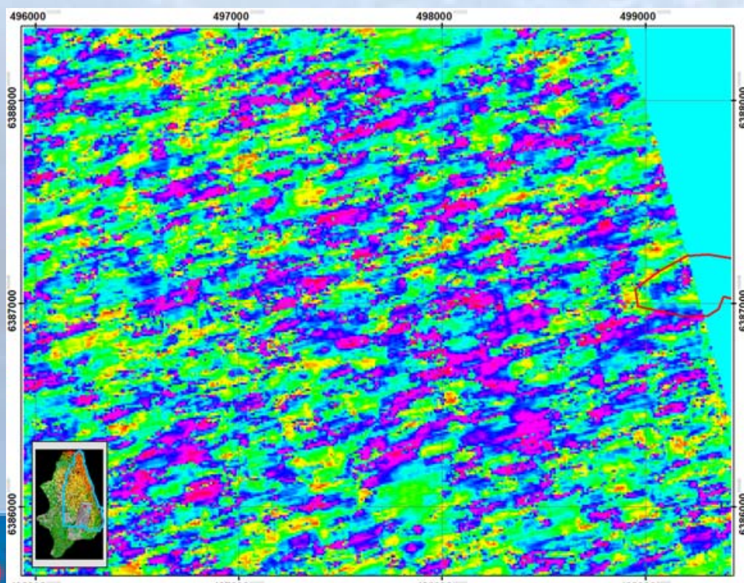
ALOS Touzi Decomposition- Phis1 (Jun. 2010)



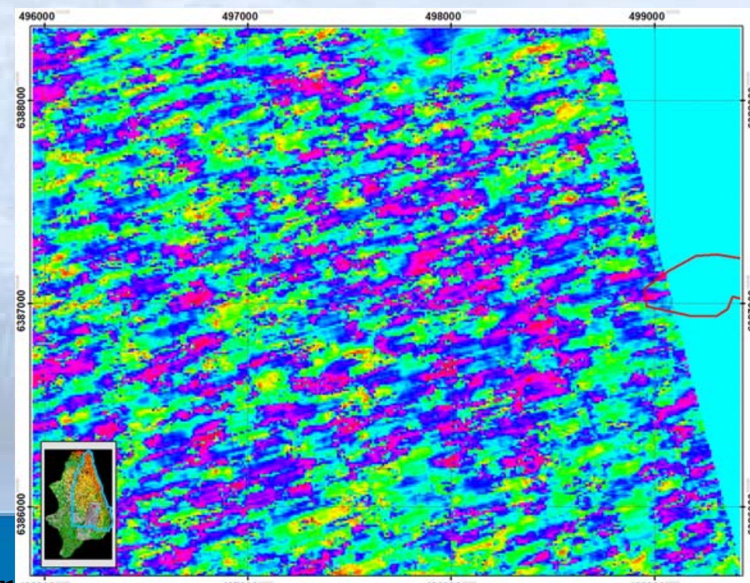
ALOS Touzi Decomposition- Phis1 (Jul. 2010)



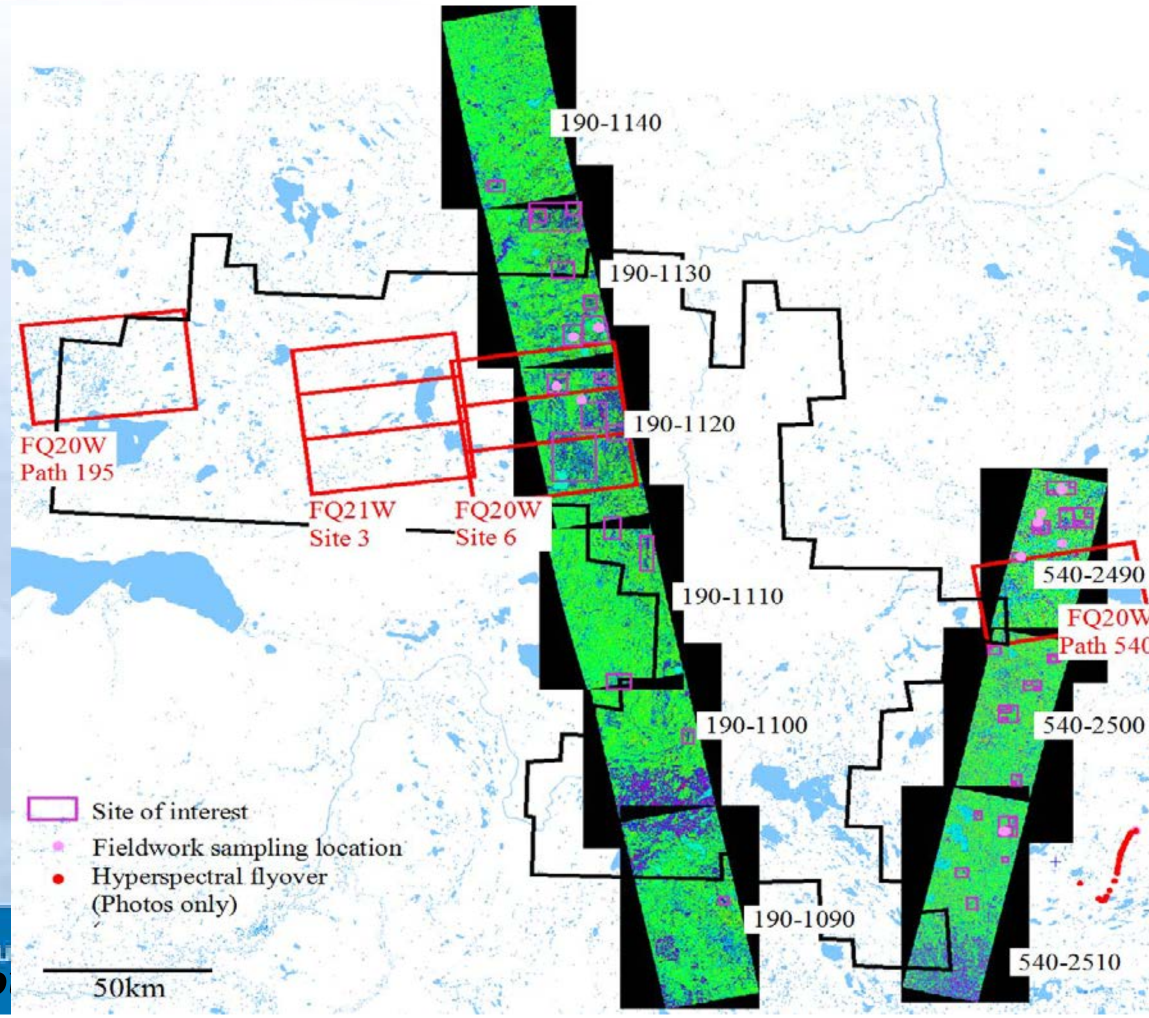
RS-2 Touzi Decomposition- Phis1 (Jun. 2010)



RS-2 Touzi Decomposition- Phis1 (Jul. 2010)



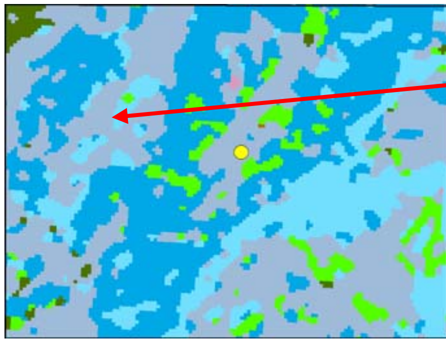
Investigation of Polarimetric ALOS and RS2 for peatland monitoring in the Athabasca Oil Sands Region



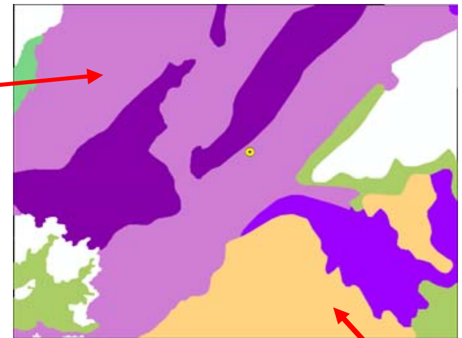
✷ **Landsat=> Treed Fen confused with black Spruce Bog !!!**

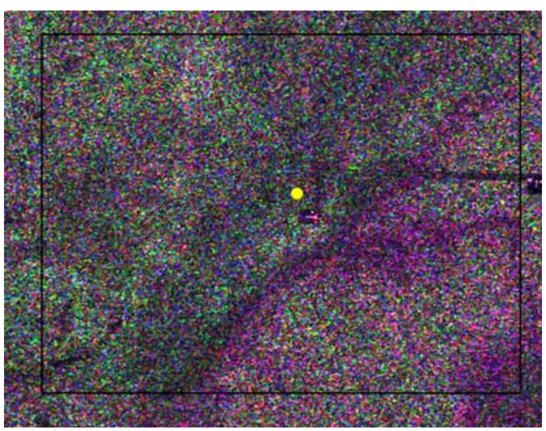
☛ **Touzi ALOS phase ➩ better class discrimination**

Landsat Classification

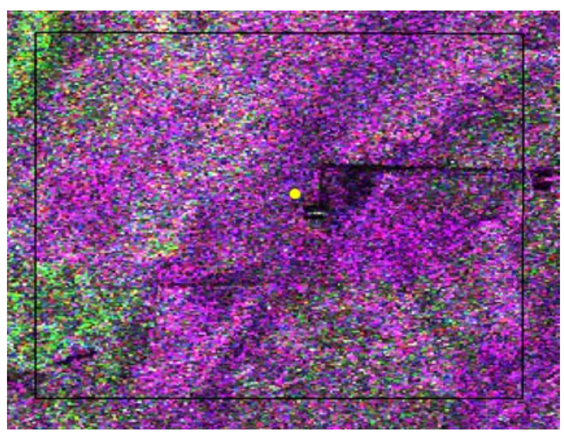


Wetland Inventory

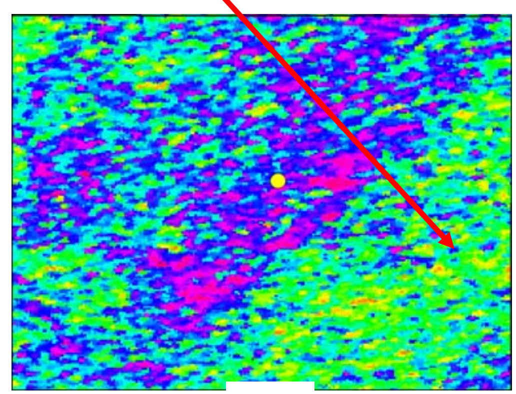




RS2_RGB (R:HH, G:HV, B:VV)

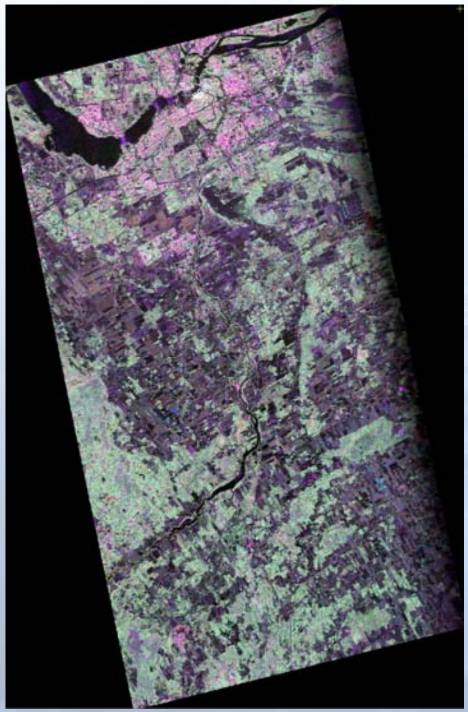


ALOS_RGB (R:HH, G:HV, B:VV)



$\Phi_{\alpha s1}$

Complementarity with the X-band **High resolution** TerraSAR (6.6mx1.18m)



ALOS

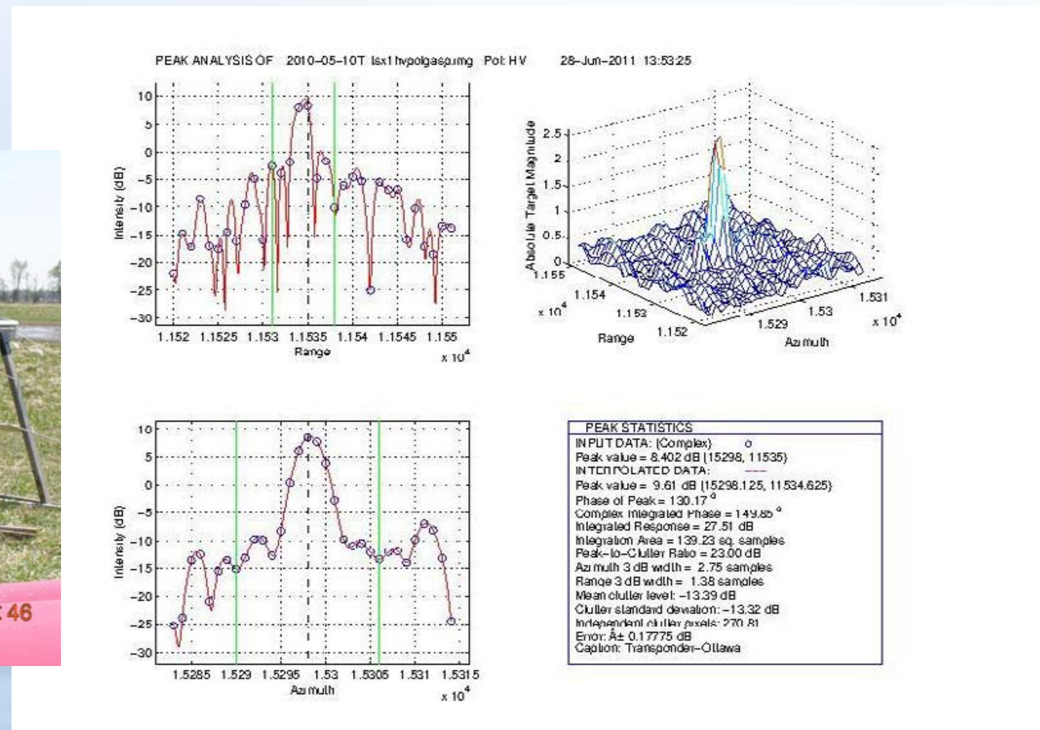
RADARSAT-2

TerraSAR-X
2010-05-10

Calibration of Polarimetric TerraSAR

☛ Significant return at HV: -25dB X-talk should be removed

⇨ Touzi calibration method validated with ALOS and Radarsat2 => *IEEE TGRS* 2009, and *TGRS* 2013



Conclusion

- Polarimetric L-band PALSAR very promising for monitoring subarctic peatland & hydrology
- Touzi $\Phi_{\alpha s}$ sensitive to the water flow underneath peat
  - Peat thickness monitoring ☛ polar bear habitat
  - Monitoring of Bog-Fen transformation due to CC
- X-C-L band complementarities is being investigated using polarimetric PALSAR and Radarsat2 and TerraSAR
- Peatand Classification using optic sensors (Landsat) and polarimetric SAR for accurate peatland classification and bog-fen transformation monitoring
- ALOS2 and Radarsat2: With Operational polarimetric capabilities and large swath (50 km)
- Future L-band TerraSAR TDX with Digital Antenna Beaming ➪ 500 km swath
- **Future missions L, C, and P band with Digital Antenna Beaming ☛ large swath**