



Assessment of polarimetric L-, and P-band polarimetric SAR for permafrost characterization along the Inuvik-Tuktoyaktuk highway corridor and surrounding environment

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CCRS

Natural Resource of Canada

Acknowledgment

NASA: P. Griffith, E. Hoy and
P. Niara

JAXA for ALOS2 images

CSA for their support under the
GRIP

And CCRS (Cum. Effect Prog.)



OUTLINE

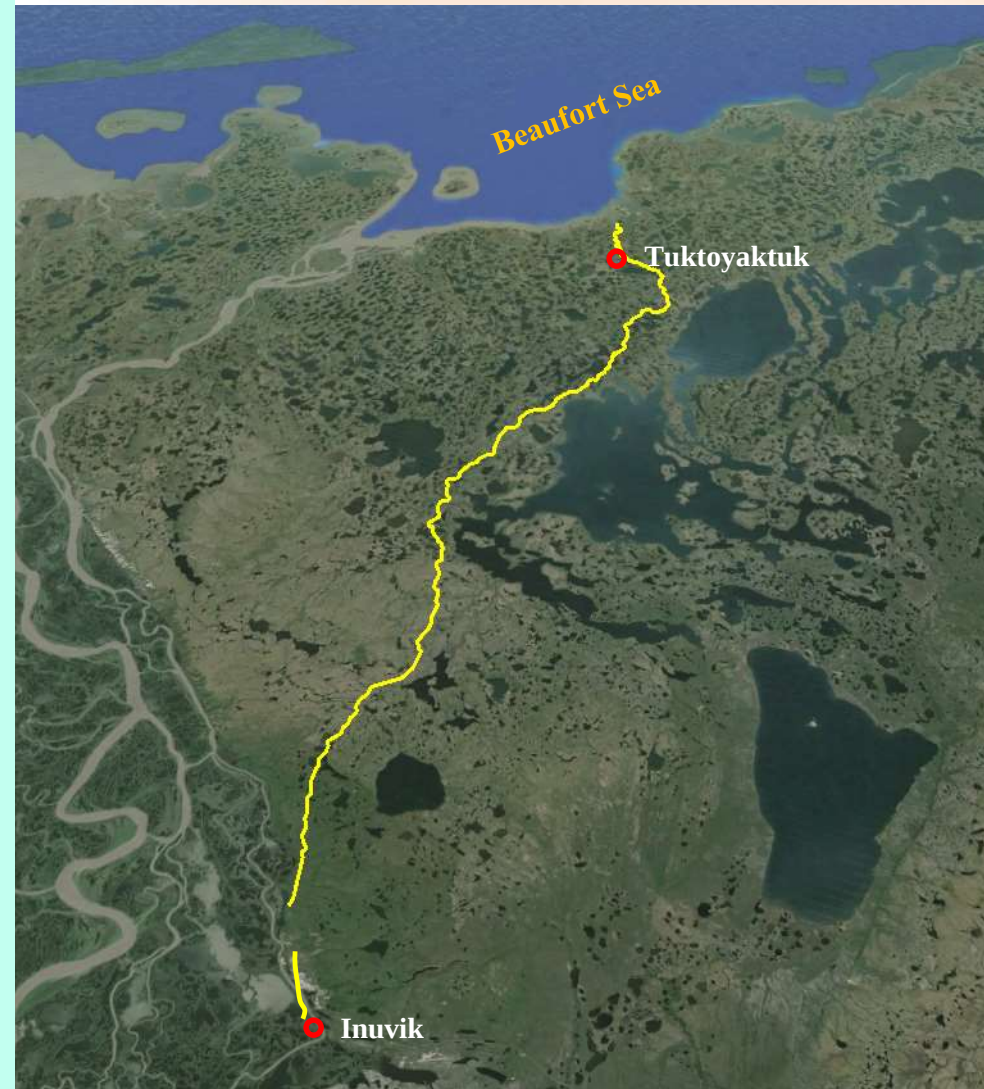


- ABoVE Project and Objectives
- Methodology
 - **Touzi decomposition** for permafrost mapping
 - **Combined** with the Touzi Descriptors (**extrema** of the Degree of Polarization)
 - Validated on discontinuous permafrost (Alberta) in collaboration with AGS (S. Pawley)
 - Requirement NESZ (-38dB) => Recalibration of ALOS2
- Inuvik-Tuktoyaktuk highway: Results obtained with L-band ALOS2 & UAVSAR and P-band AIRMOSS
 - UAVSAR and AIRMOSS (SLC format) well calibrated => NESZ (-38dB)

Innuvik-Tuktoyaktuk Highway (ITH)



- The 137 km ITH is the largest infrastructure in Canadian Arctic
- It is underlain by ice-rich permafrost, and crosses treeline from boreal forest to arctic tundra
- Climate warming affects permafrost, ecosystems, and infrastructure.
- ☞ Permafrost degradation => infrastructure stability
- ☞ Infrastructure => impact on surrounding environment
- ✿ Key parameter => Active Layer Thickness (ALT).
 - The active layer is important to many biogeochemical cycles and processes





Objective & Field data



- R. Touzi, Yu Zhang, R. Fraser, and M. Moghaddam “Investigation of the added value of L- and P-band PolinSAR for permafrost characterization and mapping”

http://above.nasa.gov/cgi-bin/above/inv_pgp.pl?pgid=3573

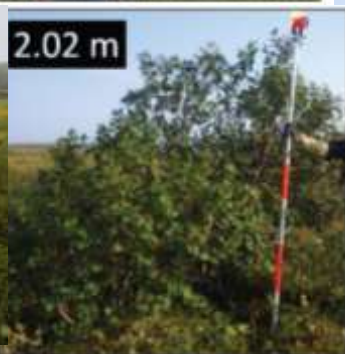
- Objective: Investigation of the added value of **polarimetric** long penetrating wavelength L- (ALOS2 and UAVSAR) and P-band AIRMOSS SAR with reference to conventional optic sensors for enhanced permafrost characterization degradation and monitoring.
- Intensive field data will be collected (jointly with our partners) during the airborne campaign
- Archived field data + in-situ sensors measurements for many years (GSC, GNWT, CCRS)
- C-band Radarsat2, L-band polarimetric ALOS and ALOS2 + Optic data (Quickbird, Landsat, Spot)



RADARSAR-II



L-band ALOS2



Field data collection



Measuring near-surface soil temperature (Tnss)

iButton temperature data logger (model DS1921G-F5#)[®]

Temperature range: -40 to 85 °C

Accuracy: 1 °C,

Data resolution: 0.5 °C

Field deployment

Deployed: Aug. 16-24, 2016

Retrieved: Aug. 15-22, 2017

Time step: 255 minutes or 4.25 hours)

Total records: 2048, or 362.7 days

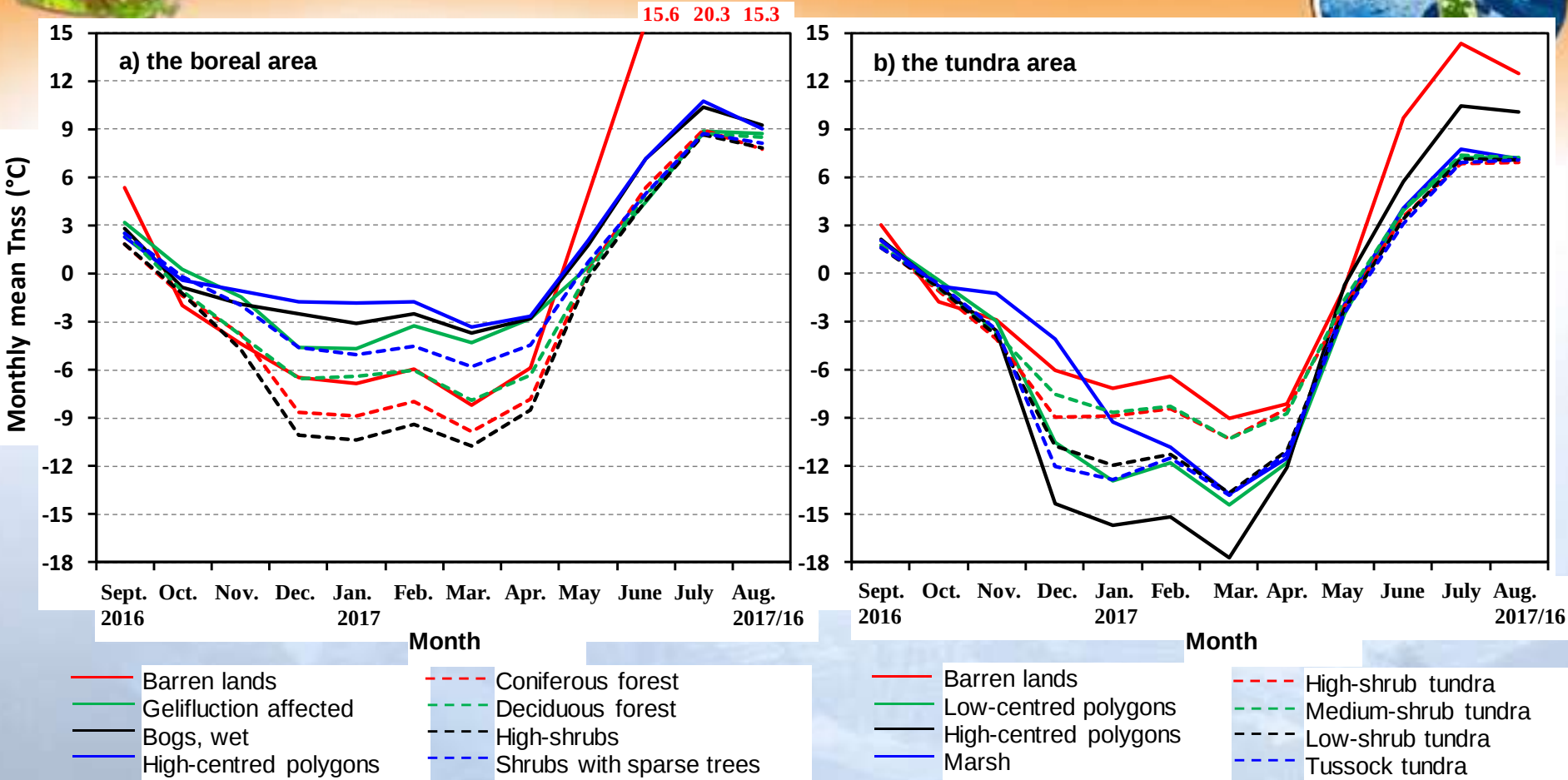
Depth: 5 inch (13 cm)

Sites:

Boreal area: 56 (6 near embankment, 1 lost)

Tundra area: 54 (9 near embankment, 2 lost)





Near-surface soil temperature and active-layer thickness =>

- Y. Zhang, R. Touzi, W. Feng, G. Hong, T.C. Lantz and S.V. Kokelj, "Landscape-scale variations in near-surface soil temperature and active-layer thickness: Implications for high-resolution permafrost mapping", Permafrost and Periglacial Processes Journal, in pres

Touzi Decomposition for Peat and Characterization



Honours by ESA: Best Promotion of polarimetric SAR (PolinSAR2009)



IEEE TGRS 2007

IEEE TRANSACTIONS ON GEOSCIENCES AND REMOTE SENSING, VOL. 45, NO. 9, SEPTEMBER 2007

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

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

1. INTRODUCTION

Abstract—The complementarity of the “coherent” and “incoherent” scattering mechanisms for enhanced wetland forests. Polarimetric SAR is used for the detection of wetland forests. It is shown that the coherent scattering mechanism presents the explicit variability and the total scattering phase, permits enhanced discrimination of wetland forests and improved identification of surrounding forests. A convenient method for wetland forest classification is proposed.

NOMENCLATURE

AGCC	Alberta ground cover classification.
AWI	Alberta wetland inventory.
COPOL	Co-polarization signature.
Cross-Pol	Cross-polarization signature.
CTD	Coherent target decomposition.
DoP	Degree of polarization. Also denoted as “ γ ”.
ρ_{max}	Maximum of the degree of polarization.
ρ_{min}	Minimum degree of polarization.
EVBD	Eigenvector-based decomposition.

CJRS 2007

Can. J. Remote Sensing, Vol. 33, Suppl. 1, pp. S59-S67, 2007

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) for wetland forest characterization. However, the limited capability of C-band SAR in vegetation type discrimination makes the use of dual-polarization (DPP) SAR data necessary for wetland mapping. In this paper, the potential of wetland characterization is investigated. The Touzi decomposition decomposition is applied to wetland scattering. In contrast with the Cloude-Peter decomposition that characterizes only the total scattering, the Touzi decomposition uses a complete set of the symmetric scattering type wetland target scattering. It is shown that, like the Cloude-Peter scattering type, the Touzi decomposition is effective for vegetation type discrimination. The phase ϕ_{pol} of the symmetric scattering type wetland target scattering. The unique information provided by decomposition is demonstrated using Canada-SAR polarimetric C-band SAR data collected over the wetlands of the St. Lawrence River, Quebec, Canada.

Résumé: L'utilisation des données radar à synthèse d'ouverture (SAR) de RADARSAT-1 pour la caractérisation de l'humidité de surface des milieux humides. Cette bande C de RADARSAT-1 est polarisation unique pour la discrimination des types de milieux humides. Dans cet article, nous analysons le potentiel de RADARSAT-2 pour la caractérisation des milieux humides. La décomposition de scattering de Touzi est appliquée à la caractérisation des milieux humides. Par rapport à la décomposition de Cloude-Peter, la phase ϕ_{pol} de la diffusion symétrique de scattering de Touzi est utilisée pour la caractérisation des milieux humides. L'information supplémentaire fournie par la décomposition de Touzi est démontrée à l'aide de données radar polarimétriques de bande C de RADARSAT-2. Il est montré que, comme la décomposition de Cloude-Peter, la décomposition de Touzi est efficace pour la caractérisation des milieux humides. La phase ϕ_{pol} de la diffusion symétrique de scattering de Touzi est utilisée pour la caractérisation des milieux humides. L'information supplémentaire fournie par la décomposition de Touzi est démontrée à l'aide de données radar polarimétriques de bande C de RADARSAT-2. Il est montré que, comme la décomposition de Cloude-Peter, la décomposition de Touzi est efficace pour la caractérisation des milieux humides.

Target Scattering Decomposition in Terms of Roll-Invariant Target Parameters

Ridha Touzi, Member, IEEE

Abstract—The Kennaugh-Heyman scattering matrix decomposition is presented in this paper 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 the independent target parameters. The magnitude and phase of the symmetric scattering type (SST) are used to represent the coherent target scattering. The Kennaugh-Heyman invariant polarization parameters (orientation angle, helicity, and maximum eigenvalue) are used to represent the incoherent target scattering. The Kennaugh-Heyman invariant polarization parameters (orientation angle, helicity, and maximum eigenvalue) are used to represent the incoherent target scattering. The Kennaugh-Heyman invariant polarization parameters (orientation angle, helicity, and maximum eigenvalue) are used to represent the incoherent target scattering. The Kennaugh-Heyman invariant polarization parameters (orientation angle, helicity, and maximum eigenvalue) are used to represent the incoherent target scattering.

θ	Orientation angle introduced by Cloude and Pottier.
α_{pol}	Symmetric scattering type (SST) magnitude.
α_{pol}	Symmetric scattering type (SST) magnitude.
α_{pol}	Symmetric scattering type (SST) magnitude.
α_{pol}	Symmetric scattering type (SST) magnitude.
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α_{pol}	Symmetric scattering type (SST) magnitude.
α_{pol}	Symmetric scattering type (SST) magnitude.
α_{pol}	Symmetric scattering type (SST) magnitude.

1. INTRODUCTION

THE OBJECTIVE of the coherent target decomposition (CTD) theory is to express the average scattering mechanism in terms of independent parameters in order to associate a physical mechanism with each component [1]–[4]. Target scattering decomposition permits the estimation of target characteristic information provided that the decomposition satisfies

R. Touzi, ALOS2-PI Workshop,



Touzi Decomposition for Enhanced Peatland Classification (TGRS 2007, 2009)



- Synthesis of 50 years R&D (Kennaugh 51, Huynen65, Cloude-Pottier 96, Grave 56)

$$[T] = \eta_1 [T_1] + \eta_2 [T_2] + \eta_3 [T_3]$$

➡ Roll invariant coherent scattering model for eigenvector:

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

➡ A **complex** entity ($\alpha_s, \Phi_{\alpha_s}$) for **unambiguous** description of target scattering

➡ **Helicity** (τ) $\Rightarrow$ Local **asymmetry** $\Rightarrow$ Forest structure

➤ 11 scattering parameters for an **unambiguous** description of target scattering

$$(\eta_1, \alpha_{s1}, \Phi_{\alpha_{s1}}, \tau_1, \eta_2, \alpha_{s2}, \Phi_{\alpha_{s2}}, \tau_2, \eta_3, \alpha_{s3}, \tau_3)$$

➡ 9 independent parameters using eigenvector **orthogonality**

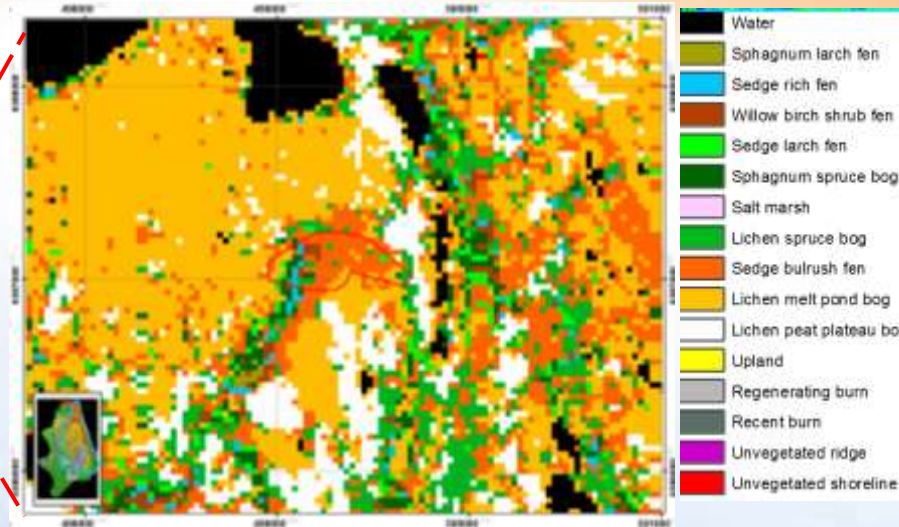
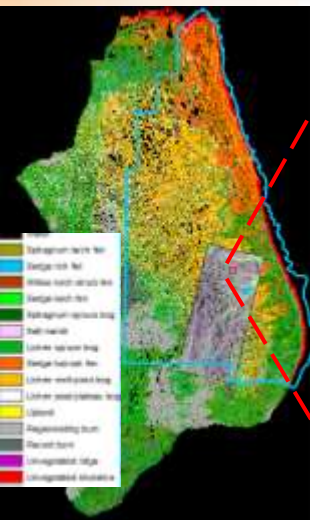
$$(\eta_1, \alpha_{s1}, \Phi_{\alpha_{s1}}, \tau_1, \eta_2, \tau_2, \eta_3, \alpha_{s3}, \tau_3)$$

Subsurface Water Flow Change

Sedge bulrush Fen & Lichen melt pond bog

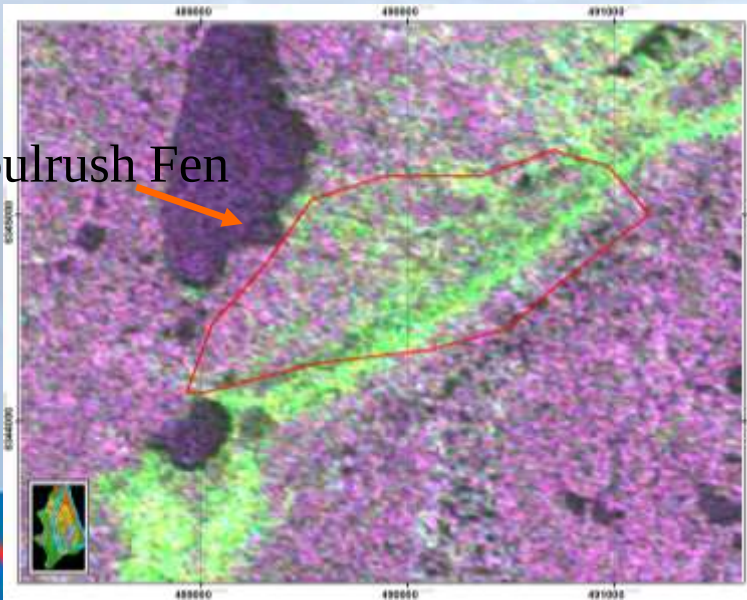
Jun 8: Active layer 13 cm

Jul 24: Active layer 27 cm

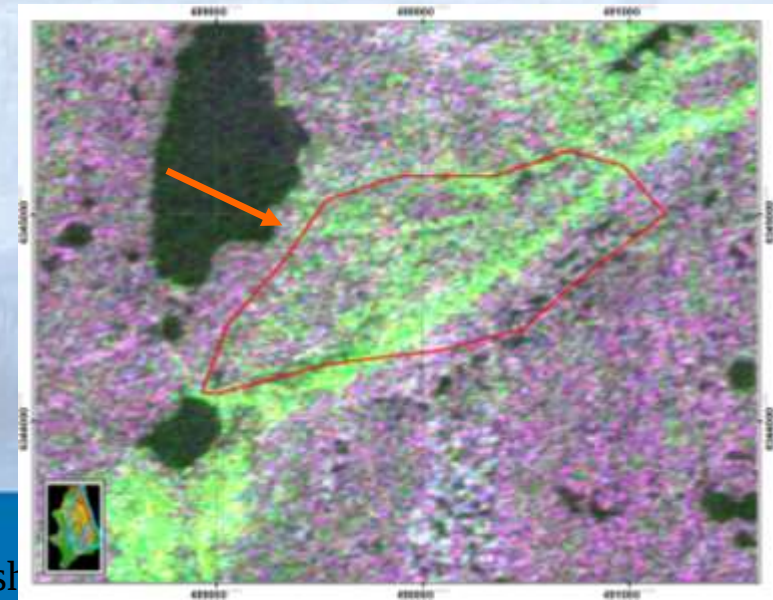


Sedge bulrush Fen

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



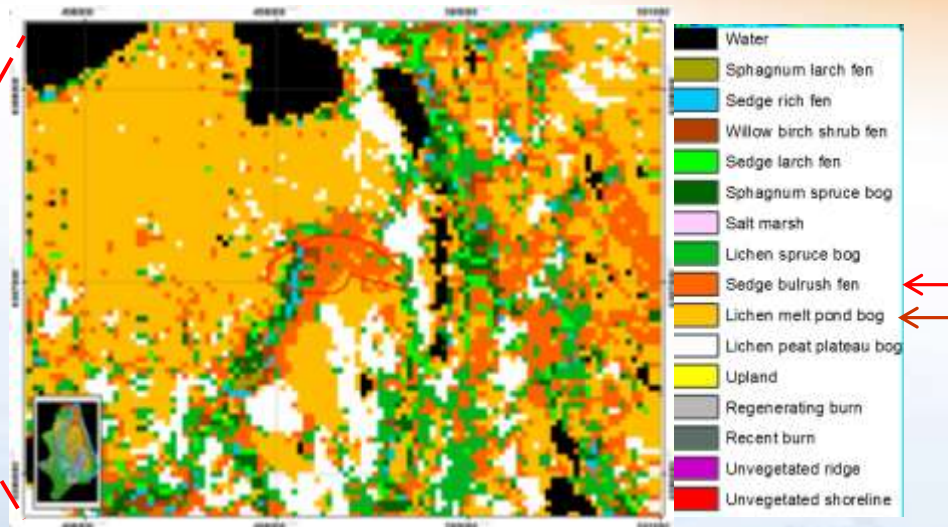
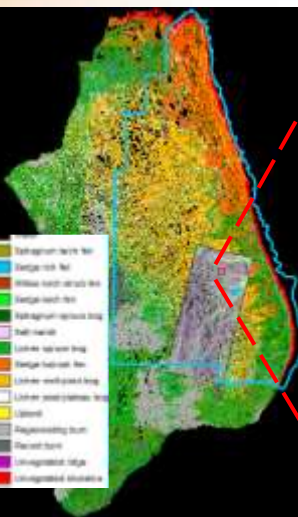
ALOS **HH**, **HV**, **VV** (Descending, Jul 24, 2010)



Sedge bulrush Fen

Site 1

Touzi scattering Phase Detects Subsurface Water Flow Change
 Low HV => excellent ALOS NESZ (-34 dB) => ALOS2 (-38dB)

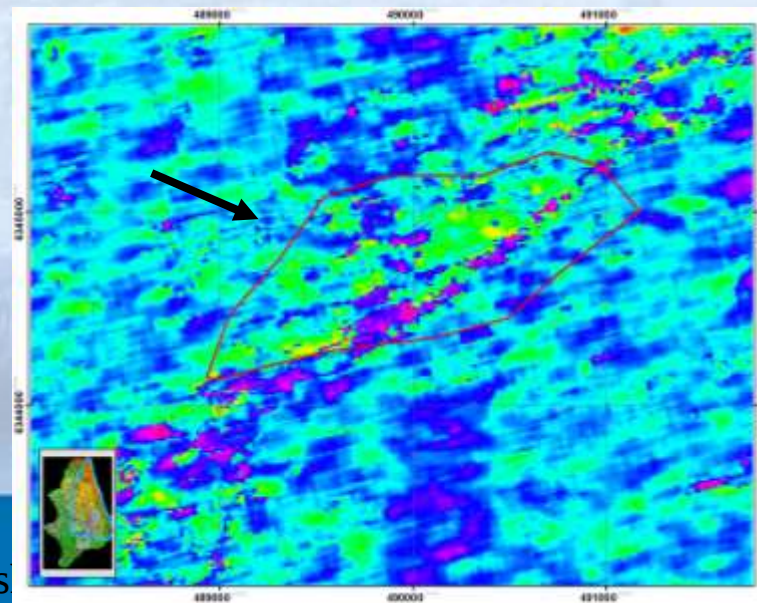
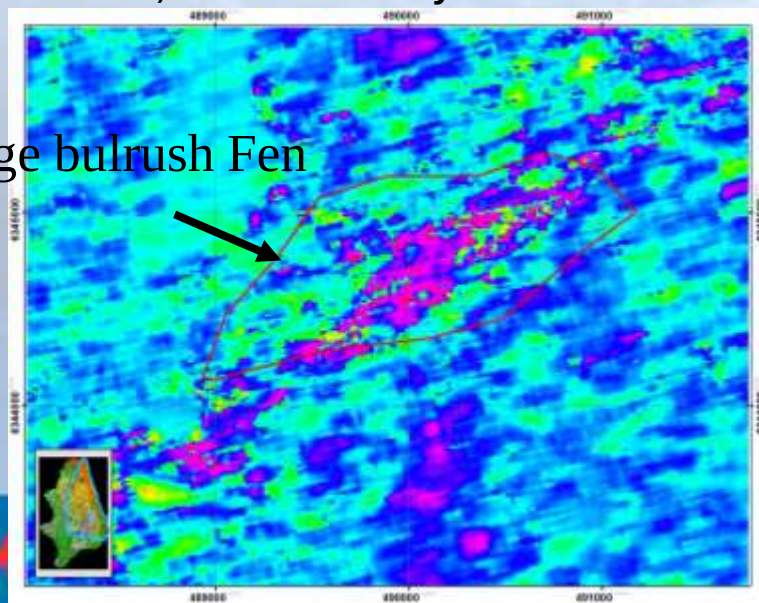


Sedge bulrush Fen

June 8, 2010: Active layer 13 cm

July 24, 2010: Active layer 30cm

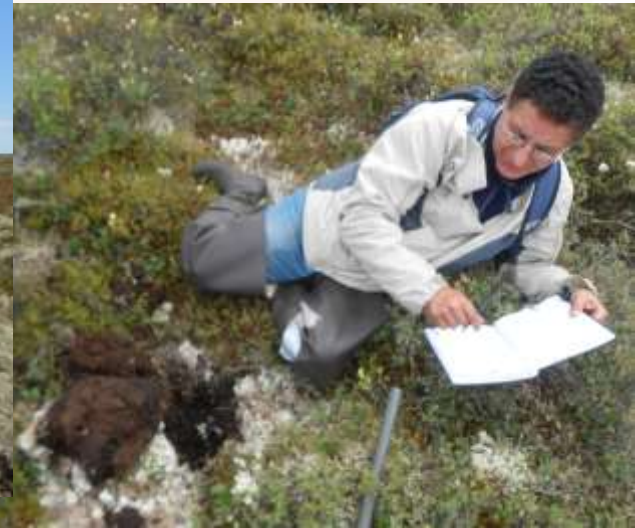
Sedge bulrush Fen





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)



Validated for Discontinuous Permafrost Mapping Namur Lake Site Alberta (jointly with S. Pawley AGS) ALOS2 FP6-4, Aug. 2014

ALOS-2 2014_08

HH/HV/VV

Depth to permafrost



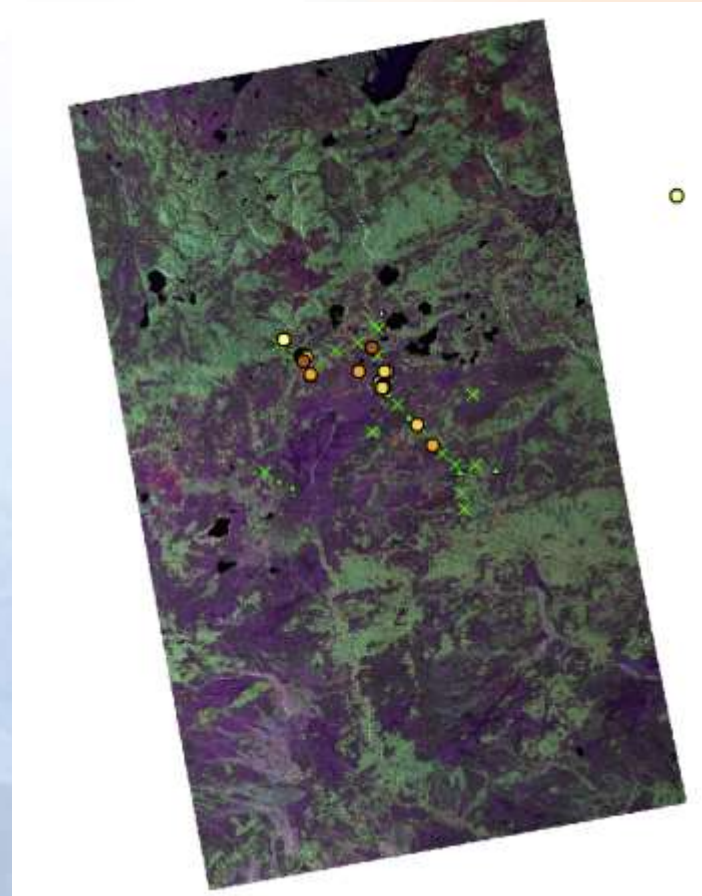
permafrost sites

Depth to permafrost (m)

- 0.15 - 0.30
- 0.31 - 0.50
- 0.51 - 0.85
- 0.86 - 1.20
- 1.21 - 1.80

no permafrost sites

- Bog
- + Burrow pit
- ◆ collapse scar
- ▲ fen
- × forest
- ★ swamp
- upland



- Field data collected by S. Pawley (AGS)
- Lidar & (Landsat-Spot) permafrost Classification (AGS)
- Landsat AGCC wetland classification (ESRD)

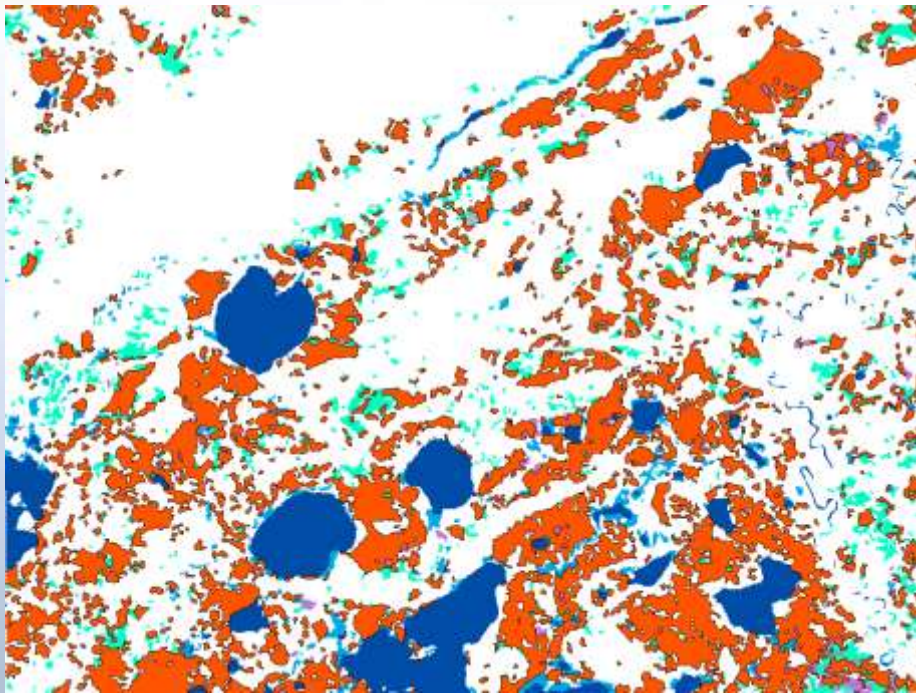
- R. Touzi, S. Pawley, M. Hosseini and X. Jiao, Polarimetric L-band PALSAR2 for Discontinuous Permafrost Mapping In Peatland Regions, Proc. of IGARSS`19, Yokohama, Japan, 28 July- 2aug. 2019

Lidar & Landsat (S. Pawley AGS) versus PLR ALOS2

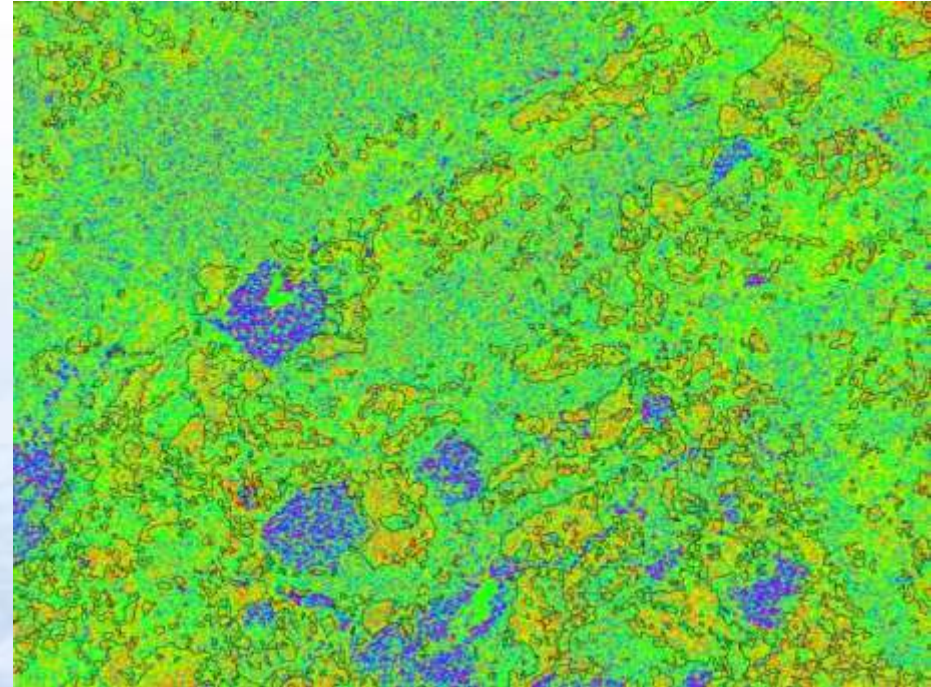


Touzi Decomposition => discontinuous permafrost mapping

- Bog
- Collapse scar bog
- Fen
- Marsh
- Permafrost
- Water



AGC classification

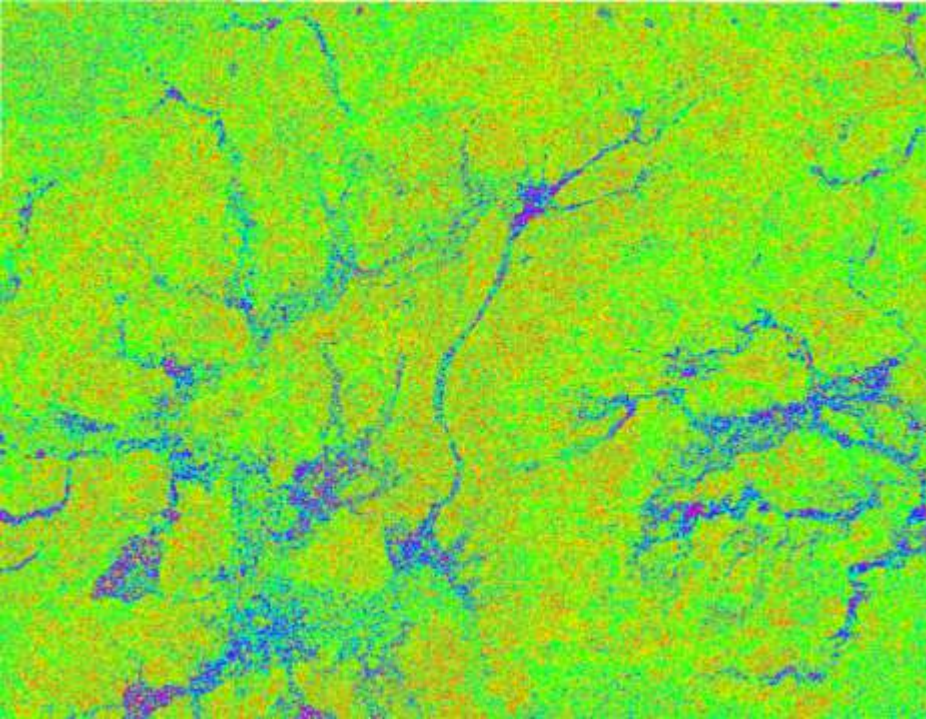


Touzi Phase

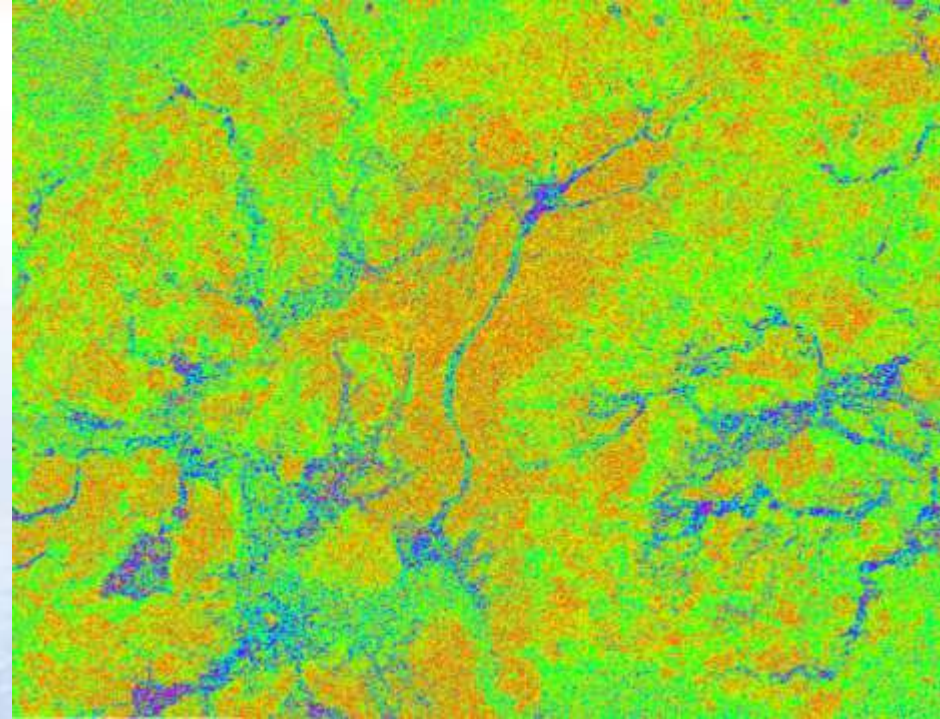
- Discontinuous permafrost (pink) in AGS classification identified (orange) in the Touzi scattering type phase
- Excellent ALOS2 NESZ (-38dB) => PLR Very promising for discontinuous permafrost Mapping and Monitoring



ALOS2 FP6-4 **Re-Calibration** Required for enhanced permafrost mapping



Original
ALOS2

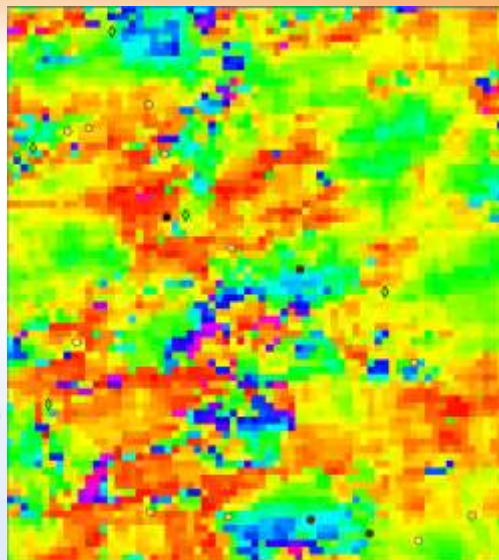


Re-calibrated ALOS2 => NESZ= -38dB

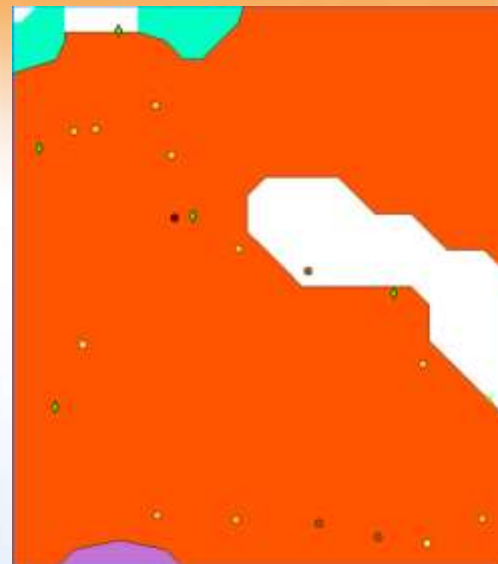
ALOS2 re-calibrated for the Distortion Matrix + Faraday Rotation



Touzi scattering Phase ϕ_{s2}



AGS Classification



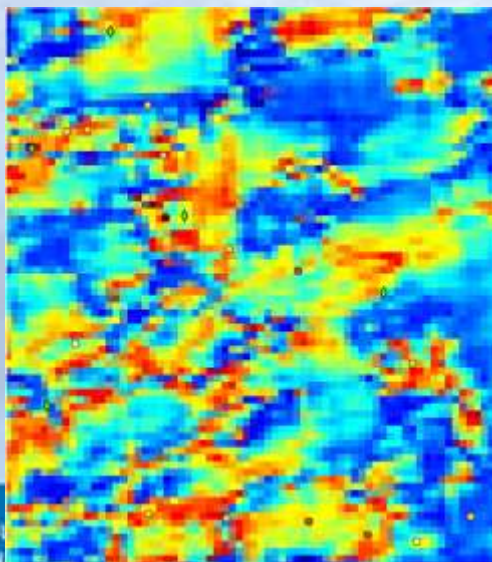
Depth to permafrost (m)

- 0.15 - 0.30
- 0.31 - 0.50
- 0.51 - 0.85
- 0.86 - 1.20
- 1.21 - 1.80

No Perm

- Bog
- + Burrow pit
- ◇ collapse scar
- ▲ fen
- × forest
- ★ swamp
- upland

Scattering magnitude α_{s2}



AGCC Classification



- Closed Deciduous
- Closed Jack Pine
- Closed White Spruce
- Graminoid Wetlands
- Shrubby Wetlands
- Black Spruce Bog
- Water

- Lidar&Optic EO classification Not accurate
- Touzi Decomposition ϕ_{s2} : Orange (70°) => subsurface permafrost
- ⇒ Permafrost detected (up to 50 cm depth)
- L-band penetration but limited => Deeper permafrost not detected



Natural Resources
Canada

Ressources
Canada

Canada



AIRMOSS P-band Polarimetric SAR (JPL)



ESA BIOMASS 2021

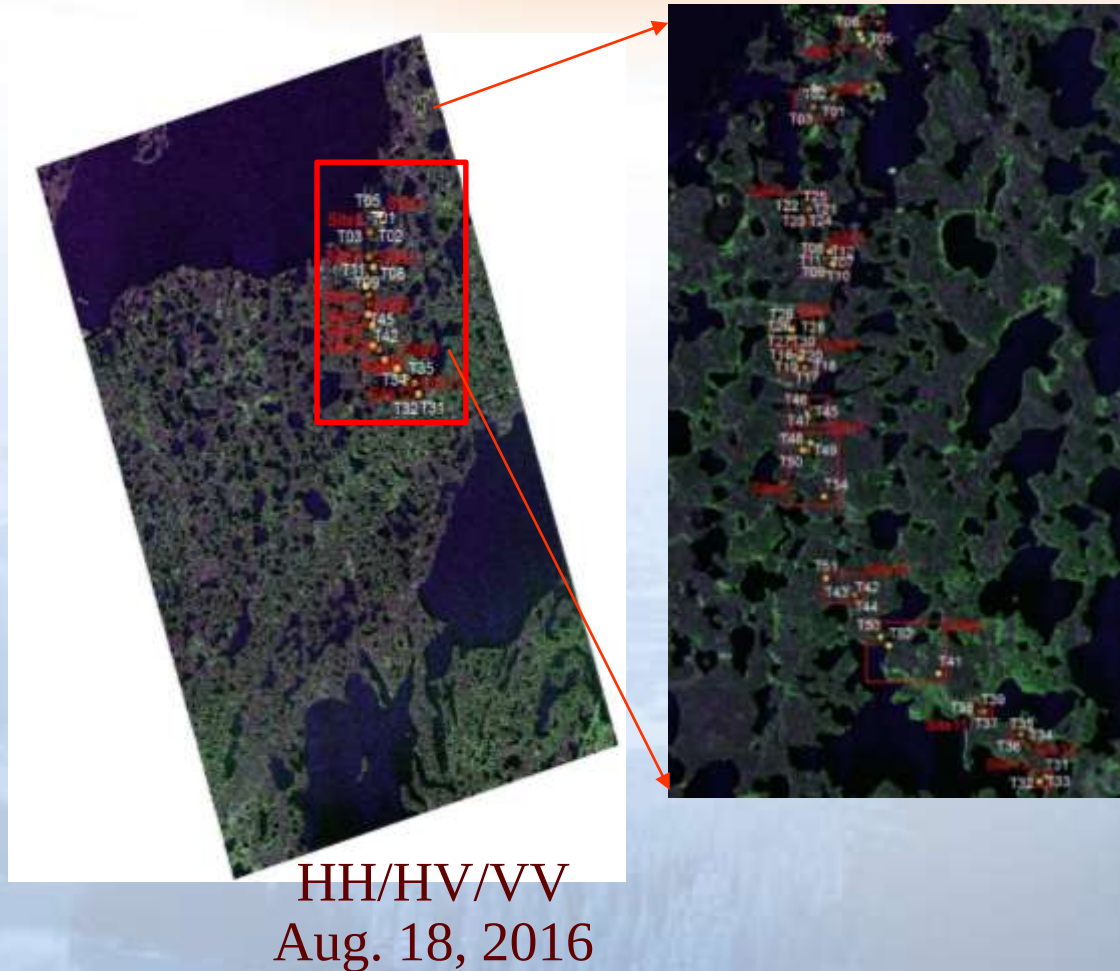
- June 20, 2017 (UAVSAR L-band)
- September 13, 2017 (UAVSAR L-band)
- August 29, 2018 (UAVSAR L-band)
- September 16, 2019 (UAVSAR L-band)
- June 6, 2017 (AIRMOSS P-band)
- August 18, 2017 (AIRMOSS P-band)



Polarimetric C-, L- and P-band SAR data



- Multi-temporal series of PALSAR2 PLR collected.
- Radarsat2 data collected (CSA & MDA)
- P-Band AIRMOSS and L-band UAVSAR data collected under ABoVE
- Intense field data collection during the 2017 summer campaign





Site 14



2017-8-22-1
(thaw
depth:0.55m)





2017-8-22-2 (thaw depth:0.47m)





2017-8-22-3 (thaw depth:0.36m)





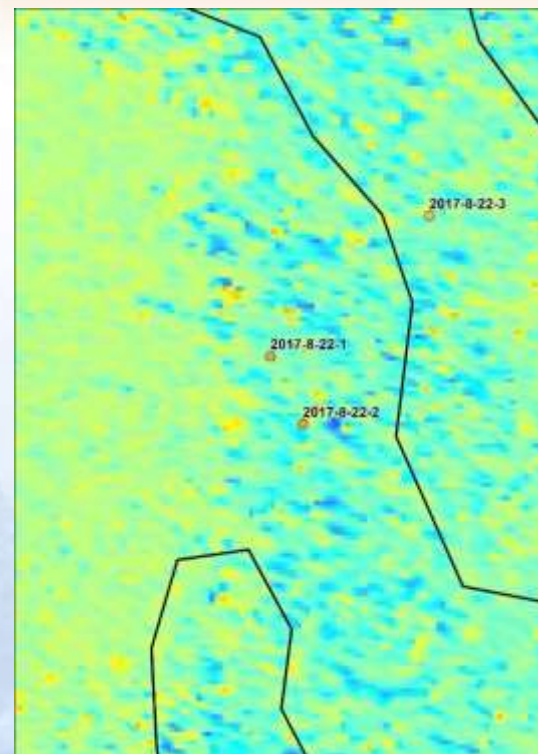
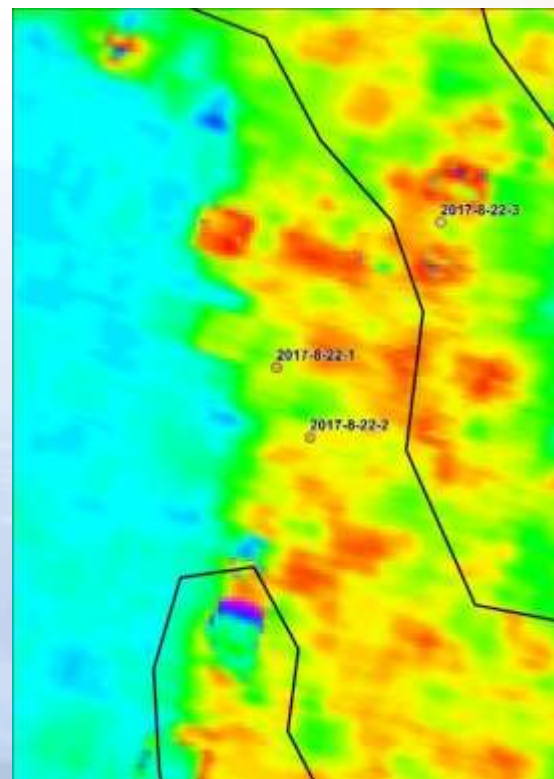
P-band AIRMOSS Touzi scattering phase



ALT=37cm



ALT=47cm



Historic air photo (approximately 2009)

AIRMOS_20170818_phis1

AIRMOS_201818_HH-VV phase

ALT=55cm



Resources

Ressources naturelles

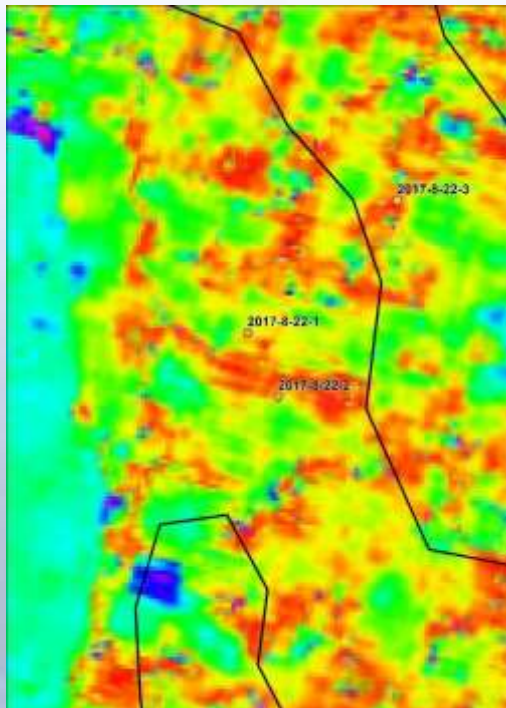
23

Canada

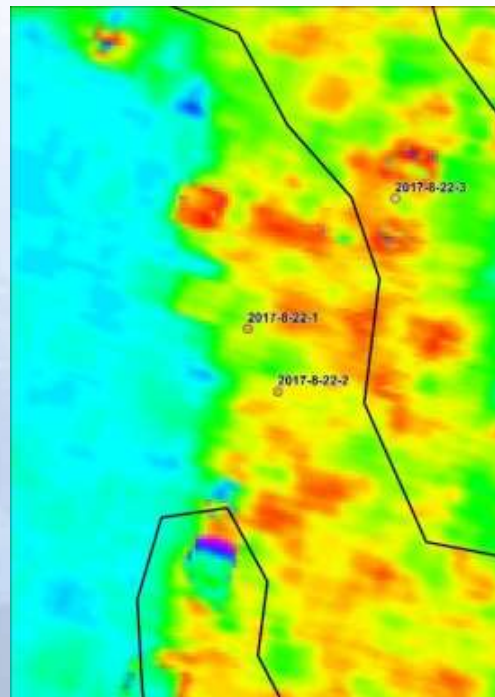
R. Touzi, ALOS2-PI Workshop, Tokyo, 24 Jan. 2018

Canada

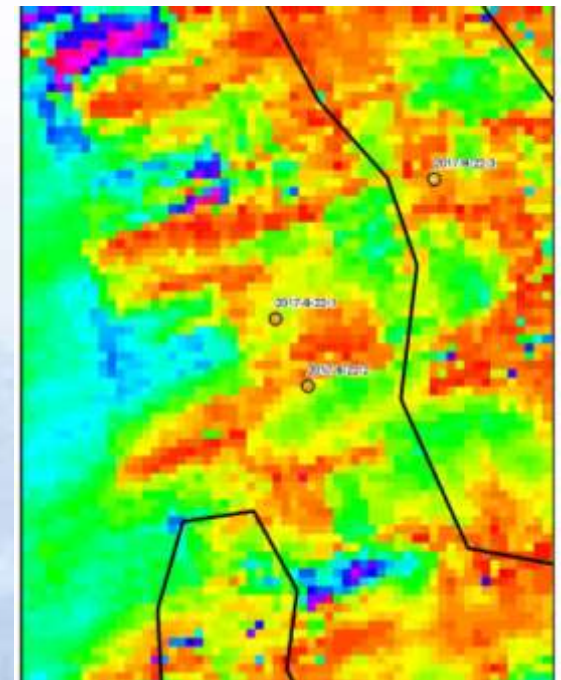
L-band ALOS2 versus L-band UAVSA and P-band AIRMOSS



UAVSAR_20190916_phis2o



AIRMOSS_20170818_phis1



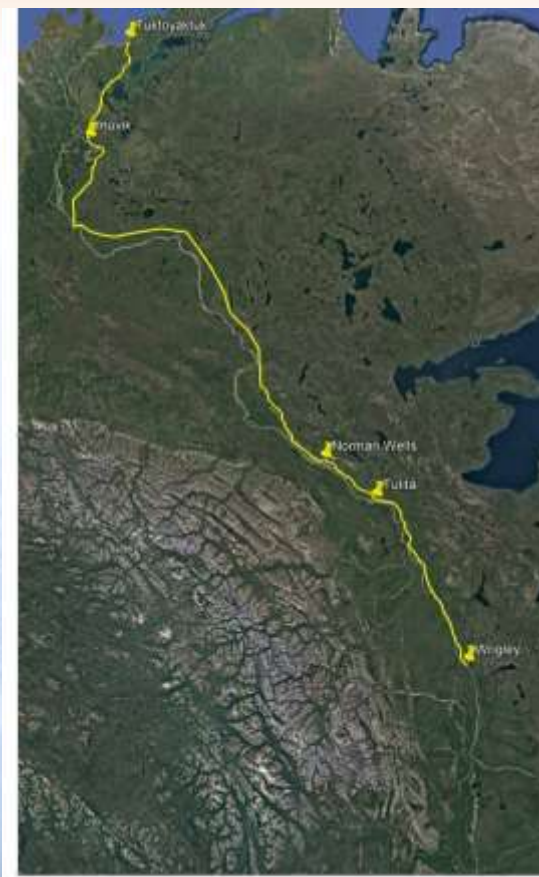
20180816_phis2o

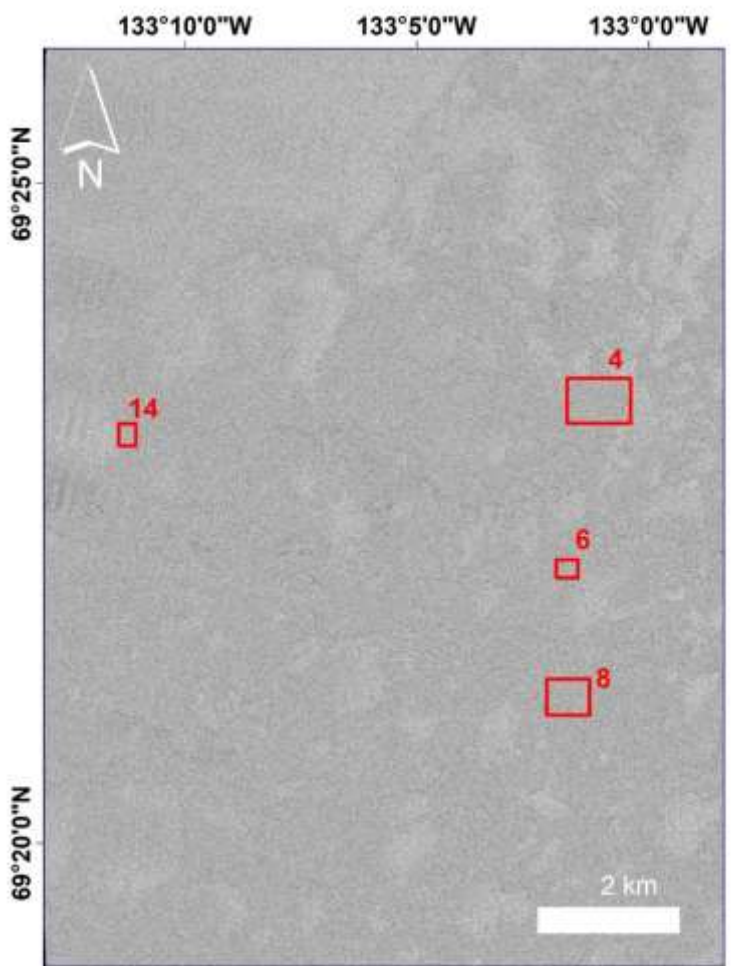


Conclusions

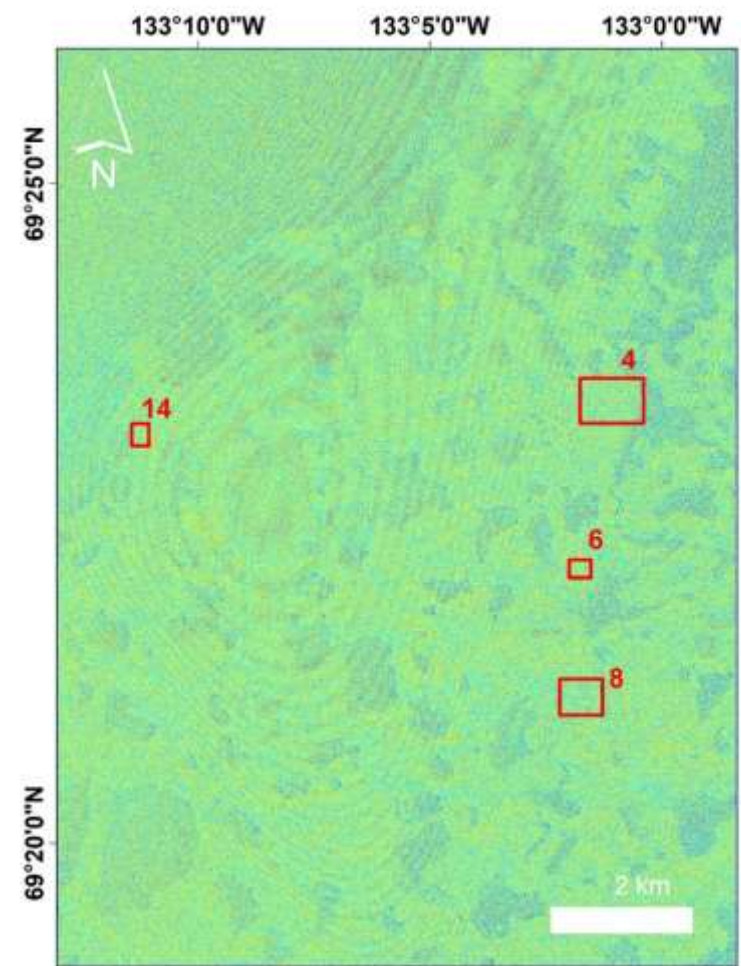


- ➡ Long penetrating L-band ALOS2 very promising for permafrost mapping (ALT).
- ✳ Recalibration of ALOS2 FP6-4 => fully exploit Excellent ALOS2 NESZ (-38dB)
- ✳ L-band **long** penetration (but **limited**) => **Deeper** permafrost not **detected**
 - ➡ More frequent acquisitions : SAR acquisition at half ALT melting => mapping all discontinues permafrost
 - ⇒ P-band longer penetration => Validation with P-band AIRMOSS => Less demanding than L-band NESZ
- ⇒ Polarimetric P-band AIRMOSS looks to be very promising for discontinues subsurface permafrost mapping and monitoring in subarctic regions => infrastructure stability
- ➡ Very promising for the Dempster –Wrigly-Highway
- ➡ Is AIRMOSS well calibrated with very low residual error?? What about UAVSAR??



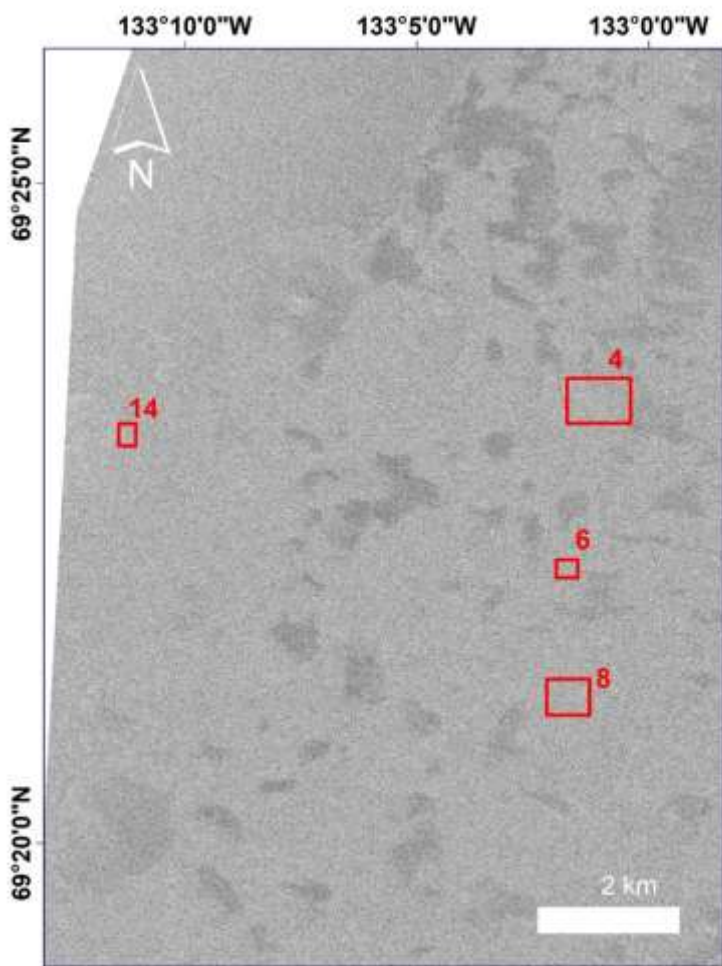


UAVSAR_20170620_Gamma_HH&HV

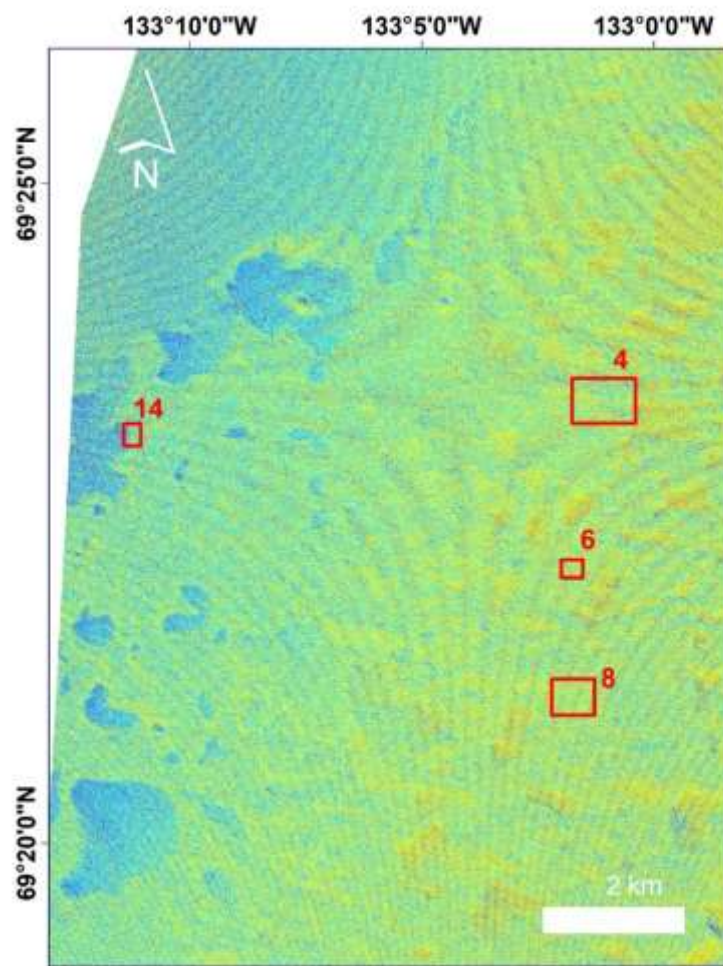


UAVSAR_20170620_Phase_HH&HV





AIRMOSS_20170818_Gamma_VV&HV



AIRMOSS_20170818_Phase_VV&HV

