Investigation of the added value of L- and P-band Polarimetric UAVSAR and AIRMOSS for the assessment of climate change impact on Arctic and Boreal Ecosystem

Ridha Touzi, Yu Zhang, Rob Fraser, and W. Chen

Canada Centre for Remote Sensing, CCMEO

Natural Resources Canada
Ressources naturelles Canada

Canada

ABoVE Airborne Campaign
Polarimetric UAVSAR & AIRMOSS

☛ L-band UAVSAR with reference to ALOS2

L-band ALOS2

- Higher resolution (1m versus 6m)
- Better NESZ (-48 dB versus -38dB)

➪ Better exploitation of HV for optimum polarimetric target scattering scattering characterization

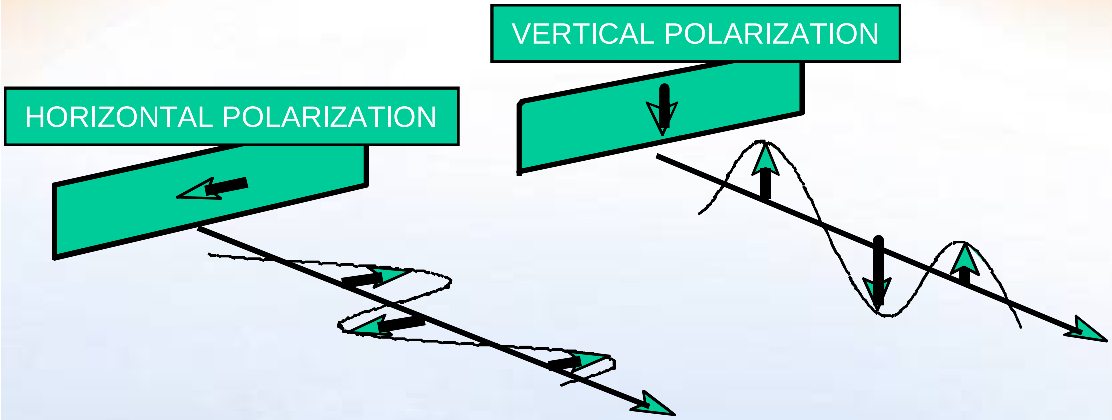
☛ P-band AIRMOSS

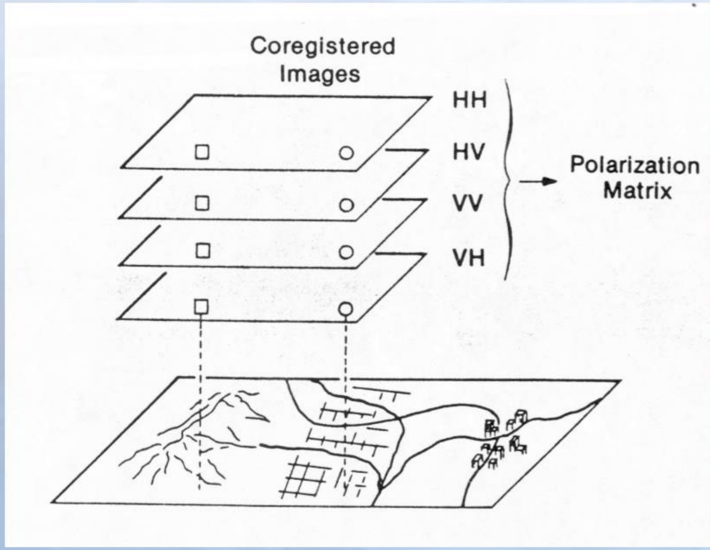
- ➢ Longer penetration with reference to L-band
- ➢ Excellent NESZ (-46 dB)
- ➢ **Well calibrated** => **pure** HV (Xtalk =-26dB)

➪ Upcoming PLR missions: L-band NISAR (3m resolution 120km swath) and BIOMASS (ESA)

ESA BIOMASS

What is a Polarimetric SAR?
Exp: Convair-580 SAR (1988)



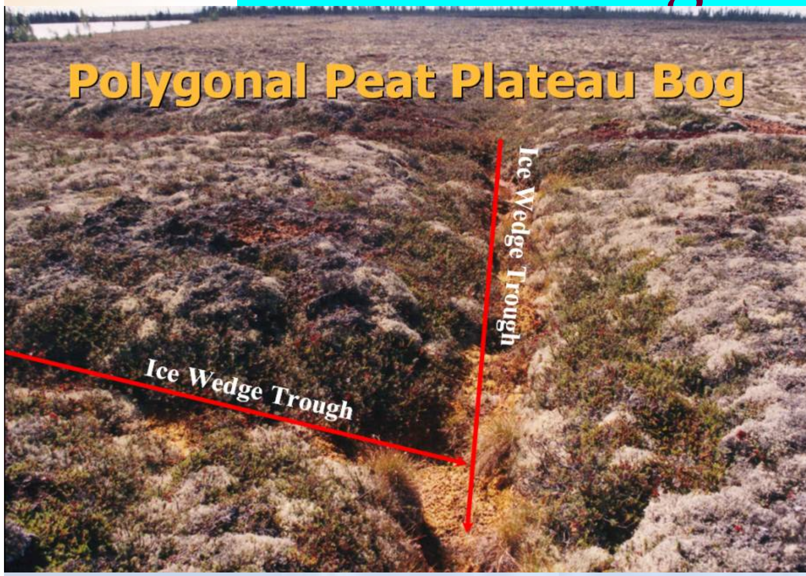


Polarization Synthesis

σ°_{TR}

☛ Peatland Under Threat (Merrit ☺)

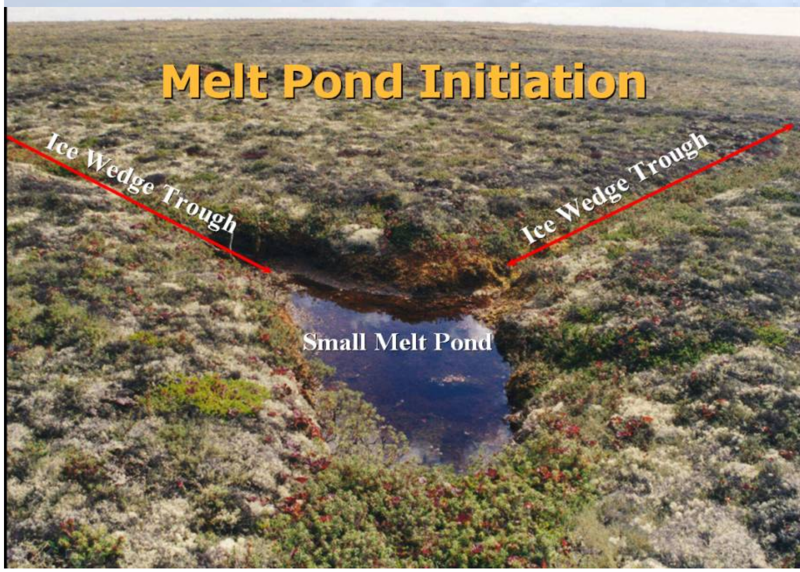
✷ WAPUSK One of the Largest Known Polar Bear Denning Areas in the World



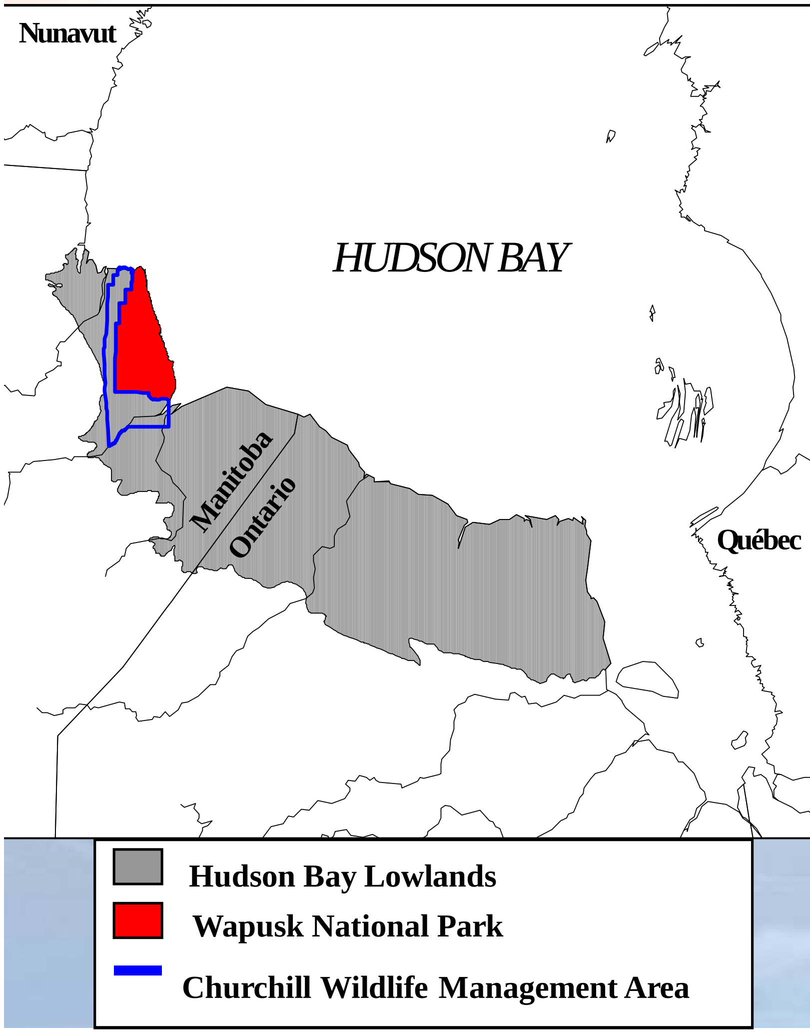
Climate Change effect:

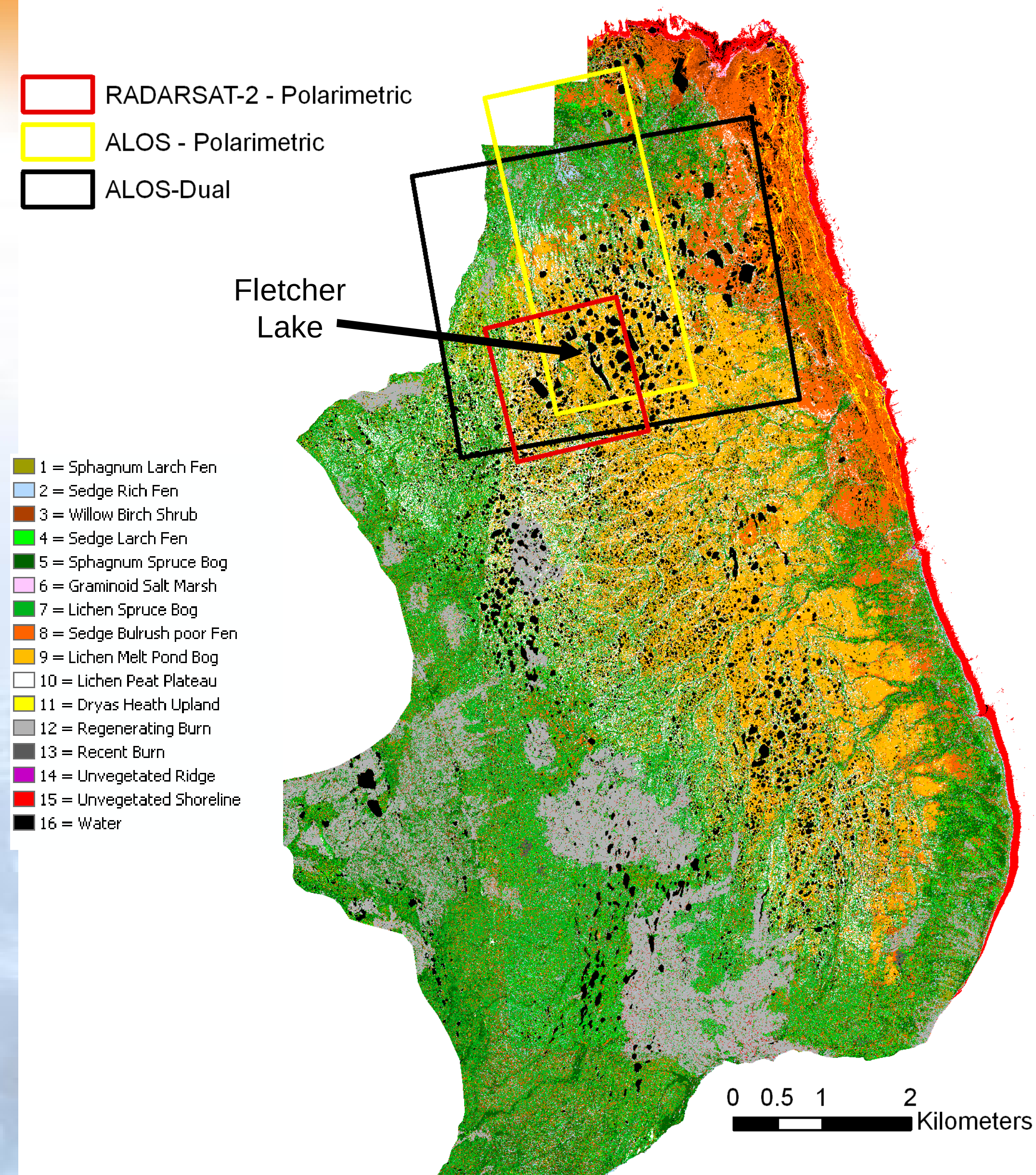
- ☛ Bogs transformed to Fen
- ➪ Affect polar bear denning habitat which is entirely within bogs with thick peat deposits
- ➪ Polar Bear under threat

☛ ALOS => peatland monitoring



Wapusk National Park RADARSAT-2 and ALOS Acquisitions





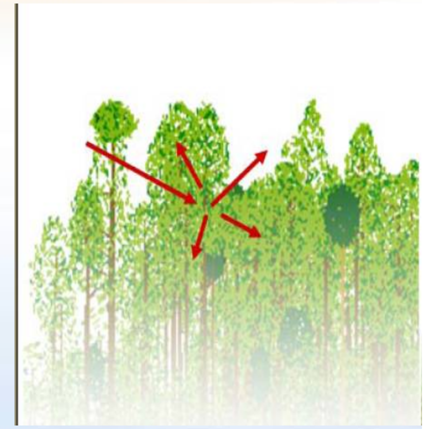
Ryan Brook's Classification
(Landsat-TM5, July, 27th, 1996)

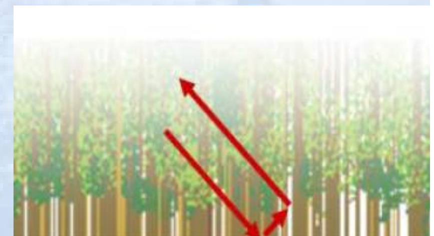
RADARSAT2

Why Polarimetric SAR for Peatland monitoring?

ALOS / PALSAR
JAXA / JAROS (J)

- **Bog-** (**Poor**)**-Fen classification** and **monitoring** not accurate with conventional Optic and SAR Sensors
- Polarimetric SAR ➪ Scattering mechanisms and target **structure**
- **Polarimetric C-** RADARSAT-2 (5cm):
  - Enhanced vegetation species discrimination
  - Enhanced wetland (surface) hydrology monitoring
- **Polarimetric** L-ALOS: large **penetration** (23cm)
  - **Peatland subsurface water flow monitoring**
  - ➪ **Bog-fen discrimination & transformation monitoring**
  - ➪ **Validated over Boreal & Subarctic peatlands**
- **Polarimetric** P-AIRMOSS: Deeper **penetration**





Touzi Decomposition for Peatland Classification: ESA => Best promotion of Polarimetric SAR ☺

- Honours by ESA: Best Promotion of polarimetric SAR (PolinSAR2009)
- Invited to contribute to ESA Book: "Principles and Applications of Pol-InSAR"

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European Space Agency

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19-Mar-2009

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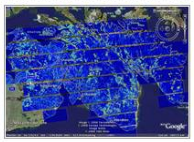


Biomass map of Scotland

New satellite techniques for looking at climate change

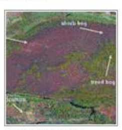
30 January 2009
More than 200 scientists from around the world have attended the weeklong POLinSAR 2009 workshop hosted at ESRIN, ESA's Earth Observation centre in Frascati, Italy. Discussions among the participants include new techniques for providing vital information on our planet that could help to combat global warming through carbon accounting, wetland preservation and improve climate models.

Using the novel polarimetric mode of the PALSAR synthetic aperture radar (SAR) aboard Japan's ALOS satellite, Dr Shane Cloude of the UK-based AEL Consultants has mapped the biomass of Scotland's forests. This marks the first time biomass data has been extracted over a large area using this sensor mode.

Forests are one of the most significant onshore stores of carbon, absorbing carbon dioxide that would otherwise increase global warming. Mapping biomass – a quantitative estimate of the organic material in a forest – is important because it allows scientists to determine the forest's capacity to store carbon.

This information will assist politicians and non-governmental organisations in planning strategies for combating global warming through international monitoring and carbon sequestering.

"Carbon trading is upon us, which means there is going to be a value to carbon and countries will be able to offset their emissions against carbon which is stored in their forests, for example," Cloude explained. "There is going to be a need for a third party to assess or validate the estimates given by countries as well to monitor any changes in them such as deforestation or degradation."

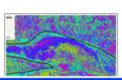


Water detection with radar

"Since one of the important variables for predicting climate change is to know what the balance between carbon sinks and sources will be, this kind of information can be fed directly into models to help improve predictions of climate change," he said.

Cloude used the polarimetric mode with ALOS radar data from April to June 2007 to produce the biomass map, which he will update this year. ESA is supporting ALOS as a 'Third Party Mission'. This means ESA uses its multi-mission European ground infrastructure and expertise to acquire, process and distribute data from the satellite to its wide scientific user community.

Cloude's findings are now undergoing validation by being compared with data from Forest Research, Great Britain's governmental department responsible for the protection and expansion of forests.



Another Earth Observation satellite in orbit equipped with the polarimetric mode is Canada's Radarsat-2.

Dr Ridha Touzi, a Senior Research Scientist at

Related news
- ESA POLinSAR 2007: Imaging forests in 3-D
- Experimental radar provides 3-D forest view
- Widening Envisat's InSAR...

R. Touzi, G. Gosselin, and R. Brook. Polarimetric L-band SAR for peatland mapping and monitoring , ***ESA Book, Springer,*** open-access, 2016

Spec. issue Wetland Inventory CJRS 07

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

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

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PRESS RELEASE
- FOR IMMEDIATE RELEASE -

PCI Geomatics Announces New Upgrade to its Geomatica Software Including its Advanced SAR Polarimetry Workstation

Richmond Hill, Ontario – July 8, 2009: PCI Geomatics, a world leading developer of geo-imaging software and systems, today announced the availability of an upgrade to its remote sensing and image processing software. Geomatica® 10.2.1 is the latest version of the image-centric desktop software which provides users with additional satellite sensor support as well as new functionality for the SAR Polarimetric Workstation (SPW).

As an industry leader in supporting satellite sensors, PCI Geomatics has included in this release support for RapidEye – a constellation of five sun-synchronous Earth observation satellites which provide large area, multi-spectral images with frequent revisits in high resolution. Additional support for the high resolution X-band SAR imagery provided by TerraSAR-X is also included in this upgrade.

The SPW provides a complete set of tools and applications designed specifically for the processing and analysis of Polarimetric SAR (POLSAR) data, and version 2.1 is now available and compatible with Geomatica 10.2.1. This includes the Touzi Discriminators which make it easier to detect a particular target in a Polarimetric SAR image. The Touzi Decomposition introduces new parameters which remove certain ambiguities not previously understood and provide vastly superior results as compared to conventional algorithms. Additionally, the SPW now supports the following sensors: Radarsat-2, Cosmo Sky-Med and TerraSAR-X.

IEEE TGRS 09

IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING, VOL. 47, NO. 9, SEPTEMBER 2009

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 management and protection of these sensitive areas. Only a few studies have been published on wetland characterization using polarimetric synthetic aperture radars (SARs). The most successful results have been obtained using the phase difference between HH and VV polarizations, $\phi_{HH} - \phi_{VV}$, which has shown

I. Introduction

Radar polarimetry, which has been an active area of research for more than 50 years [2]–[6], has started a new era with the recent launch of polarimetric satellite synthetic aperture radars (SARs), namely, L-band ALOS-PALSAR [7], X-band TerraSAR [8], and most recently C-band

IEEE TGRS 07

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 maximum polarization parameters (orientation, helicity, and maximum return). The new scattering vector model served for the assessment of the Cloude–Pottier incoherent target decomposition. Whereas the Cloude–Pottier scattering type α and entropy H are roll invariant, β and the so-called target-phase parameters do depend on the target orientation angle for asymmetric scattering. The scattering vector model is then used as the basis for the development of new coherent and incoherent target decompositions in terms of unique and roll-invariant target parameters. It is shown that both the phase and magnitude of the symmetric scattering type should be used for an unambiguous description of symmetric target scattering. Target helicity is required for the assessment of the symmetry–asymmetry nature of target scattering. The symmetric scattering type phase is shown to be very promising for wetland classification in particular, using polarimetric Convair-580 synthetic aperture radar data collected over the Ramsar Mer Bleue wetland site to the east of Ottawa, ON, Canada.

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

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.
Φ_{α_s}	Symmetric scattering type phase.
ψ, τ_m, m	Kennaugh–Huynen maximum polarization parameters: orientation angle, helicity, and maximum amplitude.
$[T]$	Coherency matrix.
λ_1, λ_2, and λ_3	Coherency eigenvalues.
λ_1	Eigenvalue of the dominant scattering.
λ_2	Eigenvalue of the second scattering.
λ_3	Eigenvalue of the third scattering.
H	Cloude coherency entropy.
α_{sg} and τ_g	Symmetric scattering type magnitude and helicity of the global scattering, respectively.

I. Introduction

The OBJECTIVE of the incoherent target decomposition (ICTD) theory is to express the average scattering mechanism as the sum of independent elements in order to associate a physical mechanism with each component [1]–[4]. Target scattering decomposition permits the extraction of target characteristic information provided that the decomposition satisfies

Innovation
The Touzi 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**

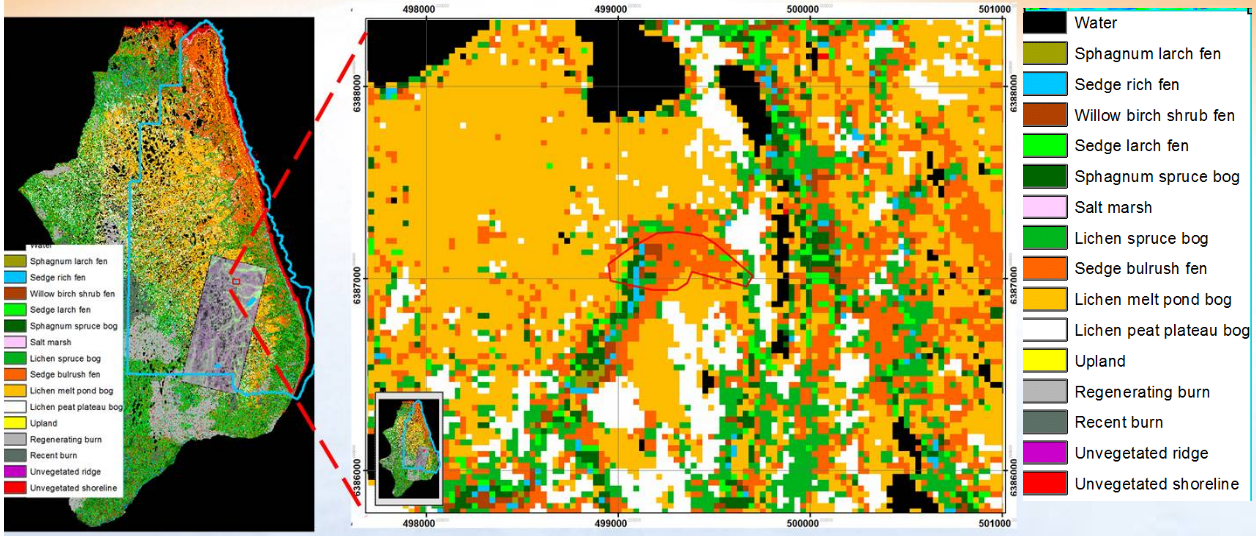
- ☛ Scattering type (**α_s, $\Phi_{\alpha s}$**)
- ☛**Helicity (τ)** ⇨ Local **asymmetry** ➡ **Forest structure**

Subsurface Water Flow Change

Sedge bulrush Fen & Litchen melt pond bog

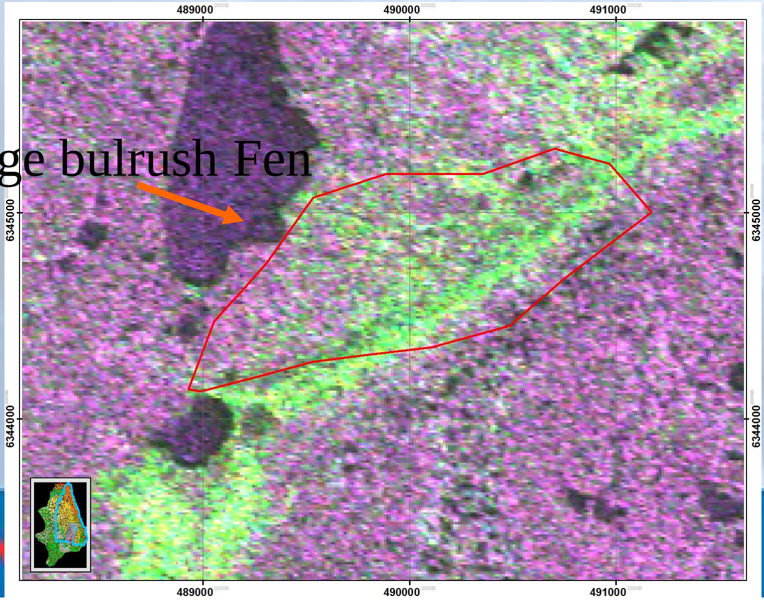
Jun 8: Active layer 13 cm

Jul 24: Active layer 27 cm

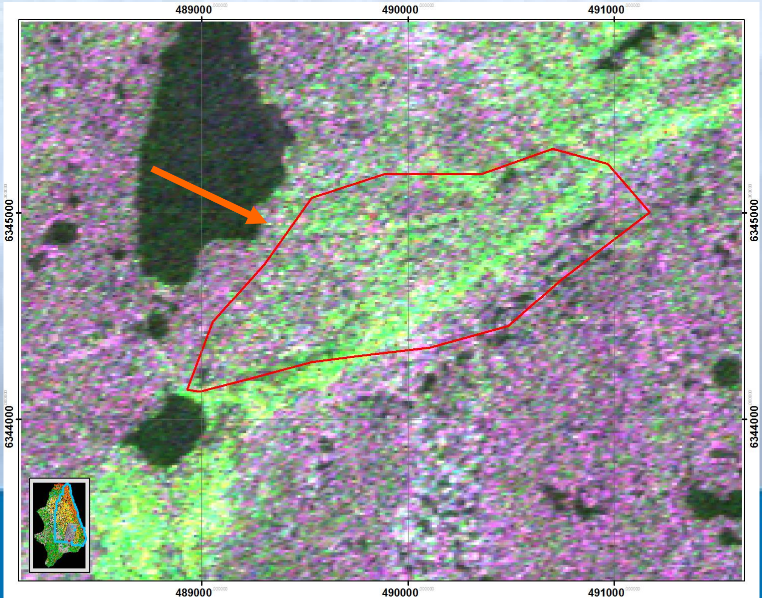


- ➢Active layer melting between June and July
- ➢Variations of fen subsurface flow
- ➢Not detected by HH, HV, VV

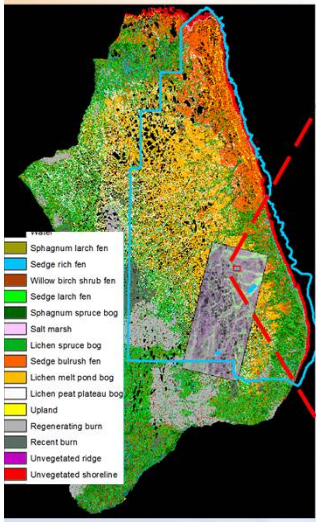
ALOS HH, HV, VV (Descending, Jun 8, 2010)

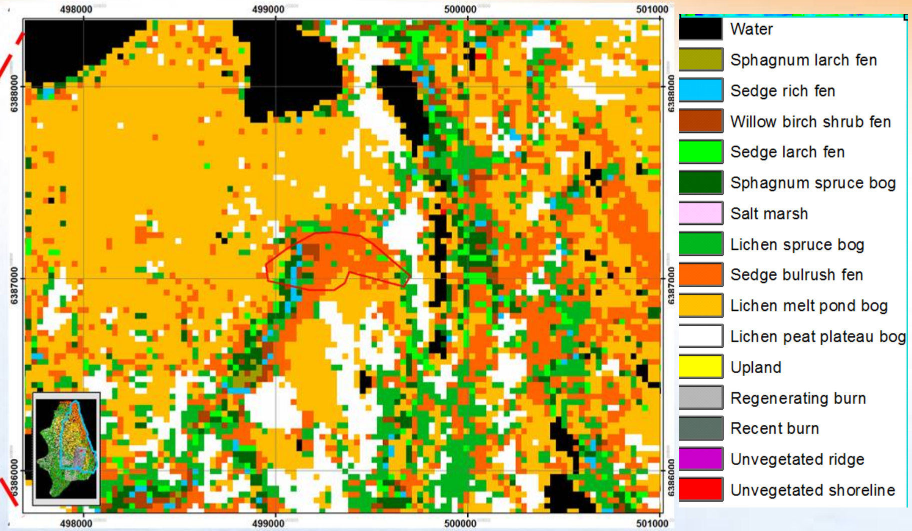


ALOS HH, HV, VV (Descending, Jul 24, 2010)



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

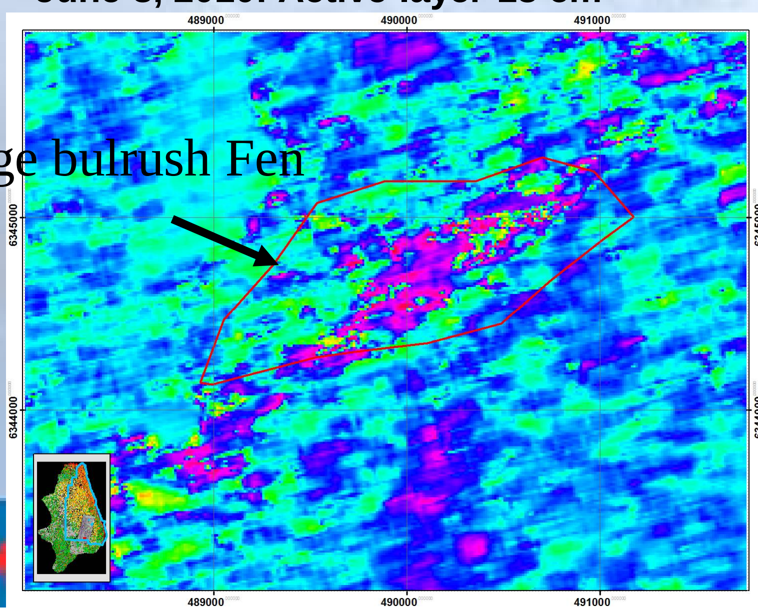




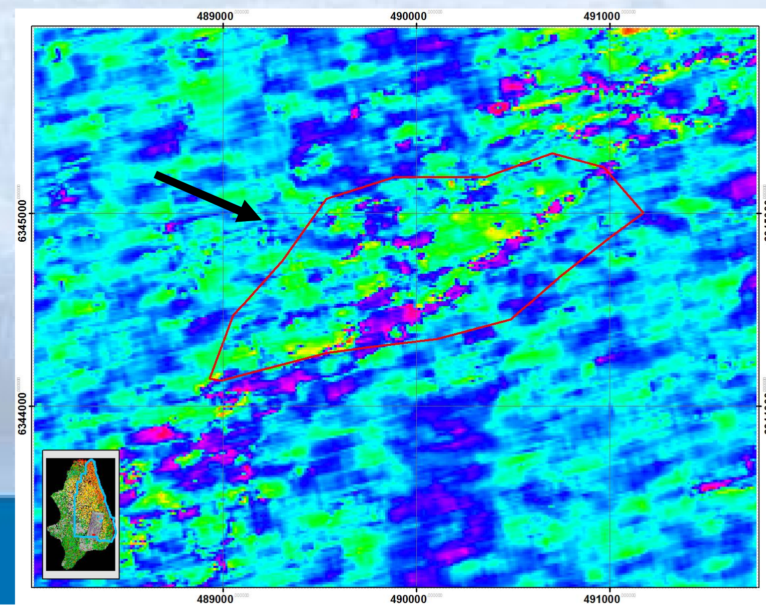
Sedge bulrush Fen

June 8, 2010: Active layer 13 cm

Sedge bulrush Fen



July 24, 2010: Active layer 27cm

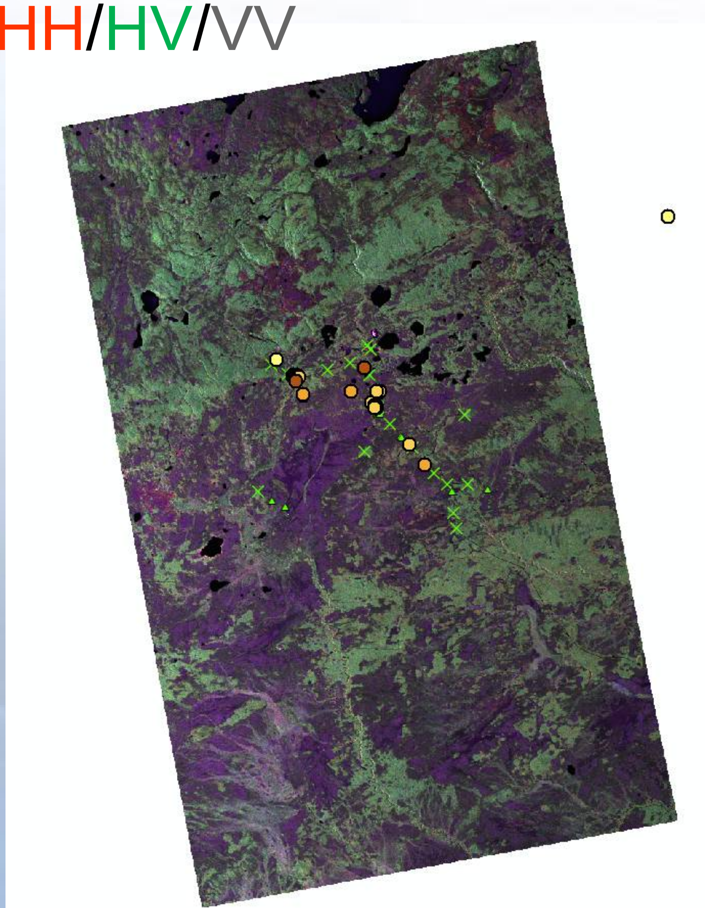


Polarimetric ALOS2 for Discontinuous Permafrost Mapping

R. Touzi and S. Pawley (AGS, Alberta)

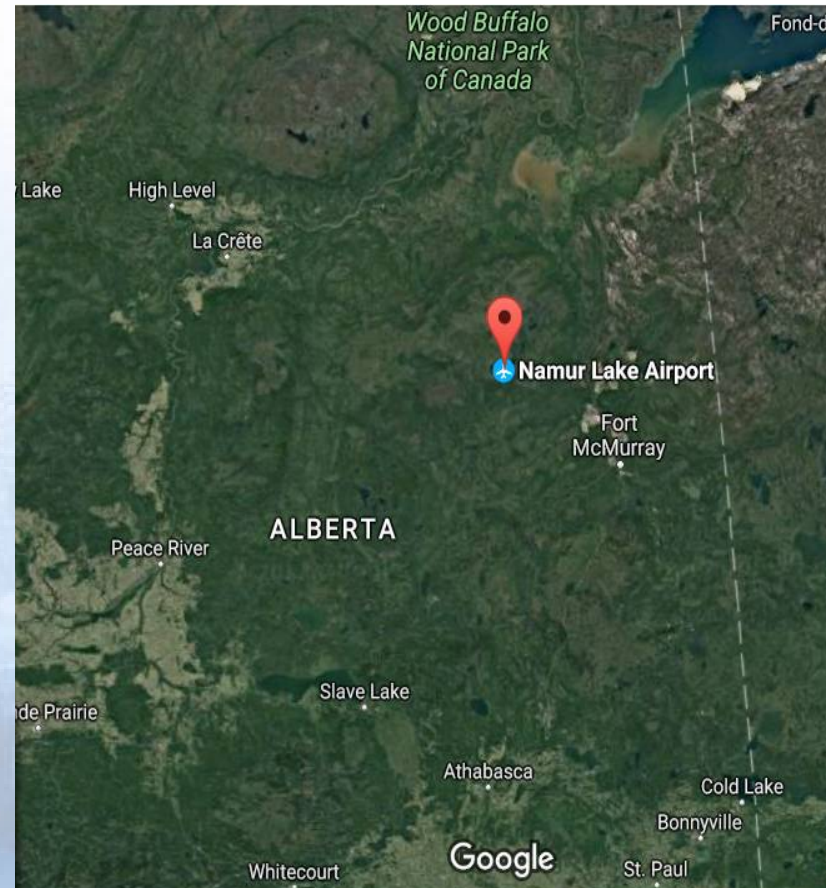
ALOS-2 2014_08_23

HH/HV/VV



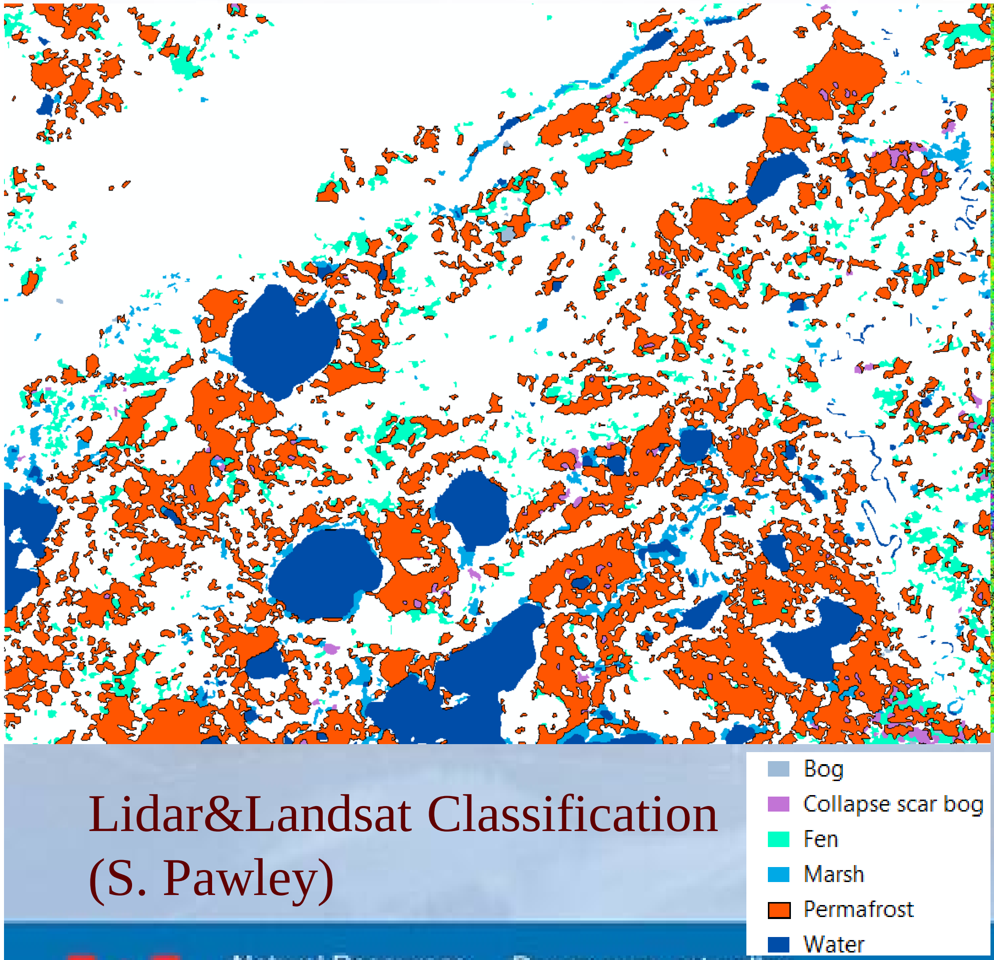
Depth to permafrost (m)

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

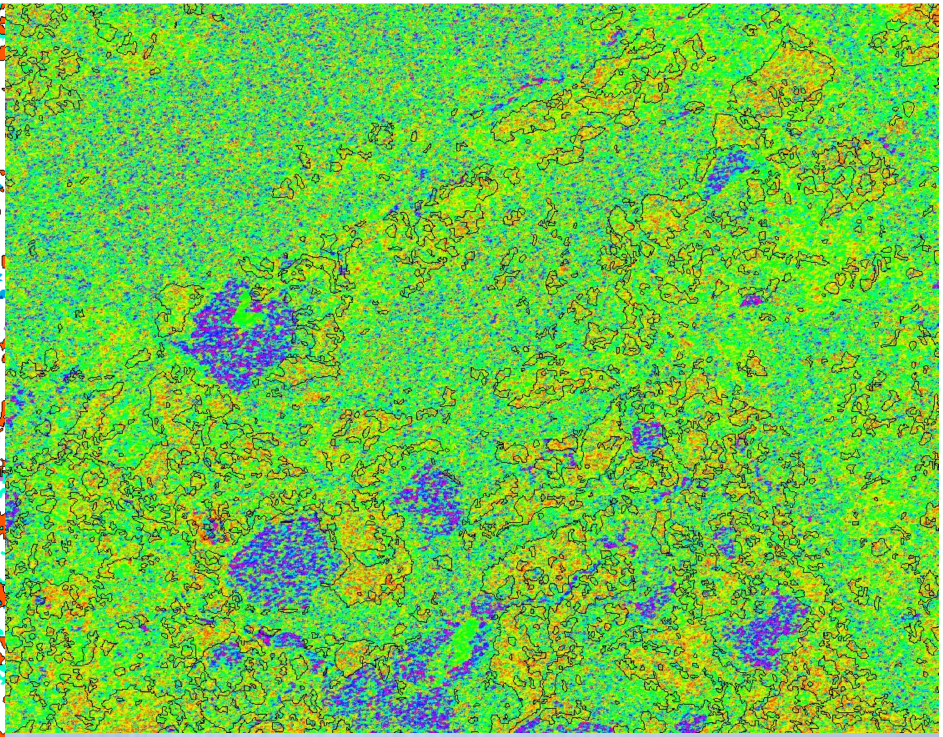


Covered by Laura's pass ☺

Polarimetric ALOS2: FP6-4 Aug. 2014
Discontinuous Permafrost mapping



Lidar&Landsat Classification (S. Pawley)



Touzi Decomposition scattering phase

Investigation of the added value of L& P-band PolinSAR for mapping and monitoring surface and permafrost conditions along the Inuvik-Tuk Highway corridor

R. Touzi, Yu Zhang, and Robert Fraser

CCRS

M. Moghaddam

USC

Peter Morse **(GSC)**

Steve Kokelj **(Northwest Territories Geological Survey, Government of the NWT)**

Trevor Lantz **(School of Environmental Studies, University of Victoria)**

- **The 137 km Inuvik-Tuk Highway (ITH) is the largest infrastructure in Canadian Arctic;**

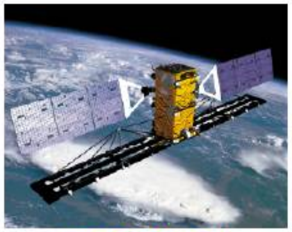
  - **It is underlain by ice-rich permafrost, and crosses treeline from boreal forest to arctic tundra;**

  - **Climate warming is most pronounced in this area, which affects permafrost, ecosystems, and infrastructure.**

  - ☛ **Infrastructure => impact on the surrounding environment**

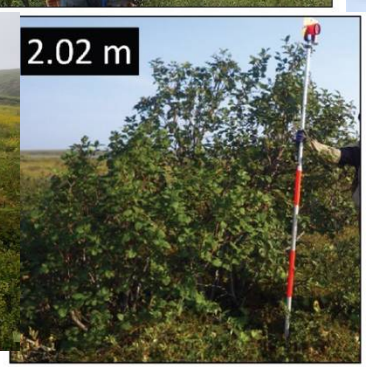
Objective & Field data

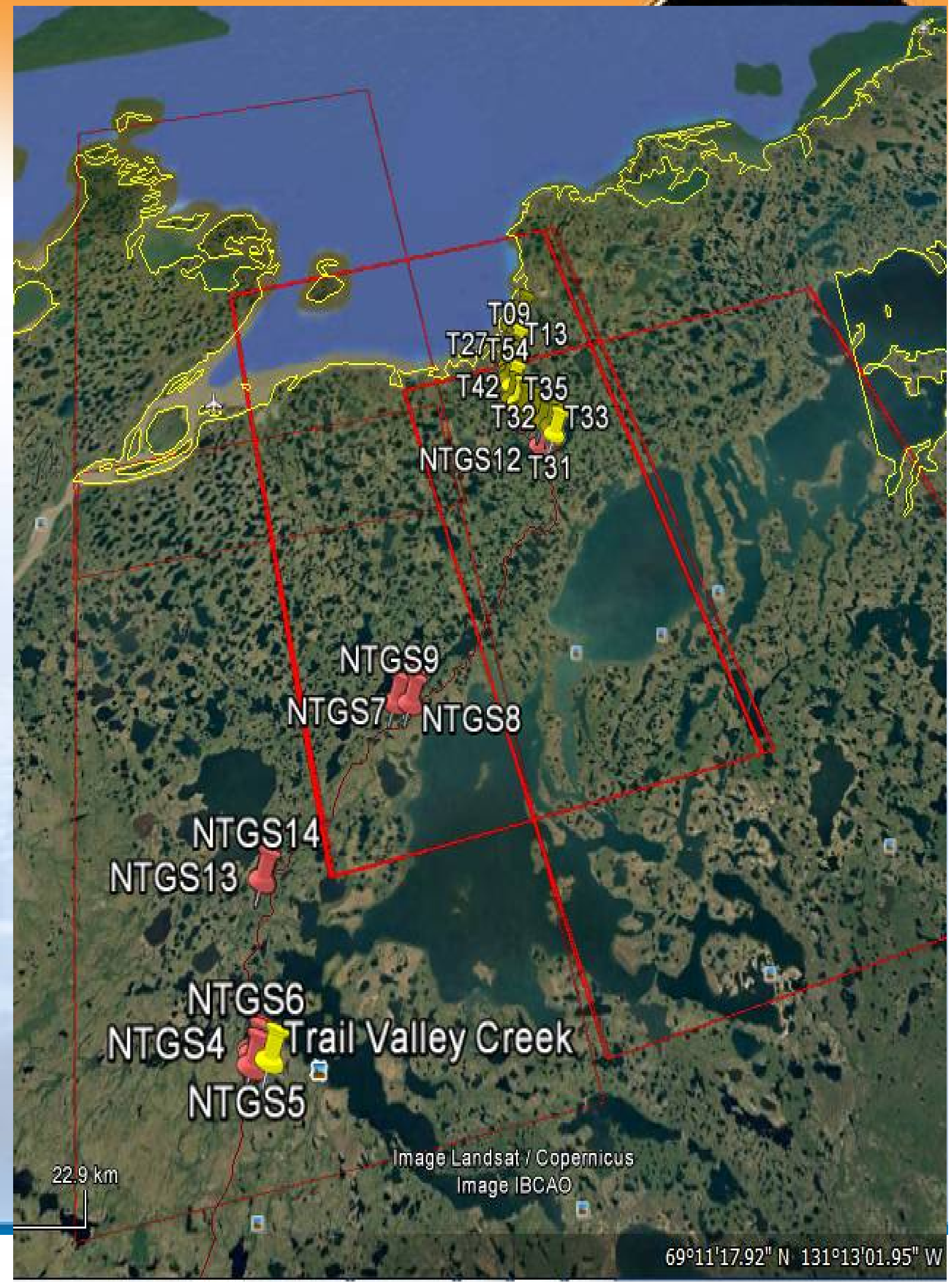
- Investigation of the added value of **polarimetric** long penetrating wavelength L- and P-band SAR with reference to conventional optic sensors for enhanced monitoring of permafrost degradation and vegetation transformation related to global climate warming.
- PolinSAR L- and P-band SAR will be conducted using repeat-pass L-band UAVSAR and P-band AIRMOS acquistion
- 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

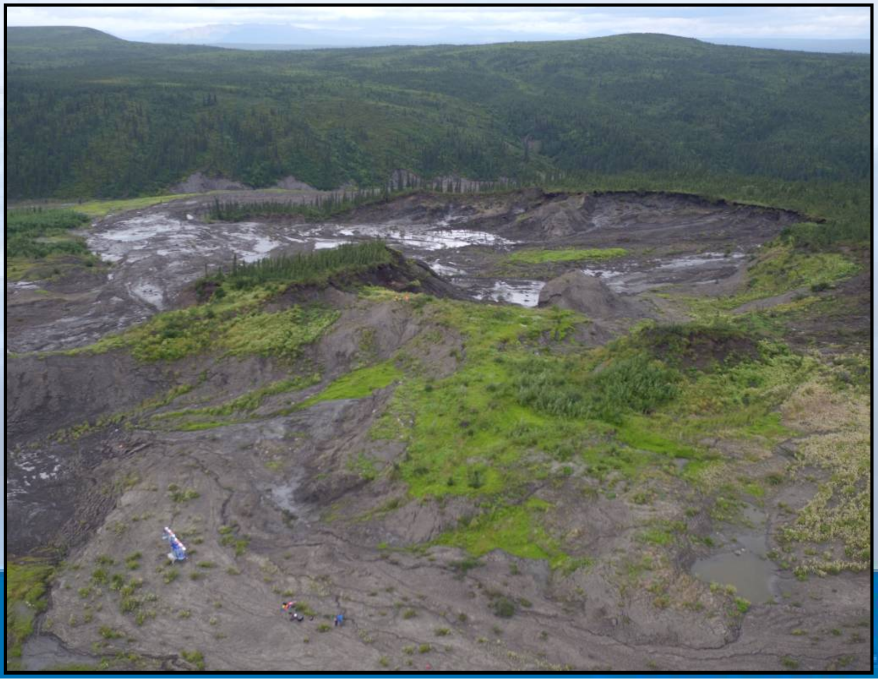
L-band ALOS2





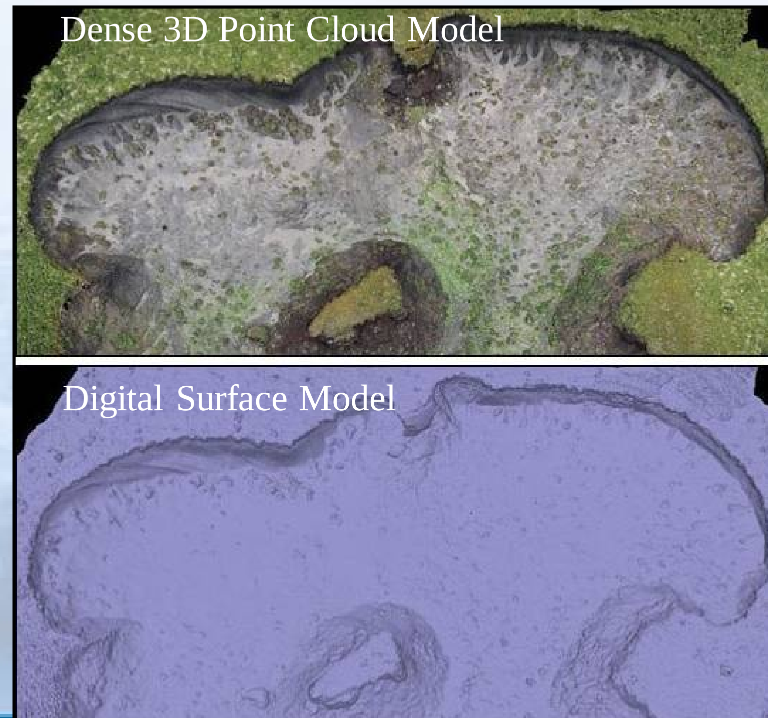
UAV-based Mapping to Measure Changes in Ice-Rich Permafrost Terrain => PolinSAR validation

- Large **thaw slumps** are a common form of thermokarst in the ice-rich permafrost regions of Northwestern Canada
- Slumps transport large volumes of sediments into stream valleys, lakes, or coastal zones impacting water quality
- There is evidence that slump activity has recently intensified in many Arctic landscapes due to **climate changes** (increased rainfall, rising air and ground temperatures,)



UAV-based Mapping to Measure Changes in Ice-Rich Permafrost Terrain

- A team from NRCan-CCRS and GNWT used UAVs to map several "mega-slumps" on the Peel Plateau of NWT in 2015 and 2016.
- UAV-based photographic surveys combined with Structure from Motion processing methods provides a low-cost and detailed means of measuring slump changes at annual or shorter time scales.

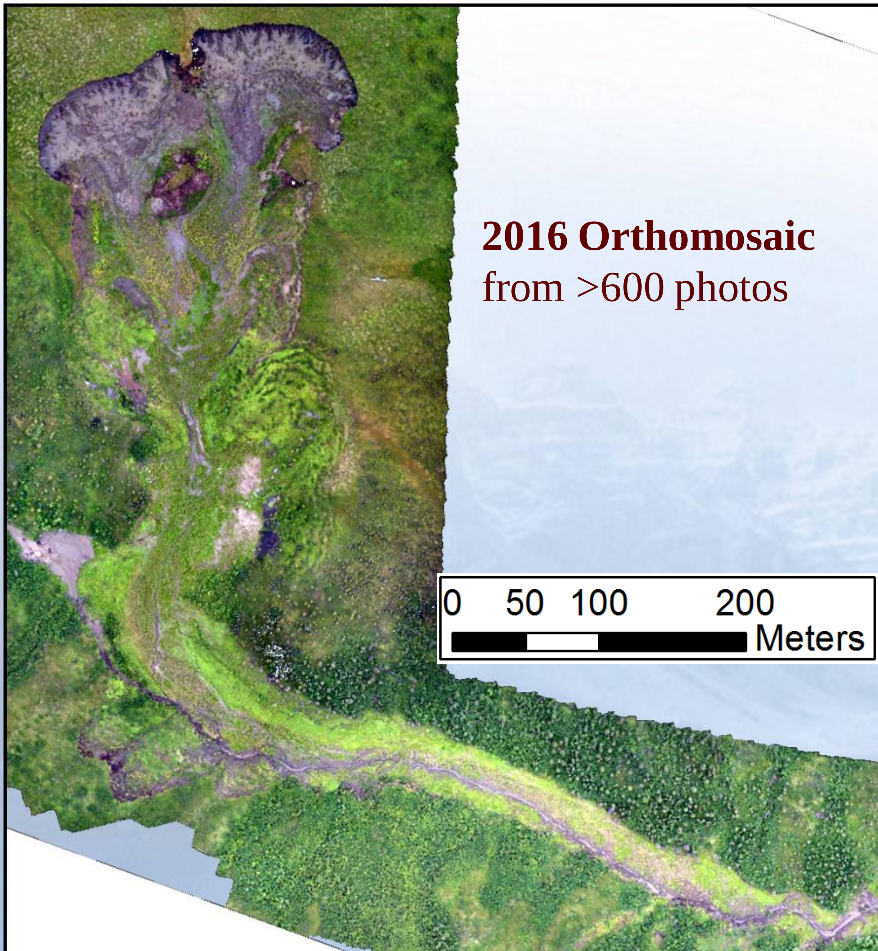


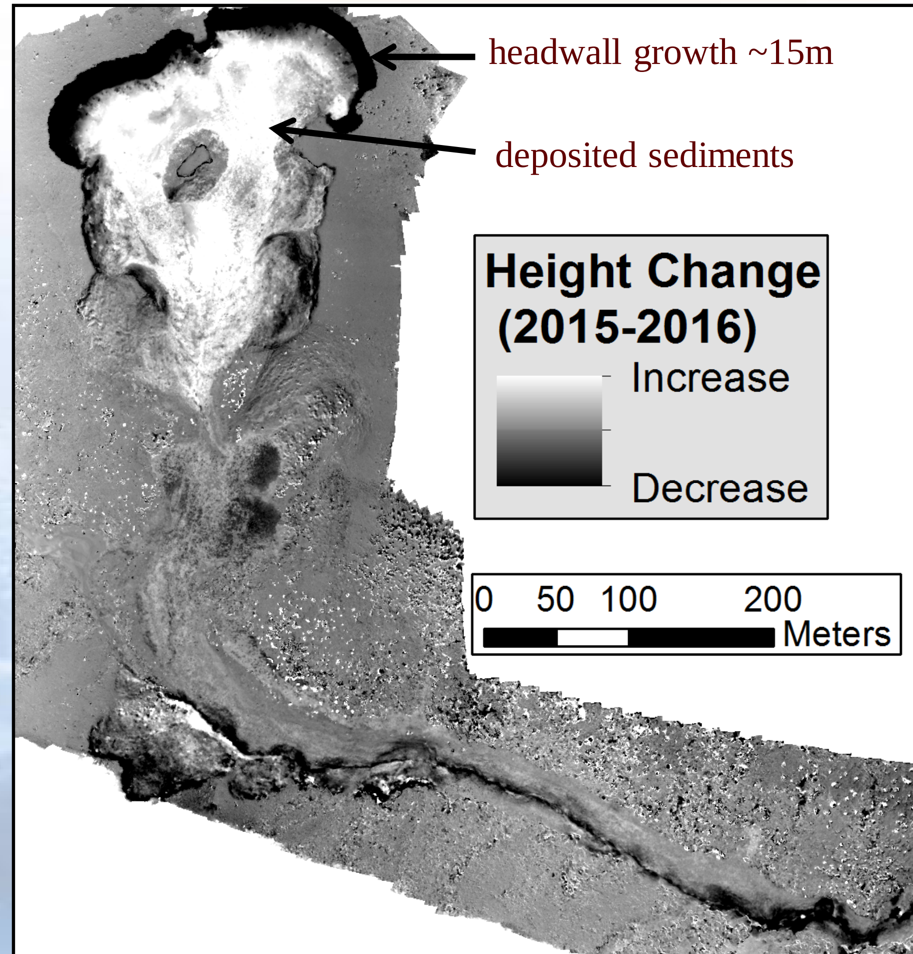
Octocopter UAV with Sony a6000 camera

Canada

UAV-based Mapping to Measure Changes in Ice-Rich Permafrost Terrain

- Changes between the UAV-based Digital Surface Models show the growth of the slump and volume of sediments that have been deposited or exported downstream.



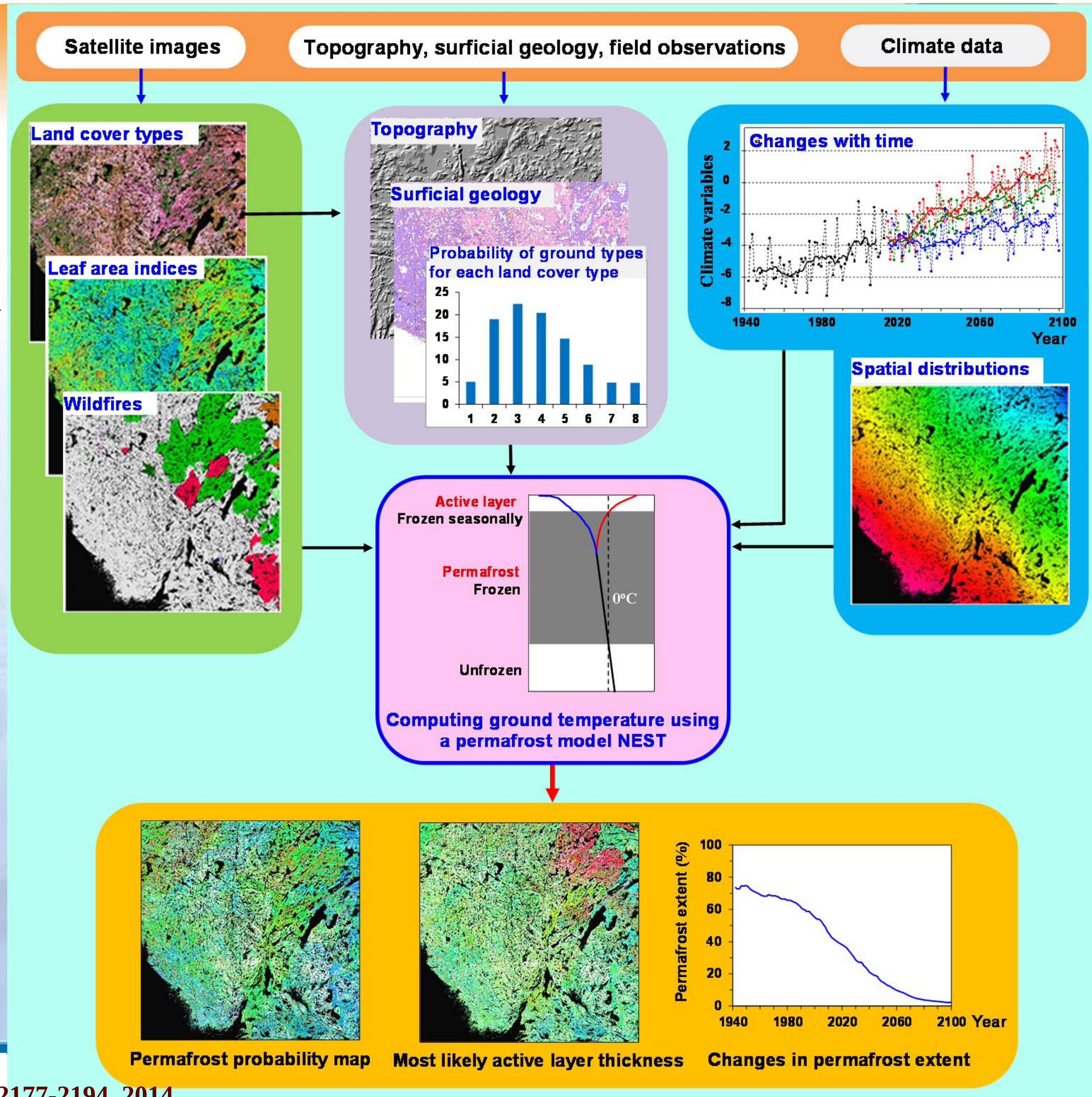


Natural Resources Canada
Ressources naturelles Canada
R. Fraser, J. Van der Sluijs, I. Olthof, S. Kokelj, J. Tunnicliffe

Canada

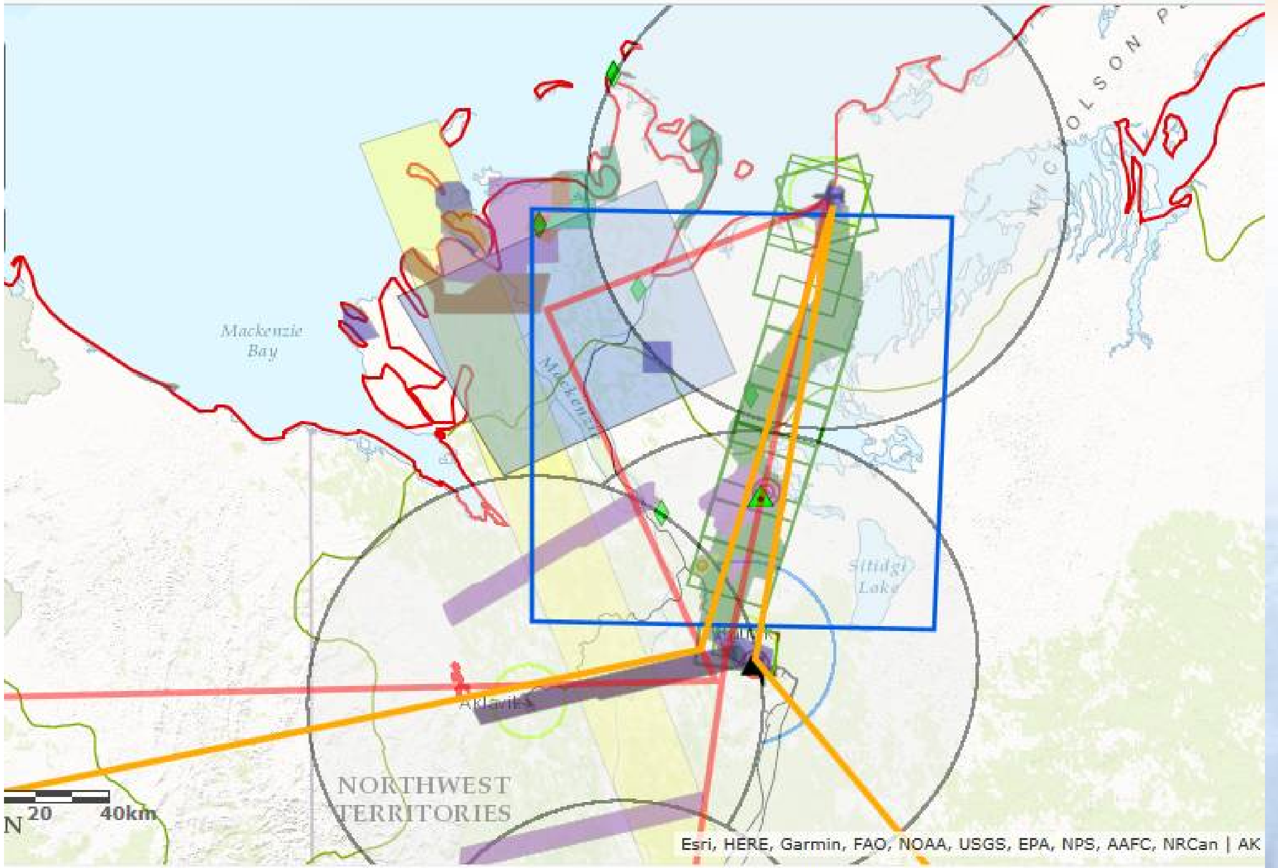
UAVSAR
+AIRMOSS
POLinSAR

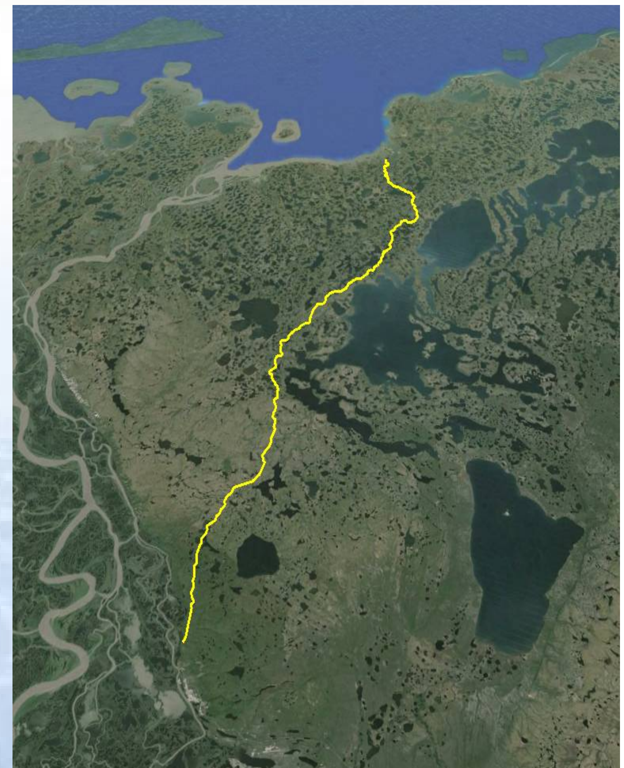
Improve Zhang's permafrost model (NEST) for ALT monitoring & projected change



Zhang, Y., et al., *The Cryosphere*, 8, 2177-2194, 2014

Flight Planning ☺☺





Remote sensing for assessing cumulative impacts on barren ground caribou

Wenjun Chen et al.

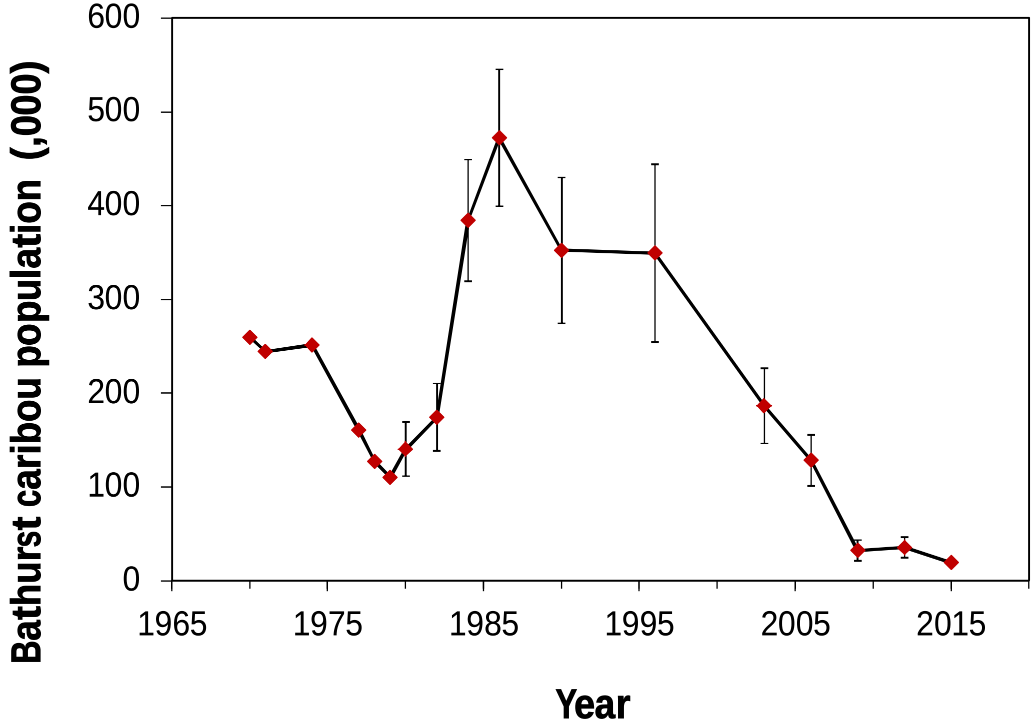
NRCan led projects:

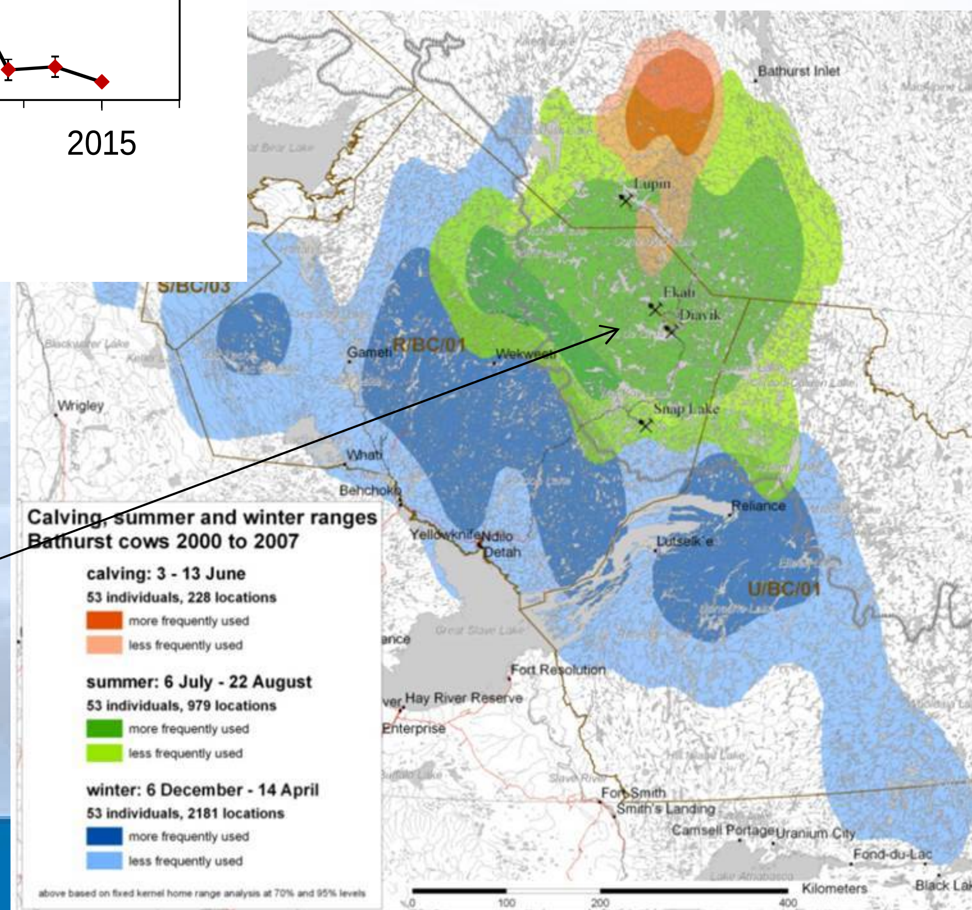
- ❖ Satellite Monitoring for Assessing Resource Development's Impact on Bathurst Caribou; funded by NWT Cumulative Impact Monitoring Program (CIMP)
- ❖ Baseline Monitoring of Arctic Vegetation and Snow Changes over the Bathurst Caribou Habitat using Satellite Remote Sensing and Community-based Field Observations; funded by CIMP

Partners: Governments (NRCan; Gov. NWT, Tlicho Government, Wek'èezhìi Renewable Resources Board); industry (Dominion Diamond Ekati Corporation, Environmental Resources Management, Integrated Ecological Research); international organizations (CircumArctic Rangifer Monitoring and Assessment Network); academia (Carleton U.)

Goal: to provide EO monitoring products and EO-based assessments of cumulative impacts of climate change, resource developments, and other factors on barren ground caribou in Canada's arctic

Cumulative impacts of climate change, resource development, and other factors on the Bathurst caribou?





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Field data

Summers 2015 & 2016: % vegetation cover, mean plant height, soil pH, dust on leaves, noise level, $PM_{2.5}$, and precision GPS records, along transects from the Ekati Diamond Mine
May-October, 2013 & 2014: % vegetation cover, mean plant height, and digital photos every 5-d, at sites near Wekweeti and Daring Lake
Summer 2005: percent vegetation cover, mean height, leaf biomass, aboveground biomass, at sites around Yellowknife and Lupin Gold Mine

Wished area: Bathurst caribou range (latitude 60-68 N, longitude 105-115 w)