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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(UCS)

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 Descriminators (**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).

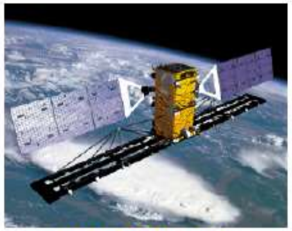
  - ➢ The active layer is important to many biogeochemical cycles and processes

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"

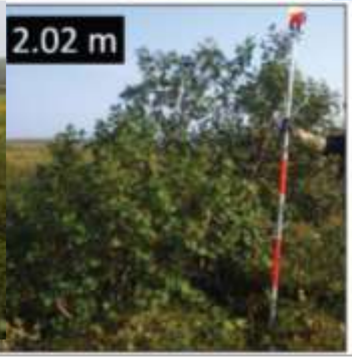
http://above.nasa.gov/cgi-bin/above/inv_pgp.pl?pgid=3573

- 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)

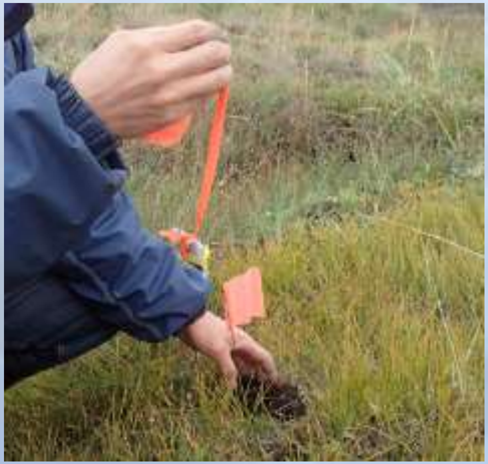


RADARSAR-II

L-band ALOS2

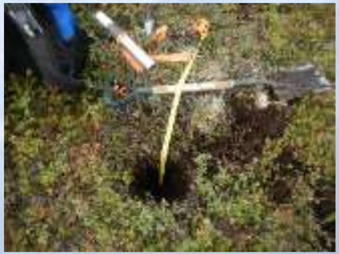


Field data collection

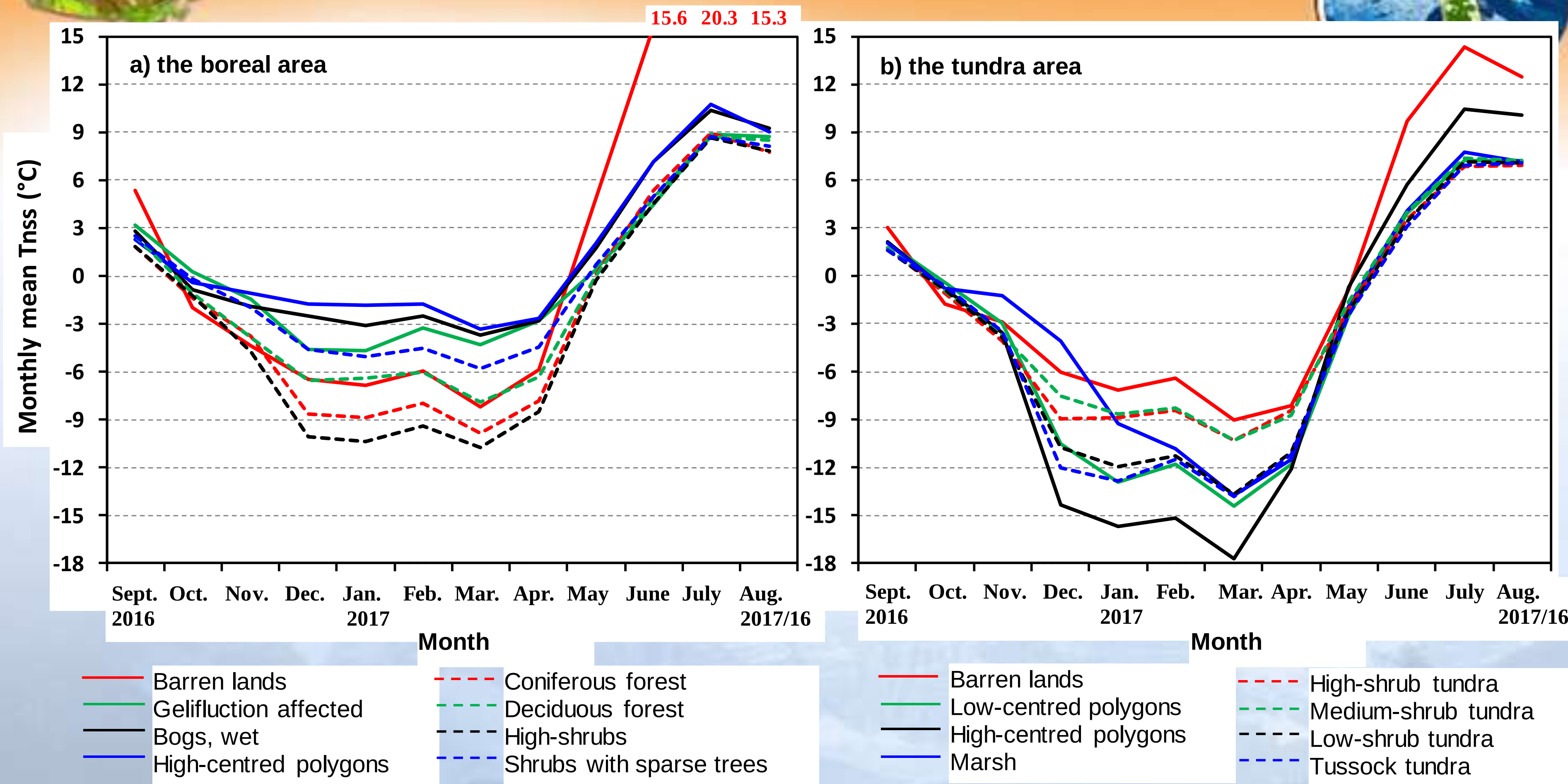


Measuring near-surface soil temperature (Tnss)

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 Peatland Characterization

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

IEEE TGRS 2007

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

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

CJRS 2007

Can. J. Remote Sensing, Vol. 33, Suppl. 1, pp. S56–S67, 2007

Wetland characterization using polarimetric RADARSAT-2 capability

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

IEEE JSTAR 2018

Scattered and Received Wave Polarization Optimization for Enhanced Peatland Classification and Fire Damage Assessment Using Polarimetric PALSAR

Ridha Touzi, *Fellow, IEEE*, K. Omari, Bob Sleep, and X. Jiao

IEEE TGRS 2009

Target Scattering Decomposition in Terms of Roll-Invariant Target Parameters

Ridha Touzi, *Member, IEEE*

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:

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

☛ A **complex** entity (α_s, $\Phi_{\alpha s}$) for **unambiguous** description of target scattering

☛ **Helicity** (τ) ➩ Local **asymmetry** ➡ Forest structure

➢ 11 scattering parameters for an **unambiguou**s description of target scattering

$$(\eta_1, \alpha_{s1}, \Phi_{\alpha_s 1}, \tau_1, \eta_2, \alpha_{s2}, \Phi_{\alpha_s 2}, \tau_2, \eta_3, \alpha_{s3}, \tau_3)$$

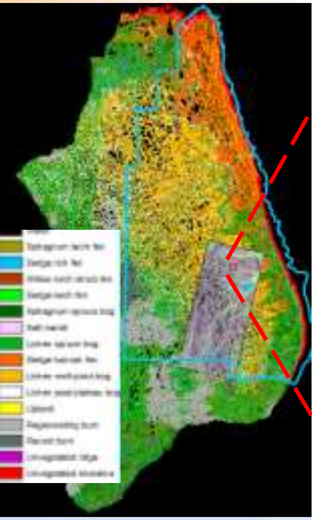
➩ 9 independent parameters using eigenvector **orthogonality**

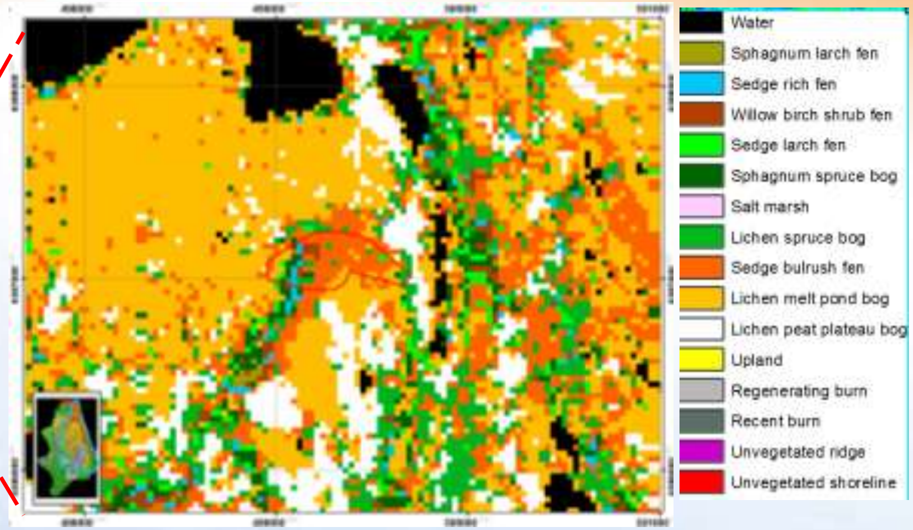
$$(\eta_1, \alpha_{s1}, \Phi_{\alpha_s 1}, \tau_1, \eta_2, \tau_2, \eta_3, \alpha_{s3}, \tau_3)$$

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

Jun 8: Active layer 13 cm

Jul 24: Active layer 27 cm

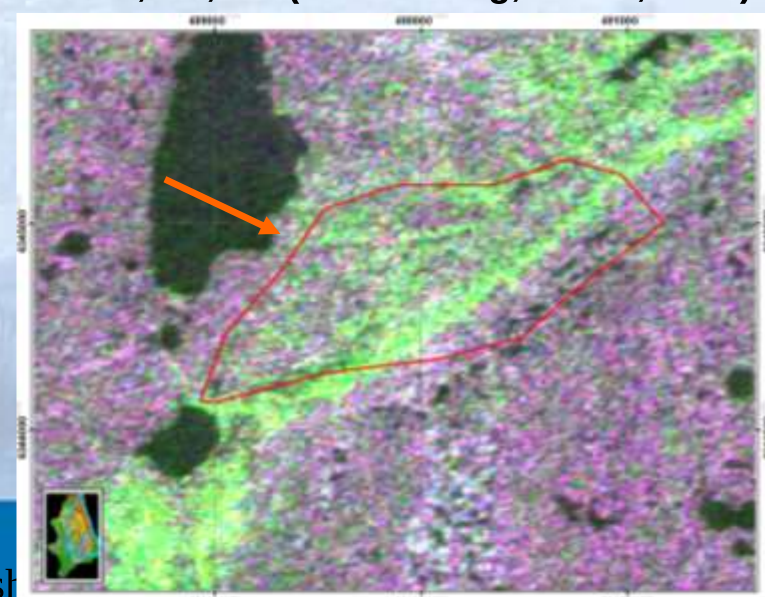




Sedge bulrush Fen

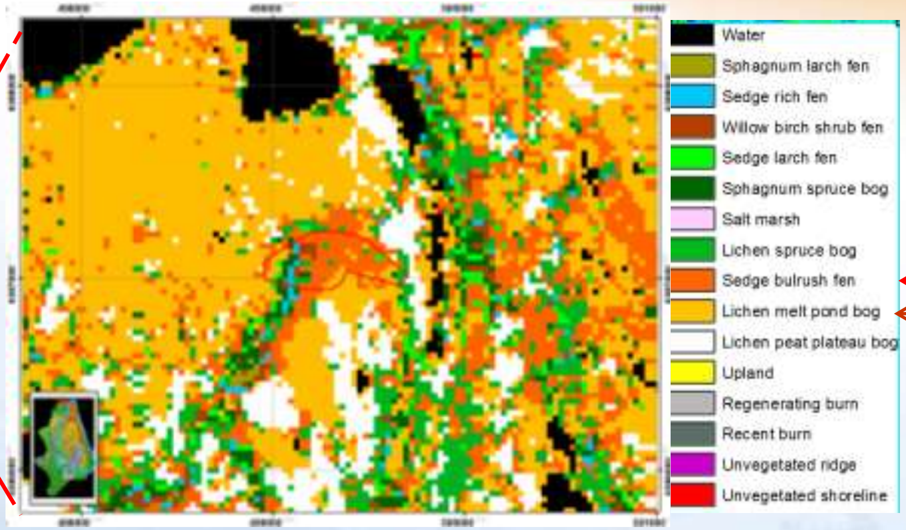
ALOS HH, HV, VV (Descending, Jun 8, 2010)

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



Site 1

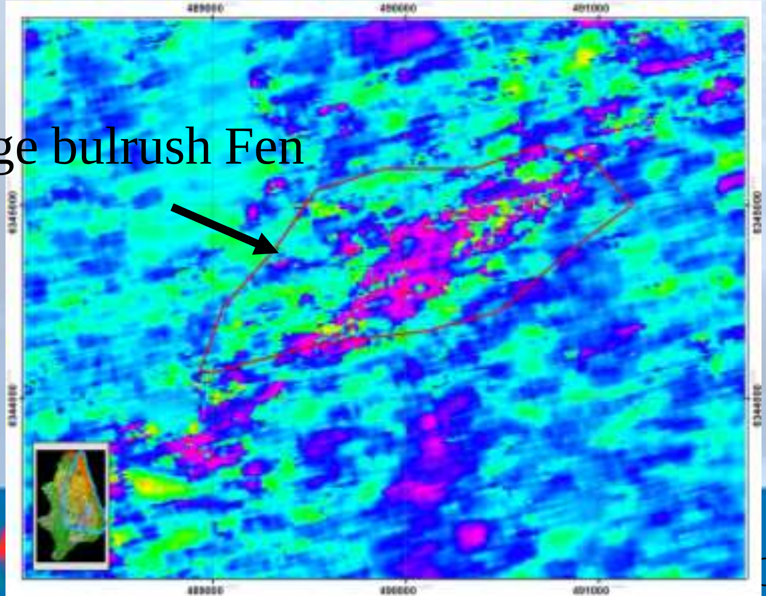
☛ Touzi scattering Phase Detects Subsurface Water Flow Change
☛ **Low** HV => **excellen**t ALOS **NESZ (-34 dB)** => ALOS2 **(-38dB)**



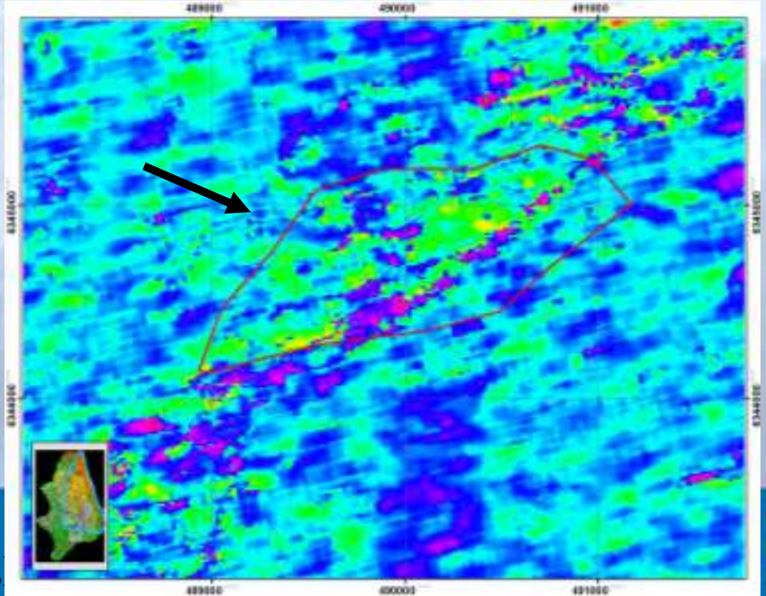
Sedge bulrush Fen

June 8, 2010: Active layer 13 cm

Sedge bulrush Fen



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

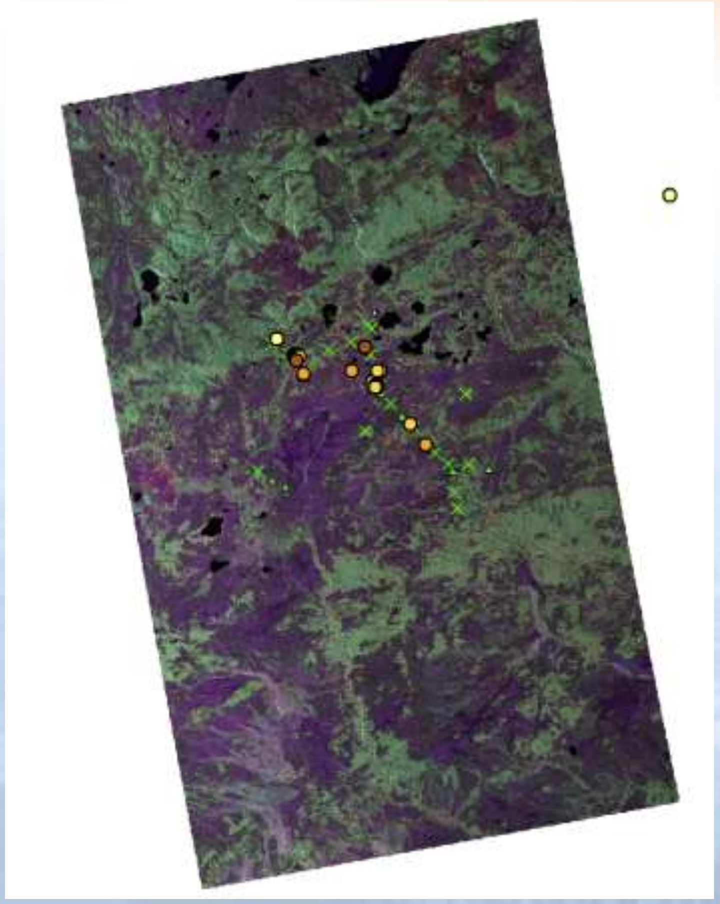
- Active layer thickness (20cm)

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

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



Depth to permafrost

permafrost sites

Depth to permafrost (m)

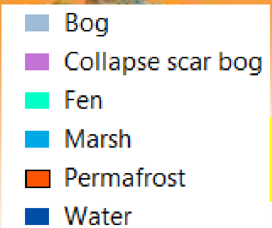
- 0.15 - 0.30
- 0.31 - 0.50
- 0.51 - 0.85
- 0.86 - 1.20
- 1.21 - 1.80

no permafrost sites

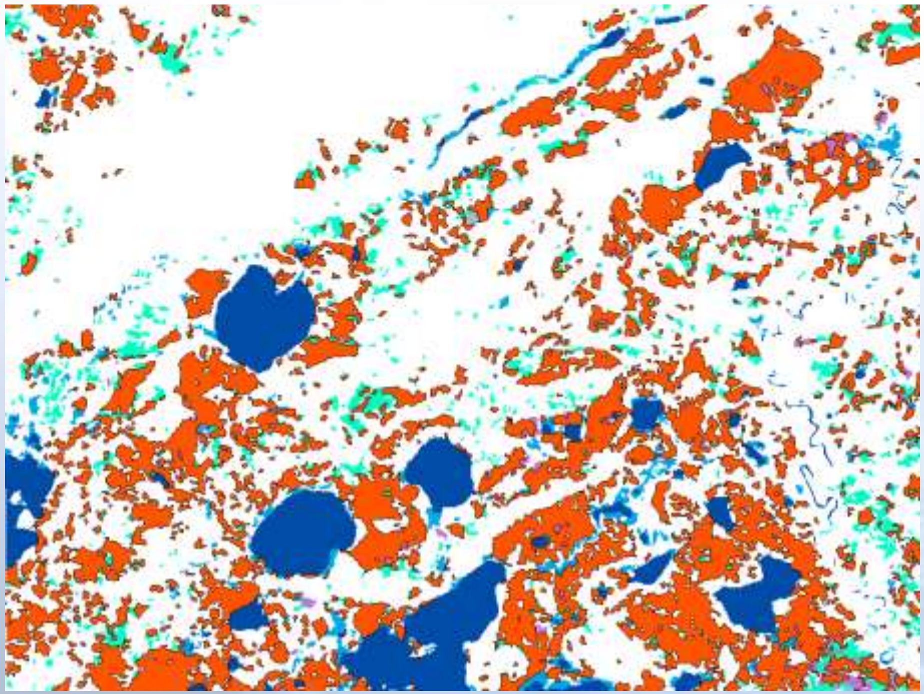
- Bog
- Burrow pit
- collapse scar
- fen
- forest
- swamp
- upland

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

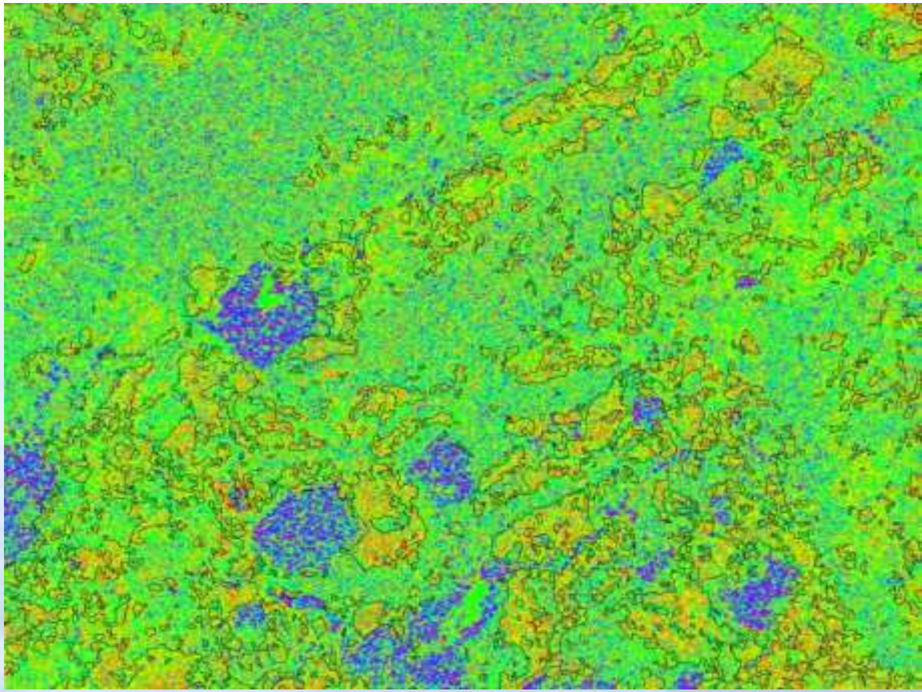
Lidar & Landsat (S. Pawley AGS) versus PLR ALOS2



Touzi Decomposition => discontinuous permafrost mapping



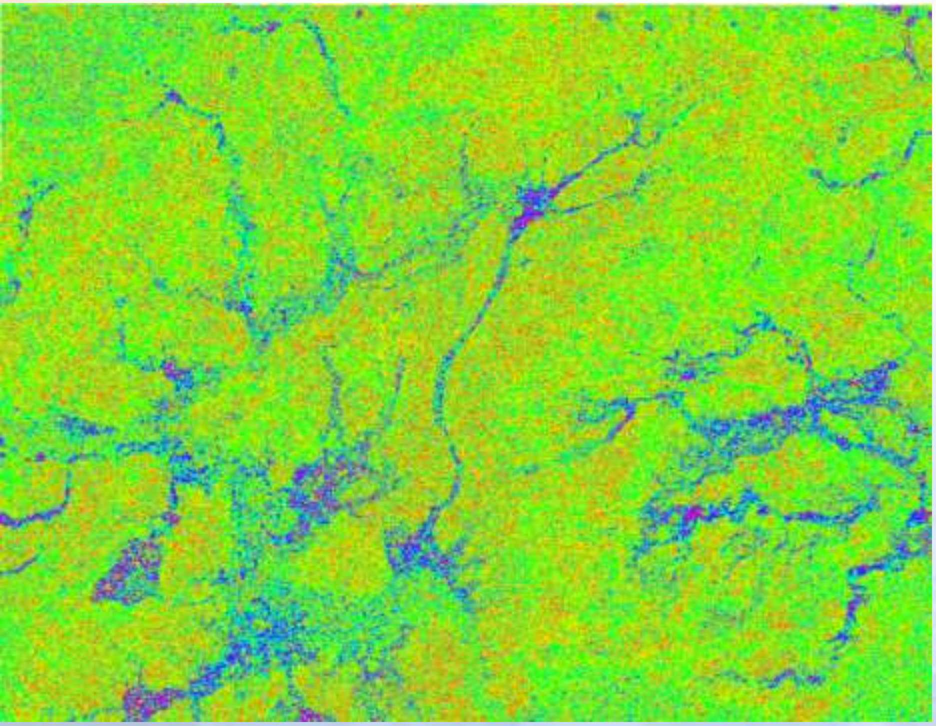
AGC classification

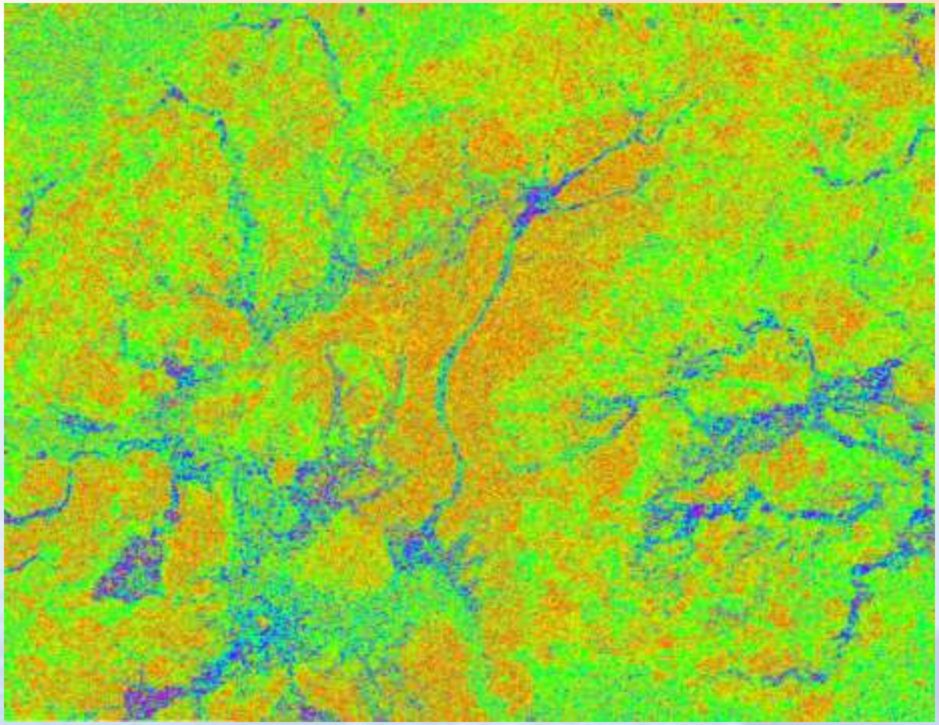


Touzi Phase

- 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

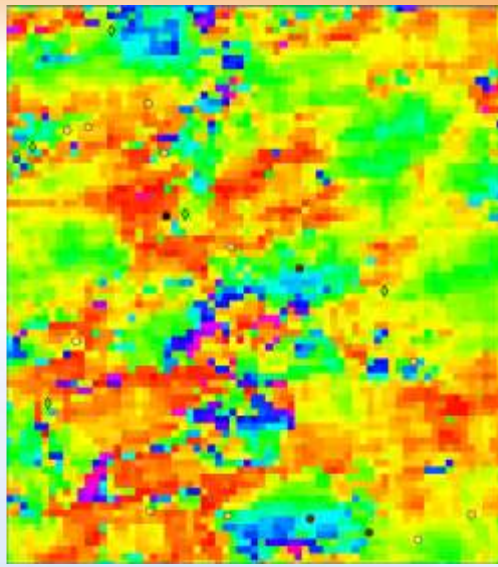
ALOS2 re-calibrated for the Distortion Matrix + Faraday Rotation permafrost

- Lidar&Optic EO classification Not accurate
- Touzi Decomposition ϕ_{s2} : Orange (70°) => subsurface permafrost

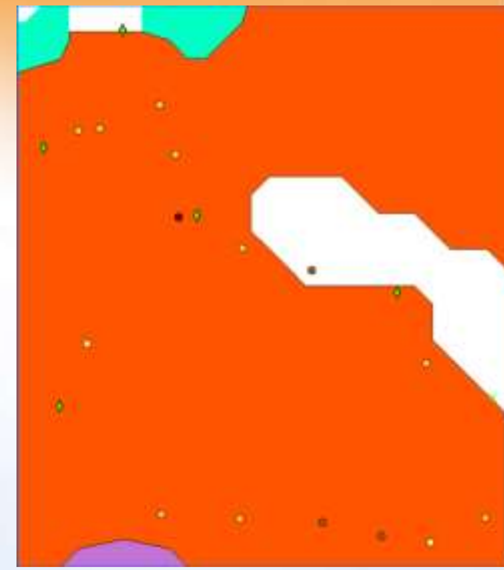
⇨ Permafrost detected (up to 50 cm depth)

- L-band penetration but limited => Deeper permafrost not detected

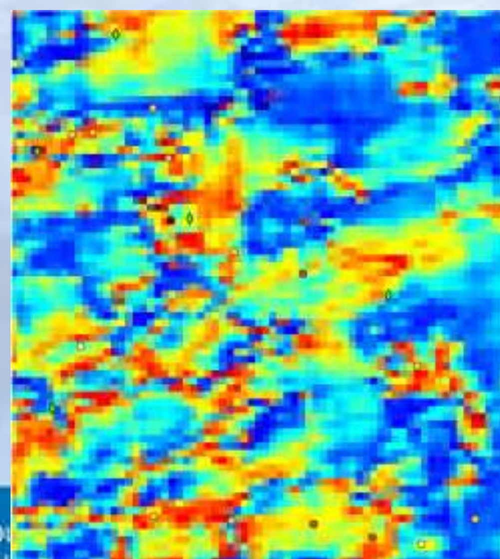
Touzi scattering Phase ϕ_{s2}



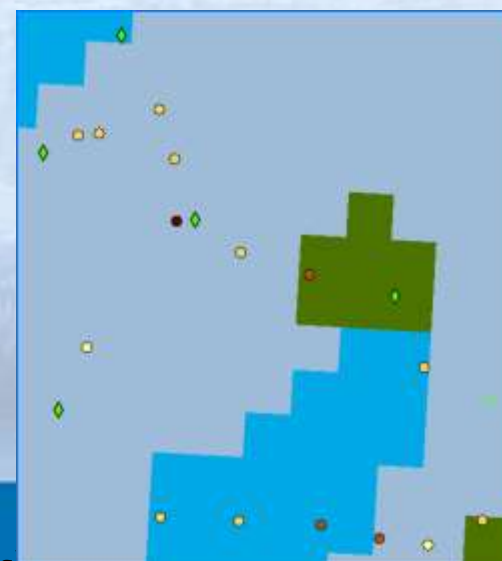
AGS Classification



Scattering magnitude $\alpha s2$



AGCC Classification



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)**

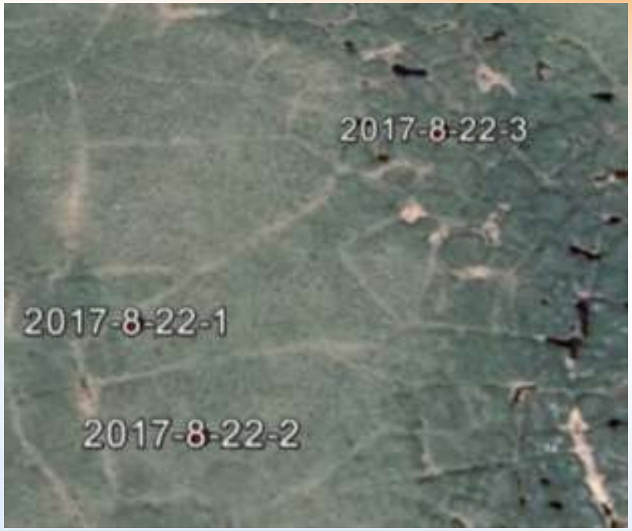
Polarimetric C-, L- and P-band SAR data

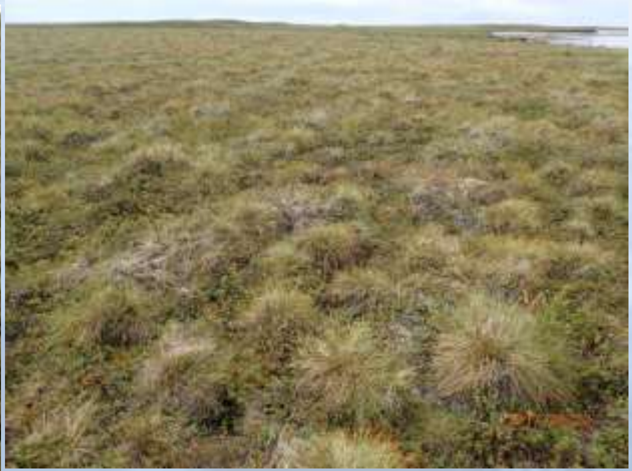
- Multi-temporal series of PALSAR2 PLR collected.
- Radarsat2 data collected (CSA & MDA)
- P-Band AIRMOSS and L-band UAVSAR data collected under ABoVE
- Intense field data collection during the 2017 summer campaign

HH/HV/VV
Aug. 18, 2016

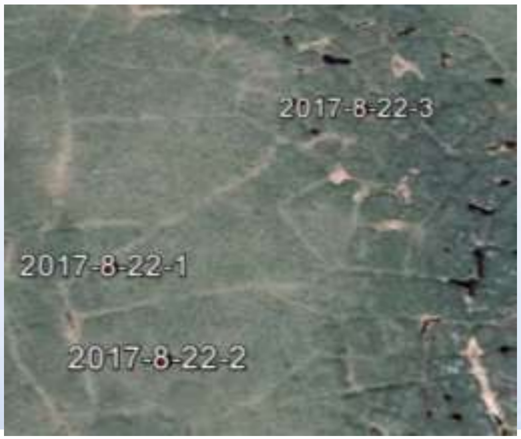
Site 14

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

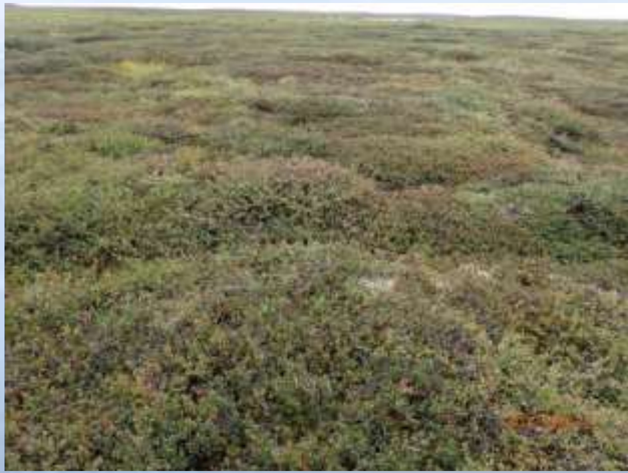




2017-8-22-2
(thaw depth:0.47m)



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

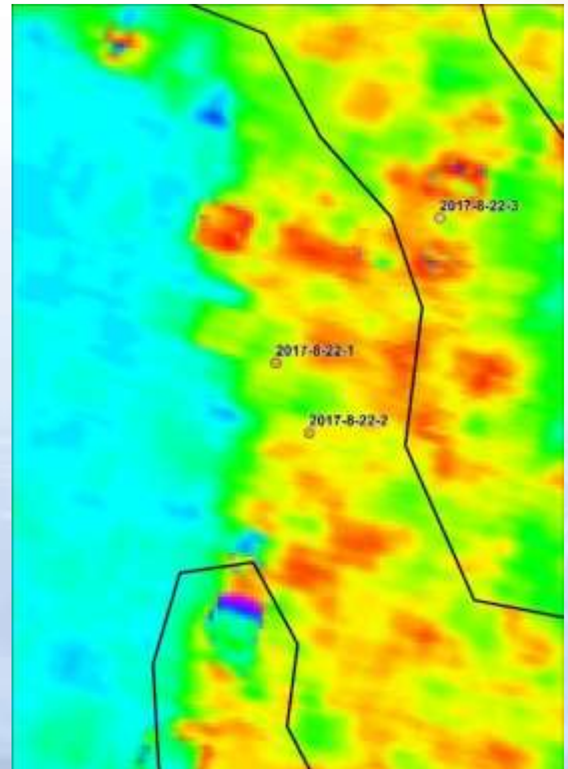


P-band AIRMOSS Touzi scattering phase

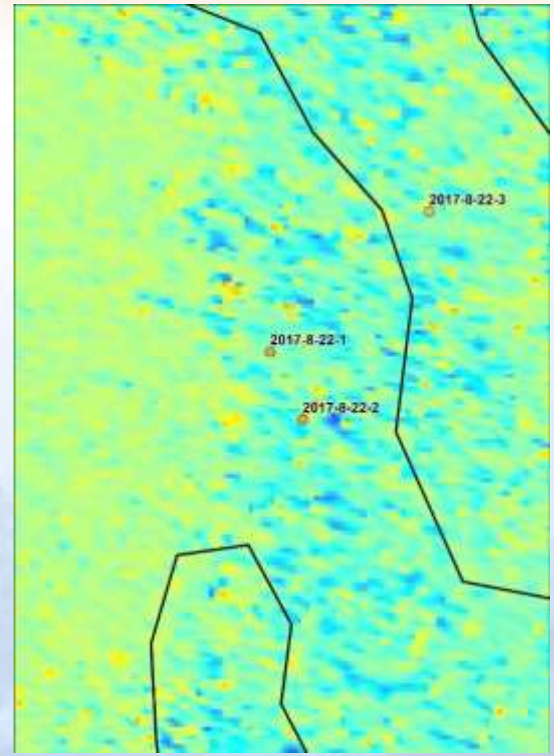
ALT=37cm

ALT=47cm

Historic air photo (approximately 2009)



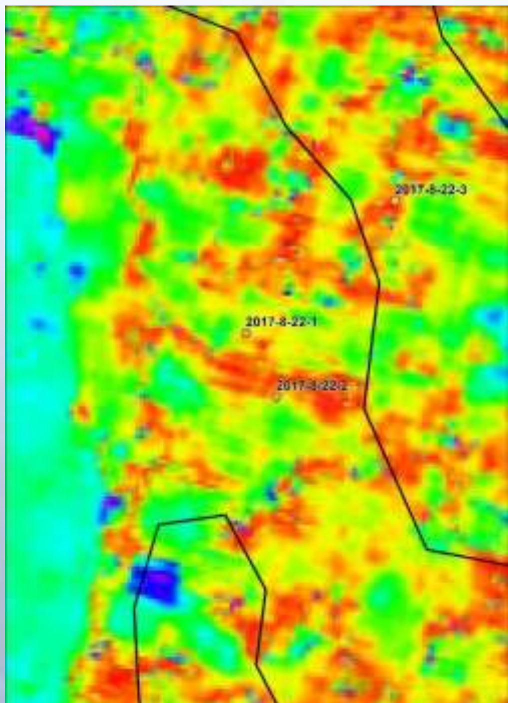
AIRMOSS_20170818_phis1



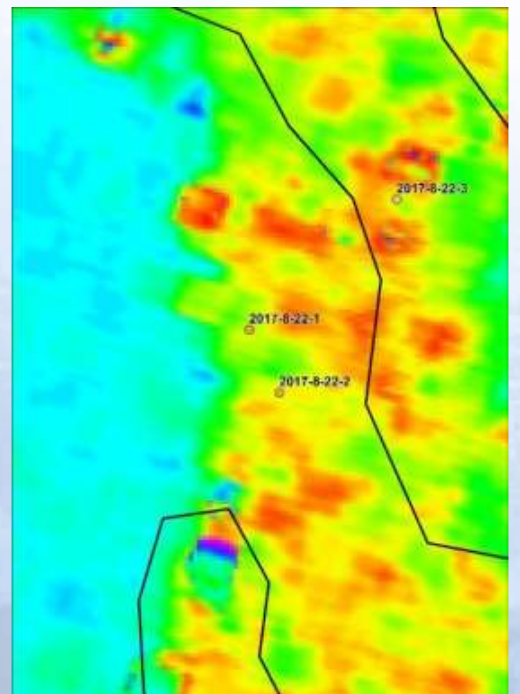
AIRMOSS_201818_HH-VV phase

ALT=55cm

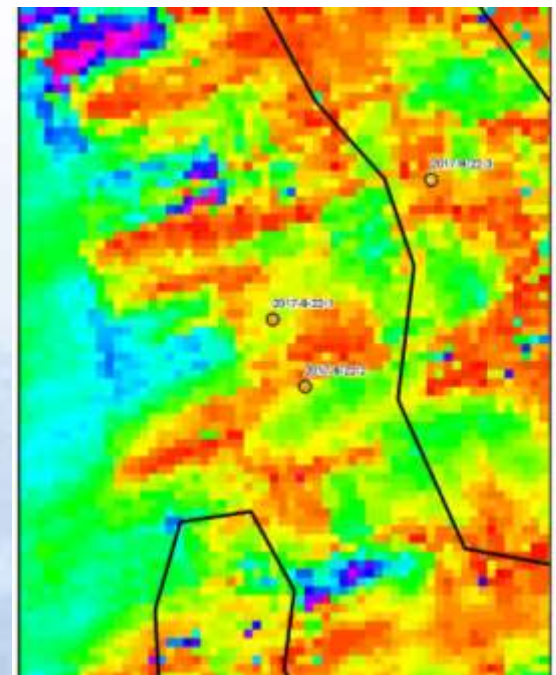
L-band ALOS2 versus L-band UAVSA and P-band AIRMOSS



UAVSAR_20190916_phis2o



AIRMOSS_20170818_phis1

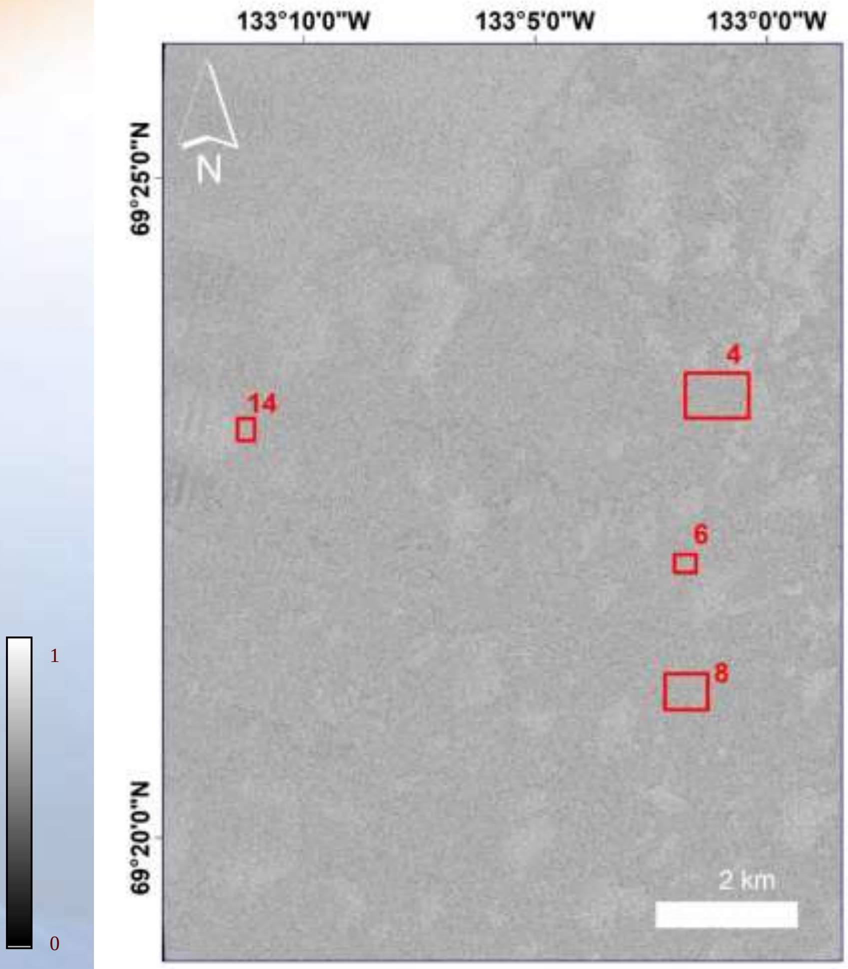


20180816_phis2o

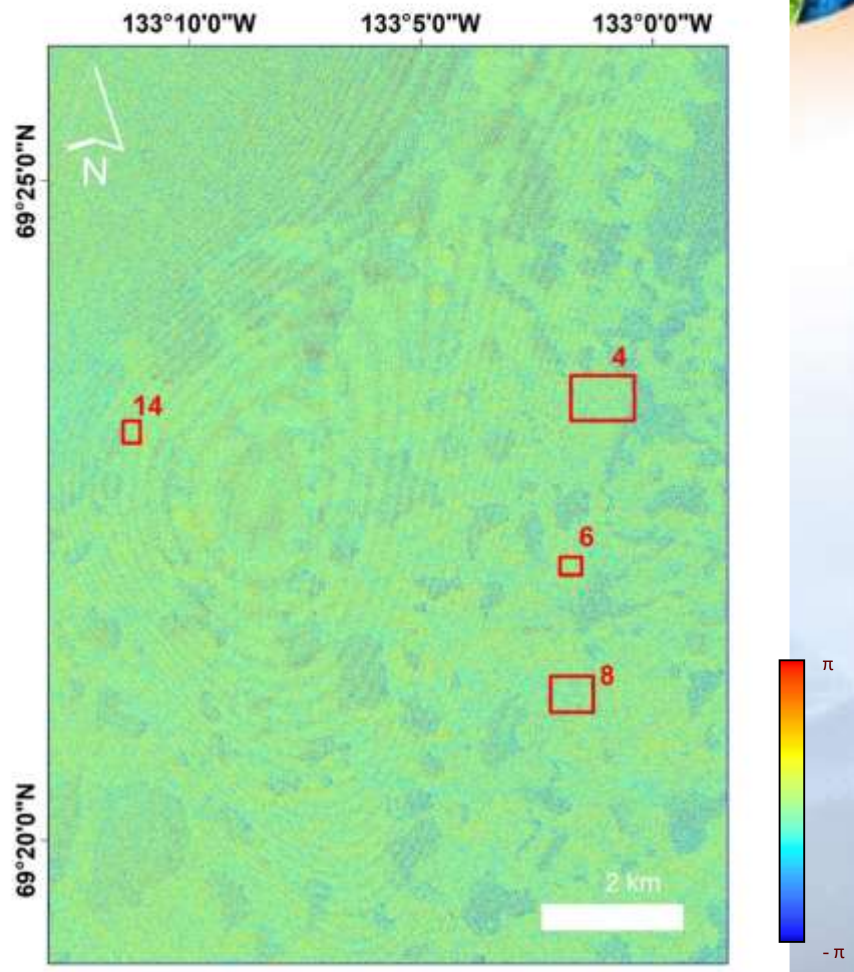
Conclusions

- 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??

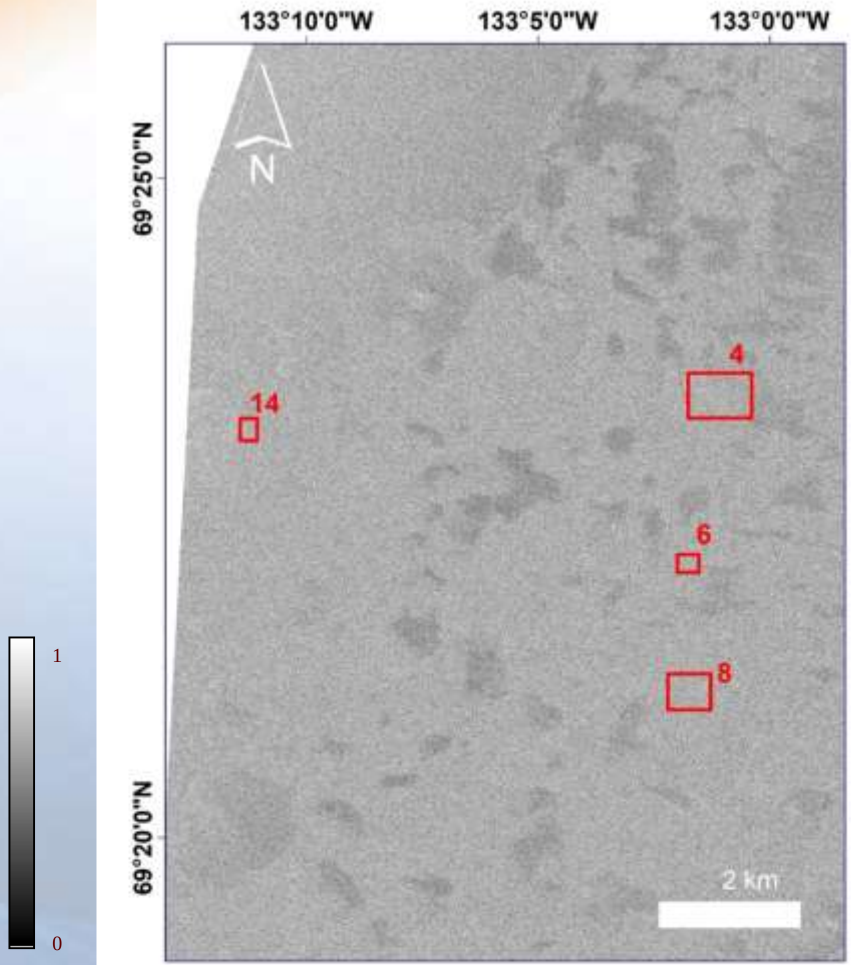
Canada



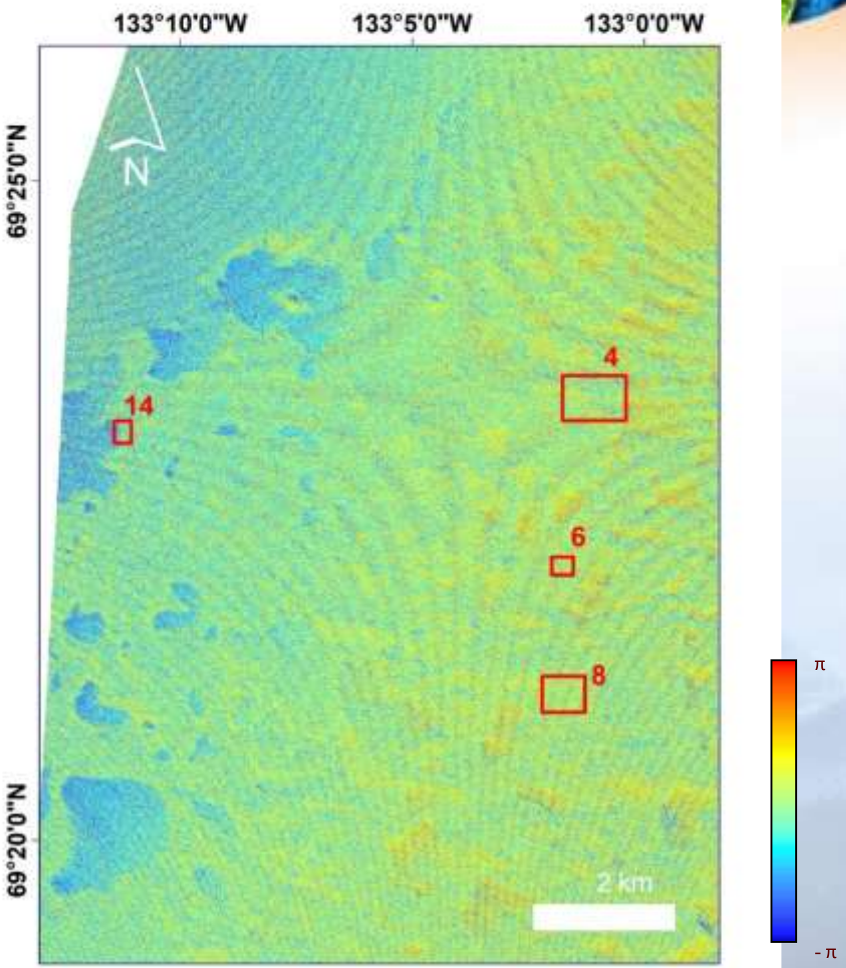
UAVSAR_20170620_Gamma_HH&HV



UAVSAR_20170620_Phase_HH&HV



AIRMOSS_20170818_Gamma_VV&HV



AIRMOSS_20170818_Phase_VV&HV