Centre - Eau Terre Environnement

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Freeze-Thaw Cycle Monitoring using Multi-Scale SMAP Satellite Products and Hydrothermal Modelling over the Canadian Tundra

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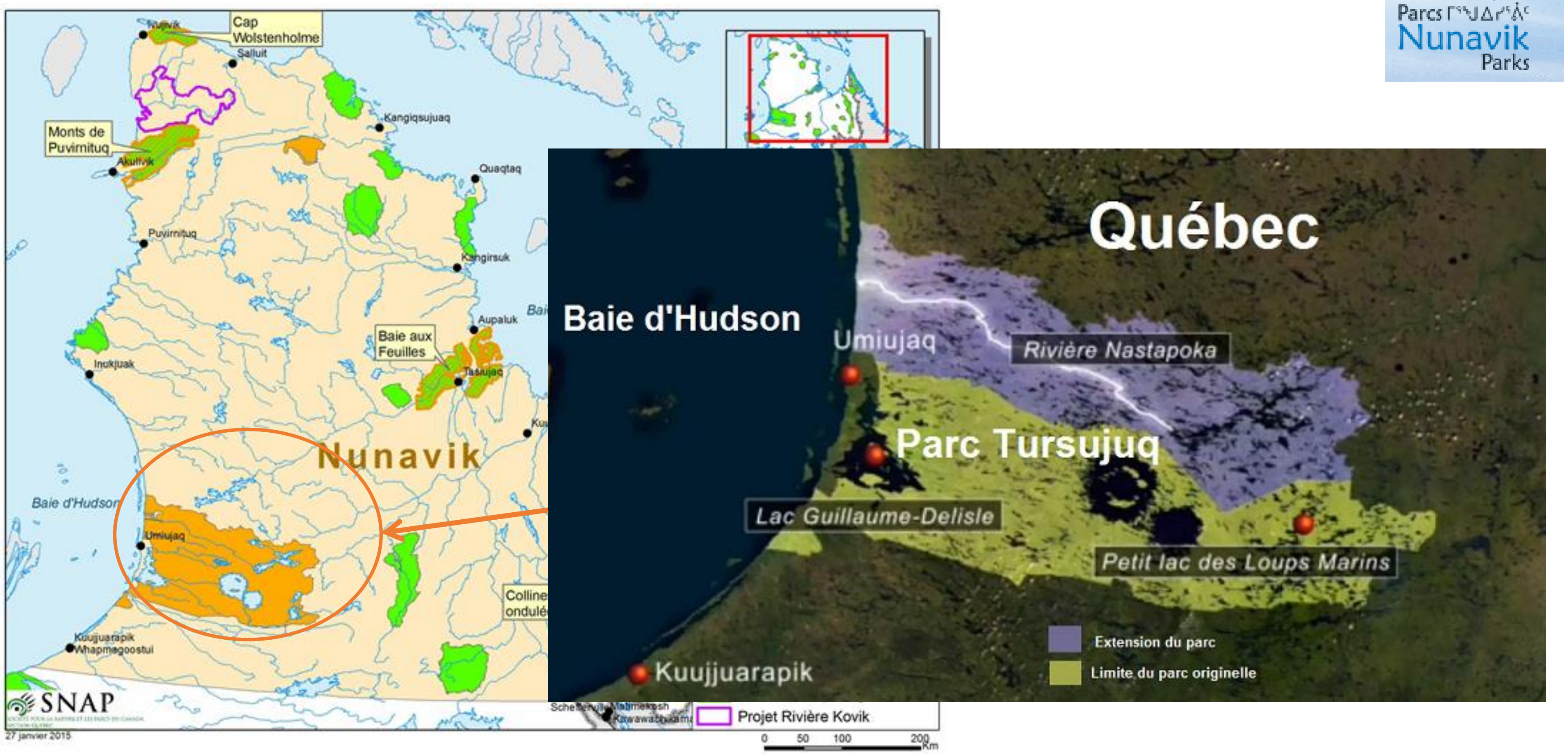
Environment Canada Environnement Canada

CENTRE D'ÉTUDES NORDIQUES
CEN Centre for Northern Studies

Study site

Tursujuq Park, Umiujaq region (Nunavik, Qc)



Discontinuous Permafrost at the three line

(a)

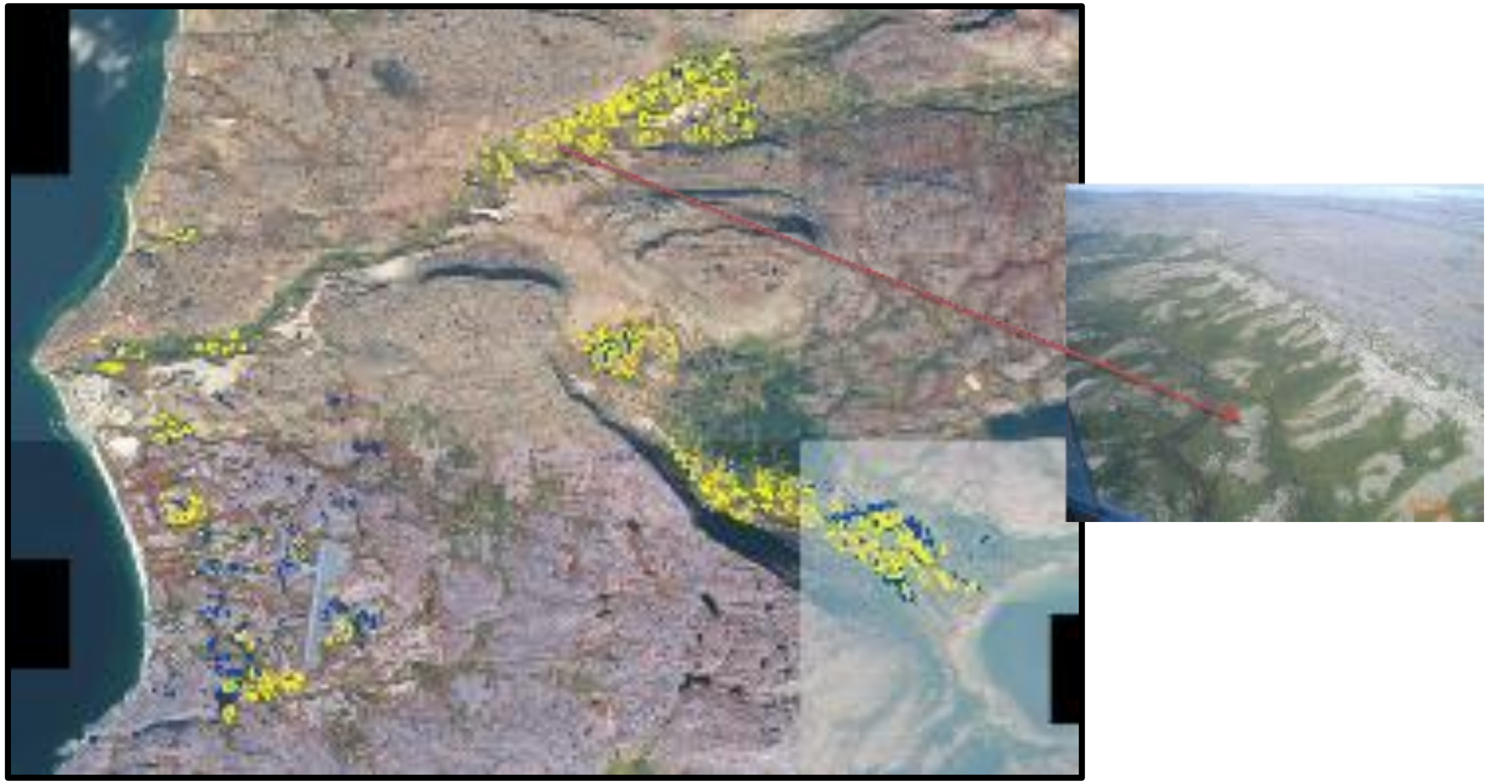

(b)

Fig 2. (a) Permafrost classification in Québec, Canada (Allard et al, 2012)
(b) Permafrost distribution (in yellow) near Umiujaq village

> IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING < 1

Comparison of TerraSAR-X and ALOS PALSAR Differential Interferometry with Multi-Source DEMs for Monitoring Ground Displacement in a Discontinuous Permafrost Region

Lingxiao Wang, Philip Marzahn, Monique Bernier, Andres Jacome, Jimmy Poulin, and Ralf Ludwig

Abstract—**Differential synthetic aperture radar interferometry (DInSAR) has shown its capability in monitoring ground displacement caused by the freeze-thaw cycle in the active layer of permafrost regions. However, the unique landscape in the discontinuous permafrost zone increases the difficulty of applying**

Permafrost represents one of the main components of the cryosphere in northern regions and has an influence on hydrological processes, energy exchanges, natural hazards, and carbon budgets. Under climate warming, permafrost degradation, which is a decrease in the thickness and/or areal extent of permafrost, is inevitable [3]. In recent years,

Objectives

1. To support a ground network in Northern Quebec as a main Cal/Val site related to F/T products in Canada over Canadian tundra and boreal forest sites.

Températures de surface 5-15-30

Site 1- **Umiujaq Sila** (Real Time)

Site 2- **Boniface** (Download)

Site 3- **Lac à l'eau Claire** (Download)

Site 4- **Lac Payne** (Real Time)

Site 5- **Camp Bélanger** (Real Time)

Objectives

2. To validate the effectiveness of L-band radar backscatters using PALSAR-2 to monitor F/T state over the Tundra and the Boreal Forest in Canada.

3. To examine active/passive remote sensing synergies and assess sub-grid heterogeneity in surface state and potential effects on soil frost dynamics over the Tundra and the Boreal Forest in Canada using radar data from PALSAR-2, RADARSAT-2 or Sentinel SAR and SMAP radiometer data.

4. To validate L1C_TB product (Low-resolution brightness temperatures with a 40-km spatial resolution and available on a 36-km Earth grid) to monitor F/T state at low resolution (40 km) over the Tundra and the Boreal Forest in Canada

Objectives

5. To test a hydrothermal model to provide soil moisture and freezing/thawing information in high spatial and temporal resolution at a watershed level. The information is crucial to better understand small scale heterogeneities of F/T related landscape features and to close the scale gap between field monitoring data and SMAP F/T products.

Objective 2 and 3

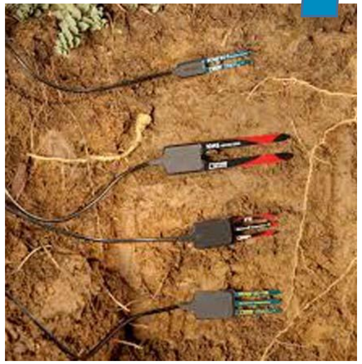
To validate the effectiveness of L-band radar backscatters using PALSAR-2




Field Work

- **Summer**: 2 Field work, 2015 and 2016

Soil moisture and temperature sensor



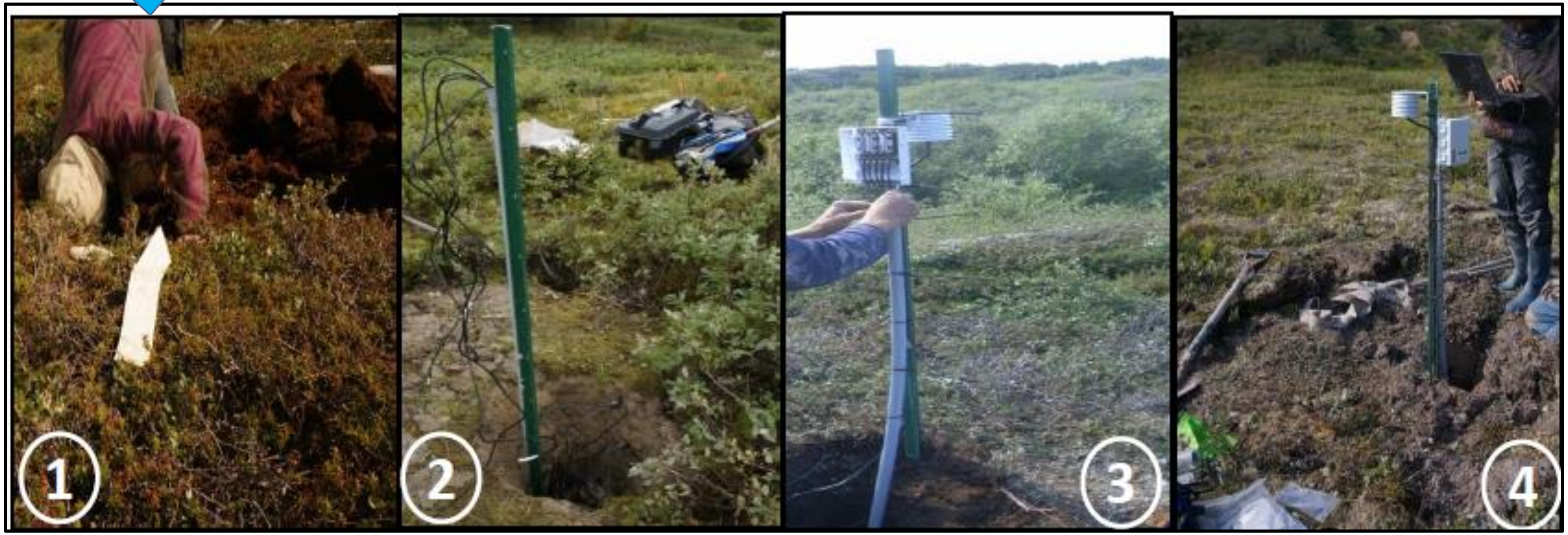
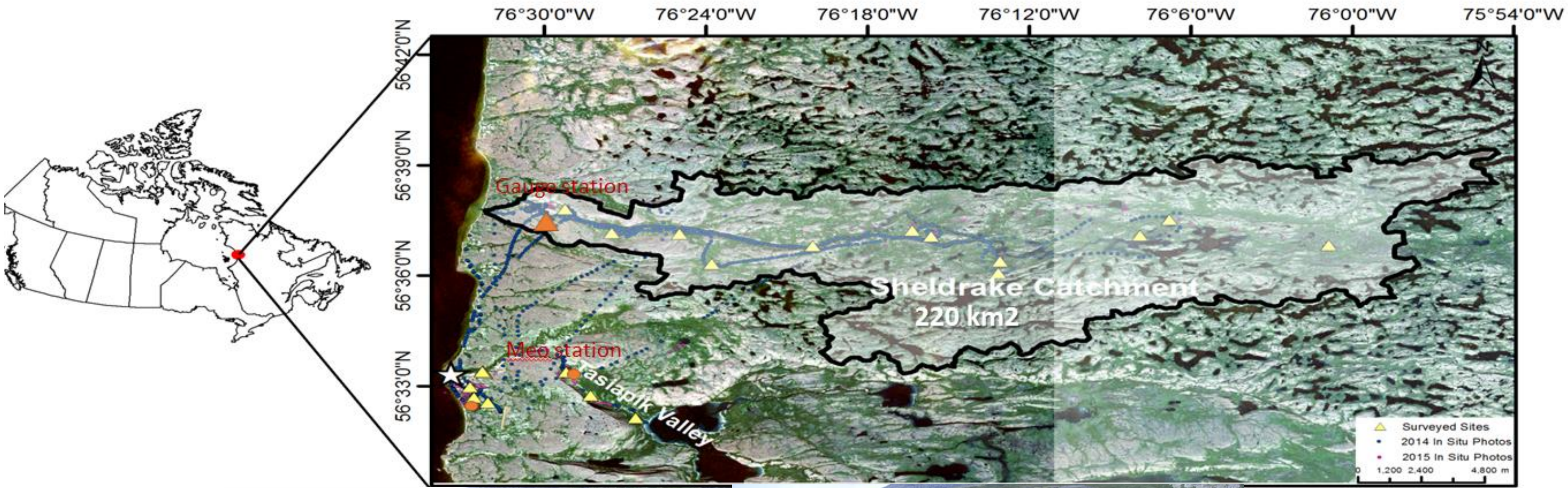


Figure 3. Installation of temperature and soil moisture sensor in Umiujaq region

Localisation of Temperature Sensors


76°30'0"W
76°24'0"W
76°18'0"W
76°12'0"W
76°6'0"W
76°0'0"W
75°54'0"W
56°42'0"N
56°39'0"N
56°36'0"N
56°33'0"N
Gauge station
Meo station
Taslapik Valley
Sheldrake Catchment
220 km2
Surveyed Sites
2014 In Situ Photos
2015 In Situ Photos
0 1,200 2,400 4,800 m

GPS photo

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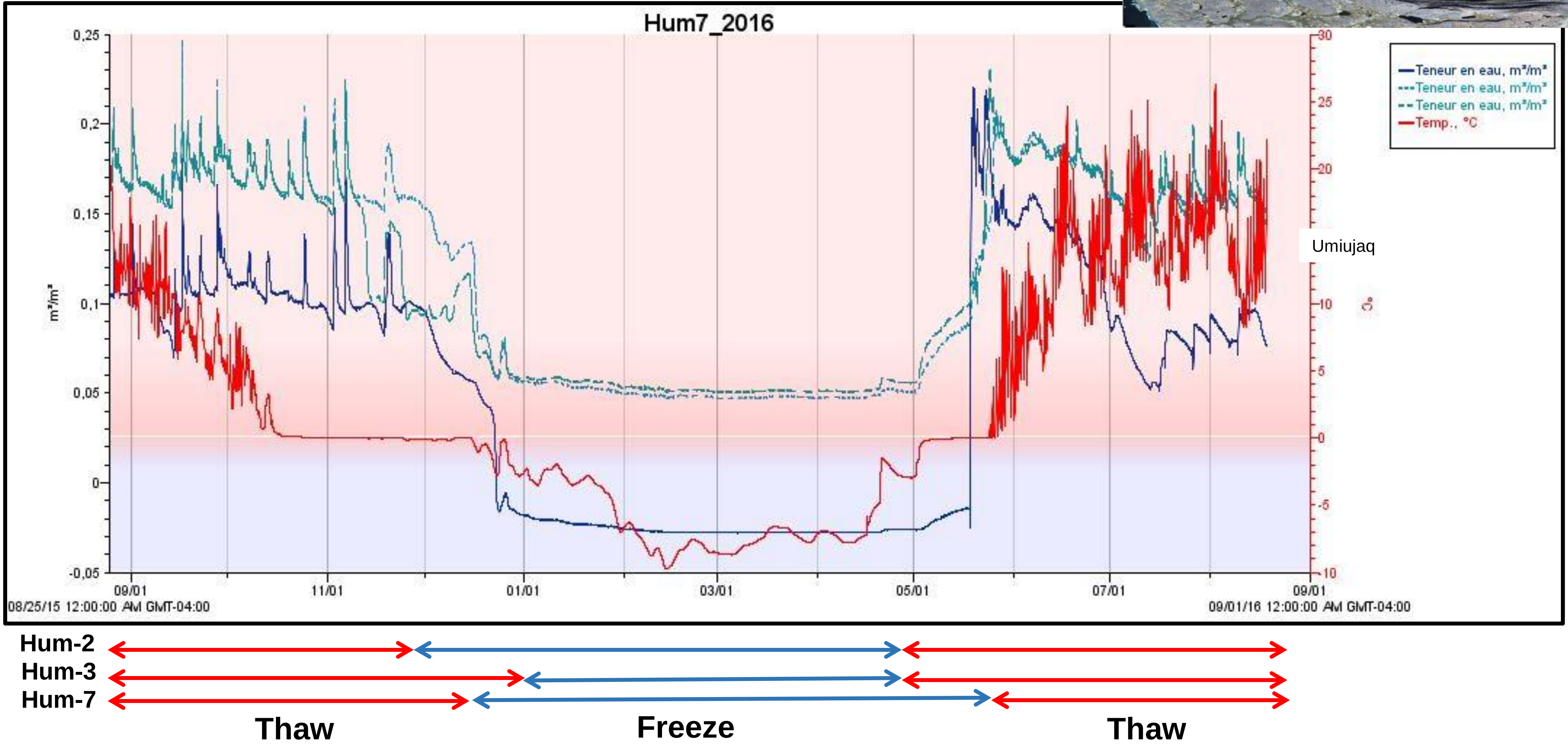
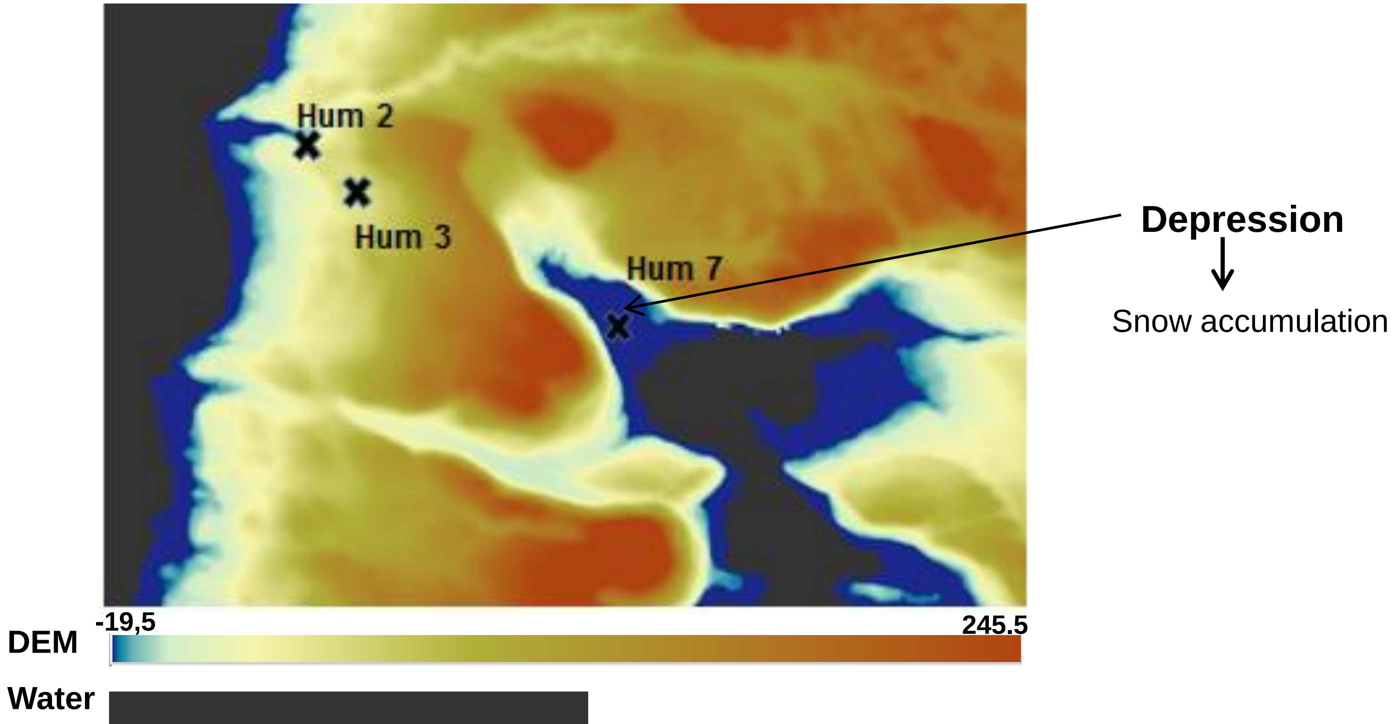
Temperature and soil moisture profiles

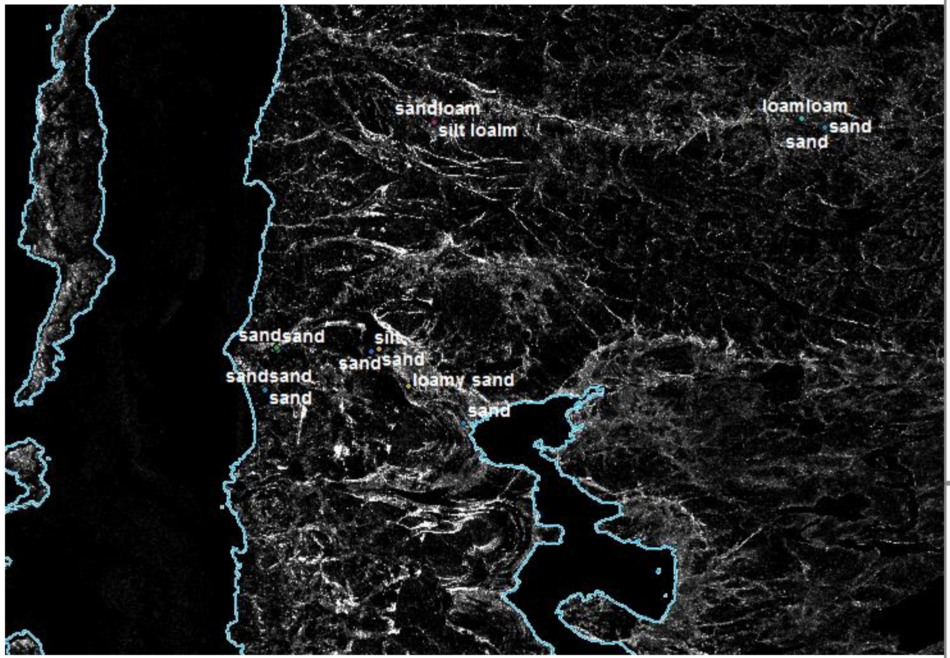


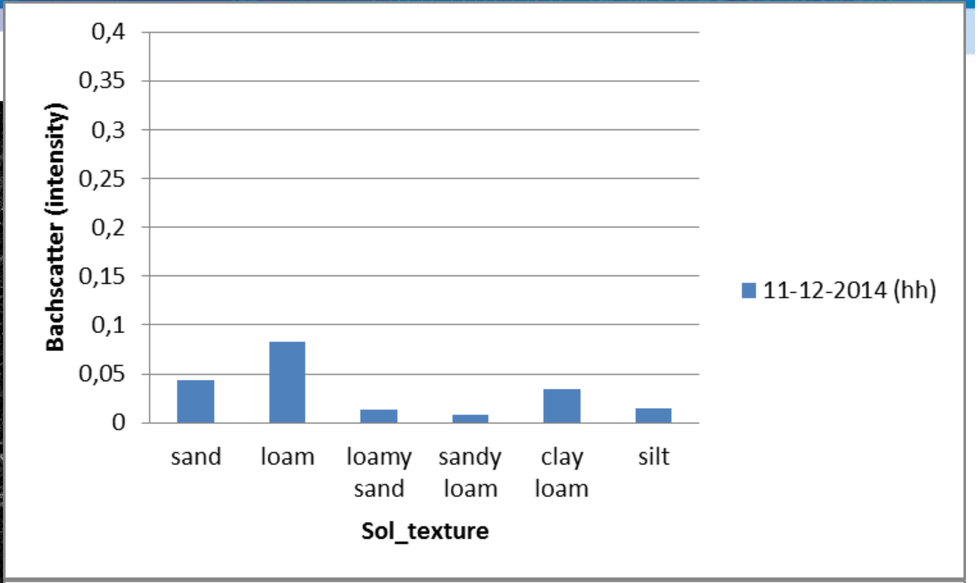
Tab 1. Thaw/Freeze cycle :station Hum 2, Hum 3, Hum7

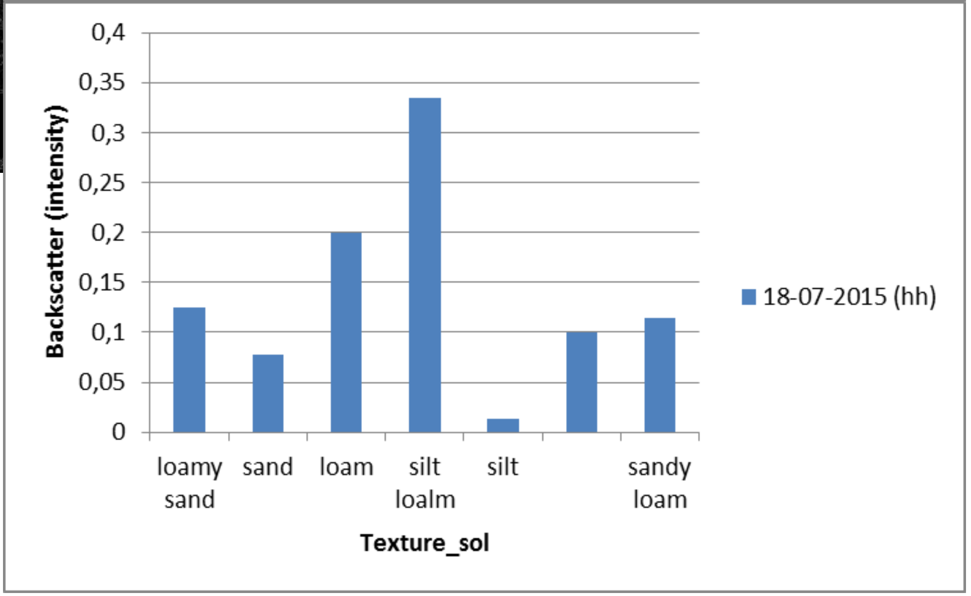
Station	Latitude	Longitude	Freeze date	Thaw date	Duration of freeze thaw cycle
Hum 2	56.55583	-76.48178	**26 Nov 2015**	**03 May 2016**	**159**
Hum 3	56.55853	-76.48178	**30 Dec 2015**	**14 May 2016**	**136**
Hum 7	56.54042	-76.43808	**24 Nov 2015**	**20 May 2016**	**178**

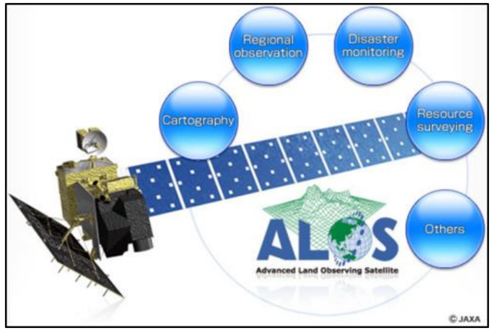
station	Sol texture	Vegetation
hum2	Sand	Shrub & lichen mixed
hum3	Sand	Shrub dominant
Hum7	Sand	Shrub dominant

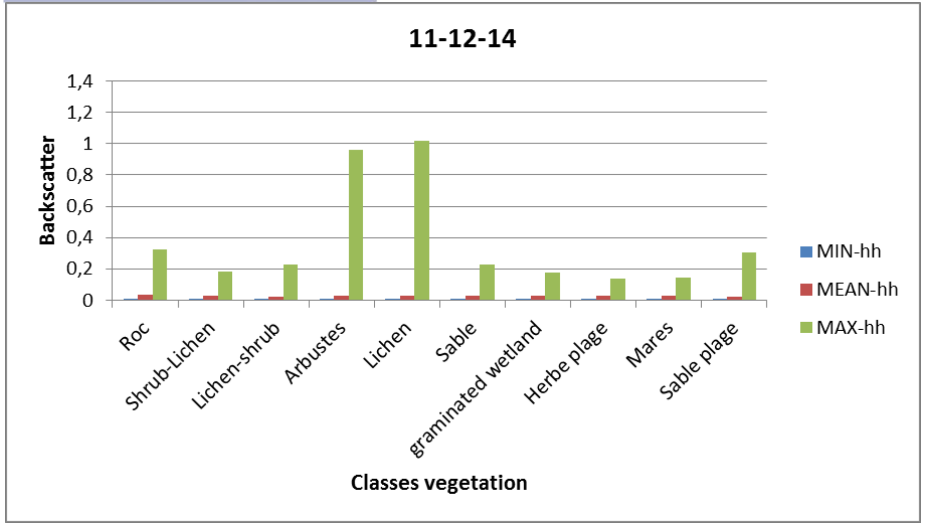


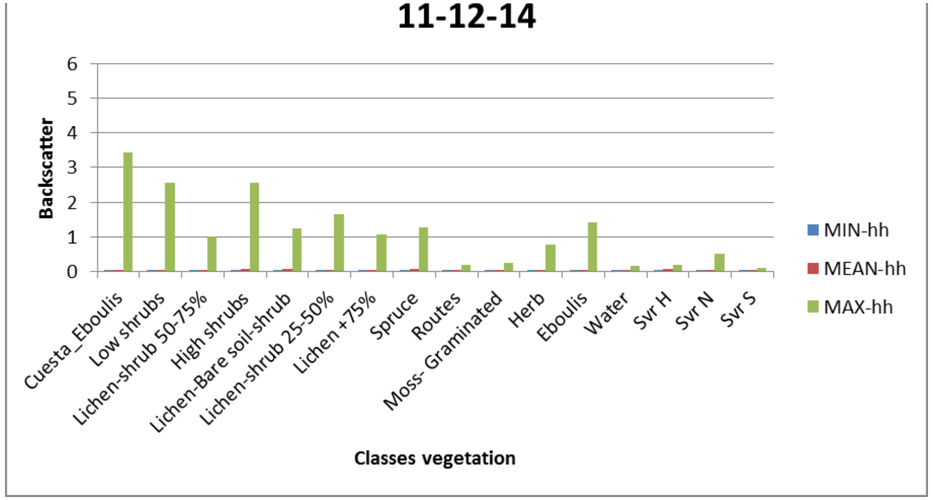

sandloam
silt loalm
loamloam
sand
sand
sandsand
silt
sandsand
sandsand
sand
loamy sand
sand

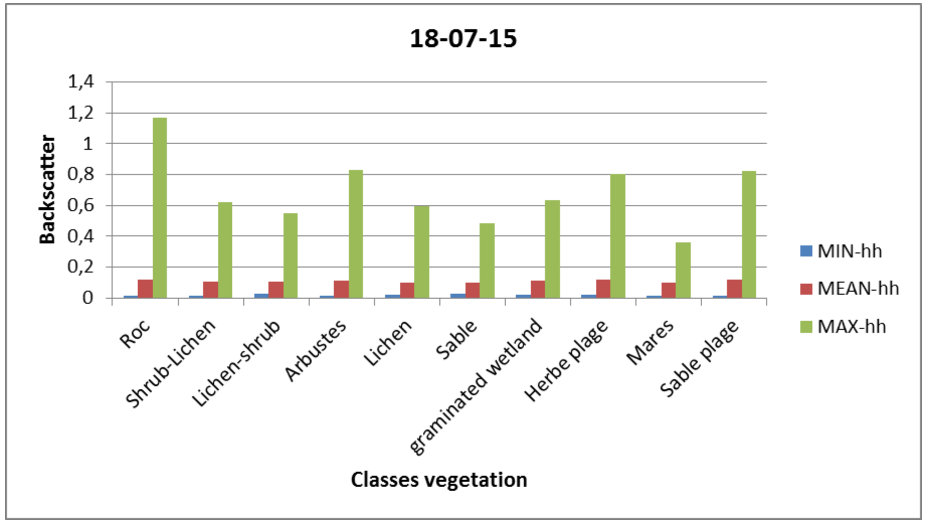

Bachscatter (intensity)
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
sand
loam
loamy sand
sandy loam
clay loam
silt
Sol_texture
11-12-2014 (hh)

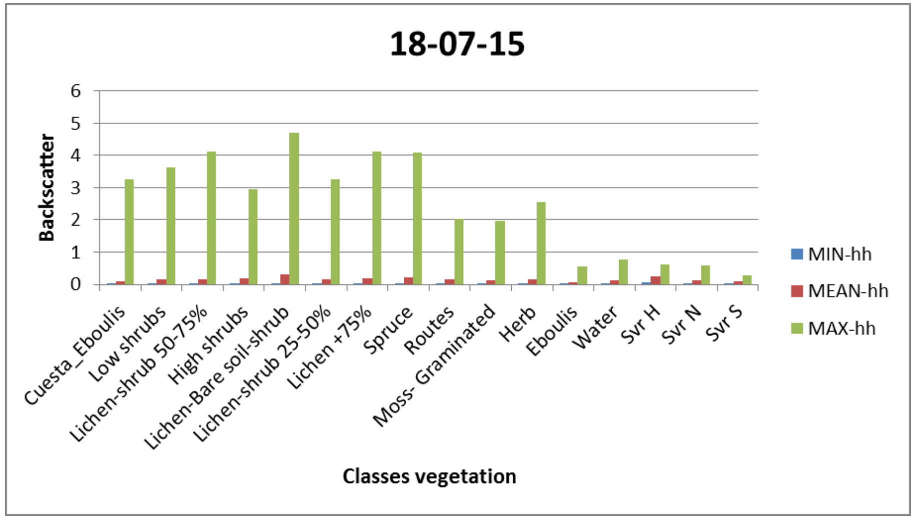

Backscatter (intensity)
0,4
0,35
0,3
0,25
0,2
0,15
0,1
0,05
0
loamy sand
sand
loam
silt loalm
silt
sandy loam
Texture_sol
18-07-2015 (hh)


Regional observation
Disaster monitoring
Cartography
Resource surveying
Others
ALOS
Advanced Land Observing Satellite
© JAXA









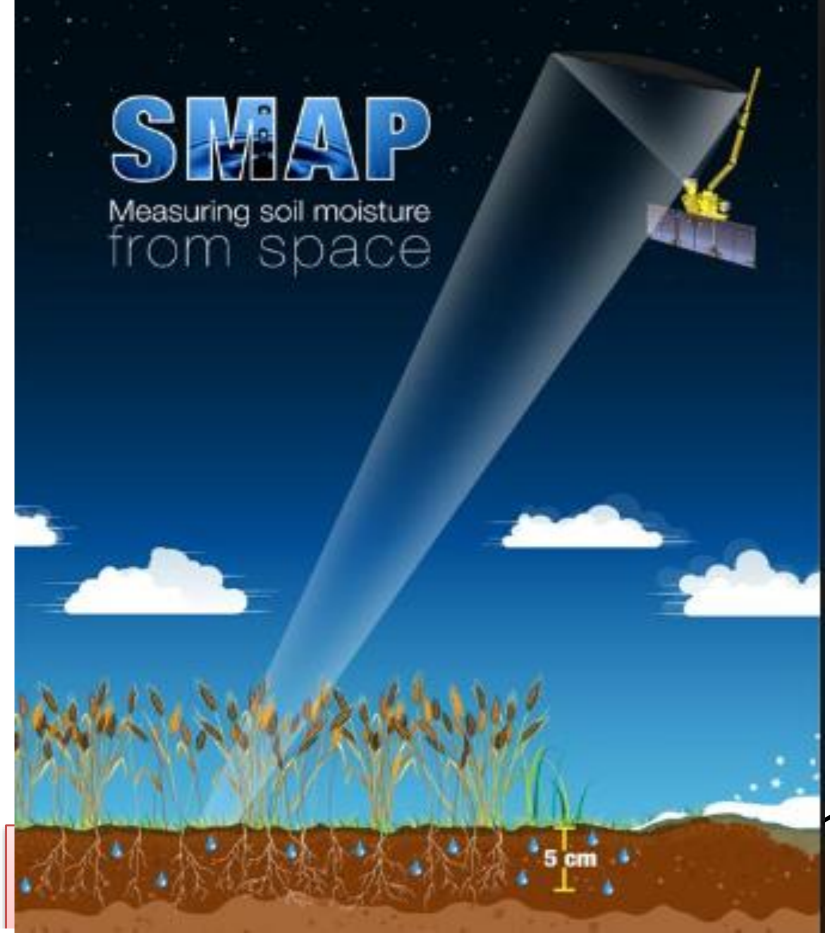
Examples of side results

Examples of valley results

ALOS-PALSAR_2

Study the sensibility of the signal to

1. **vegetation**
2. **2-sol texture**



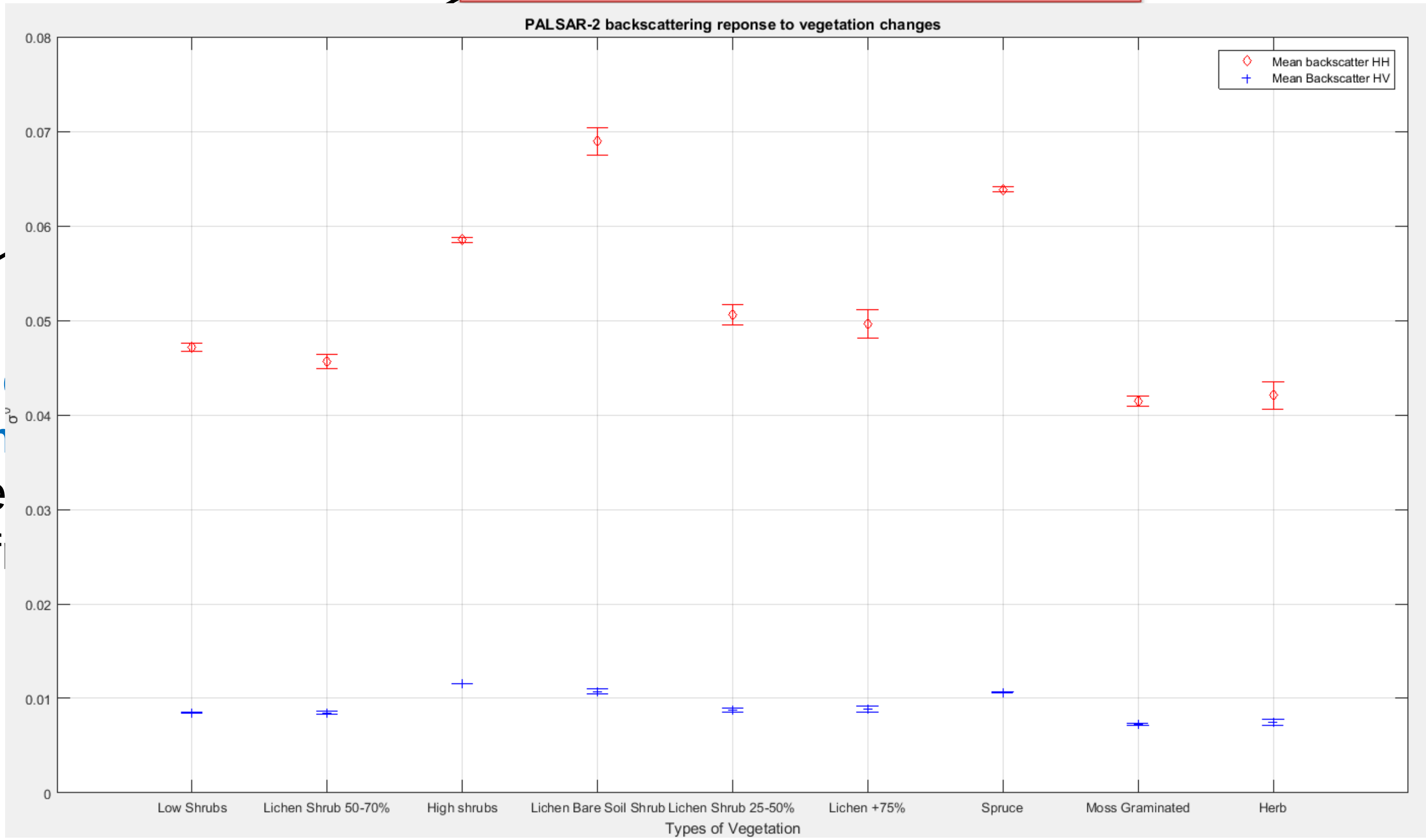


Figure.
with

While radar waves in X-band are only refle

Only L-band systems can receive signals f

Objective 4

To validate L1C_TB product for Freeze/Thaw over the Canadian Tundra




Mapping Freeze and thaw cycle using SMAP data

Database: active and passive

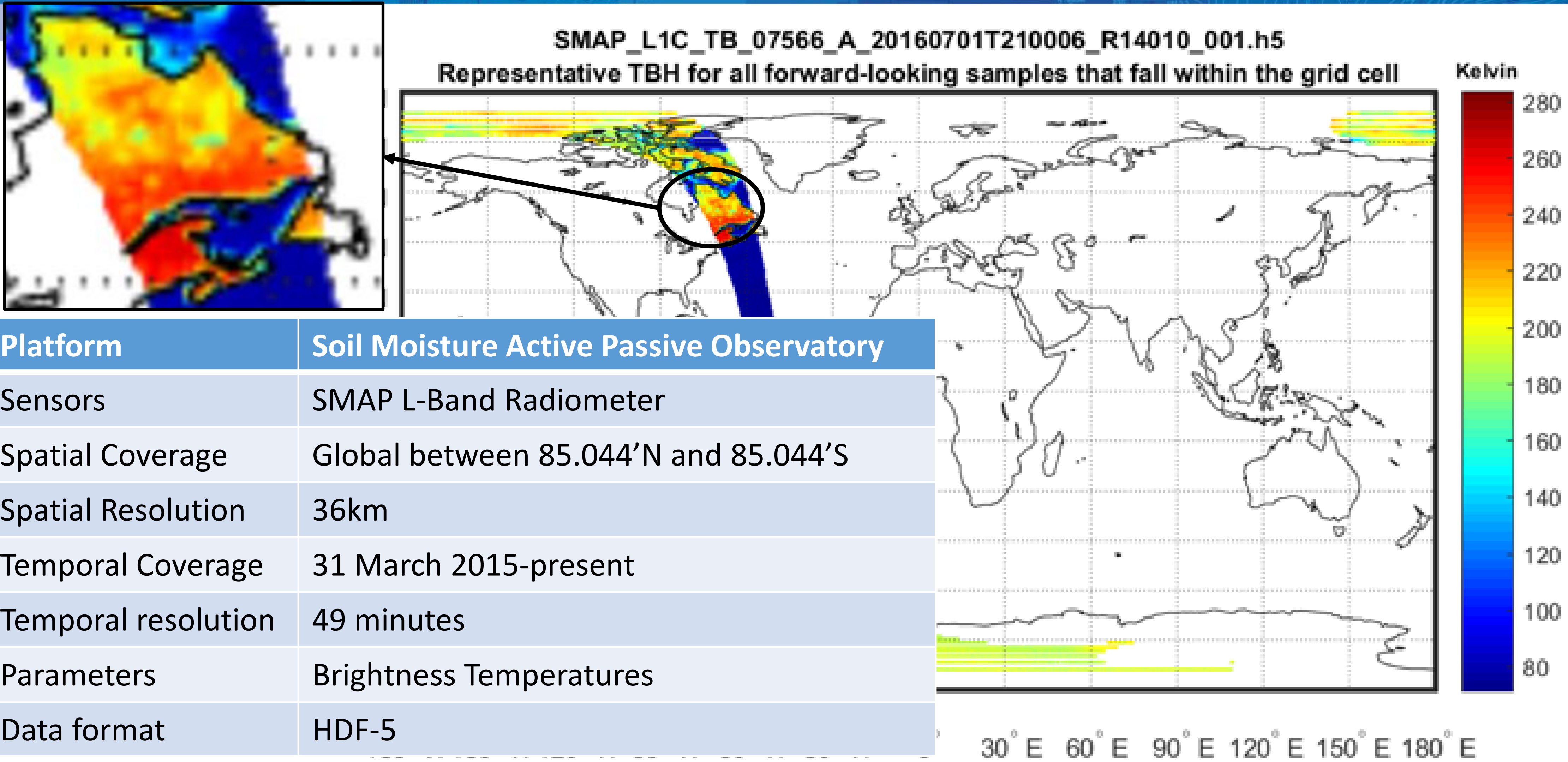
Step 1

SMAP data

Product	Description	Gridding (Resolution)
L1A_Radiometer	Radiometer Data in Time-Order	-
L1A_Radar	Radar Data in Time-Order	-
L1B_TB	Radiometer T_B in Time-Order	(36×47 km)
L1B_S0_LoRes	Low-Resolution Radar σ_o in Time-Order	(5×30 km)
L1C_S0_HiRes	High-Resolution Radar σ_o in Half-Orbits	1 km (1-3 km)#
L1C_TB	Radiometer T_B in Half-Orbits	36 km
L2_SM_A	Soil Moisture (Radar)	3 km
L2_SM_P*	Soil Moisture (Radiometer)	36 km
L2_SM_AP*	Soil Moisture (Radar + Radiometer)	9 km
L3_FT_A*	Freeze/Thaw State (Radar)	3 km
L3_SM_A	Soil Moisture (Radar)	3 km
L3_SM_P*	Soil Moisture (Radiometer)	36 km
L3_SM_AP*	Soil Moisture (Radar + Radiometer)	9 km

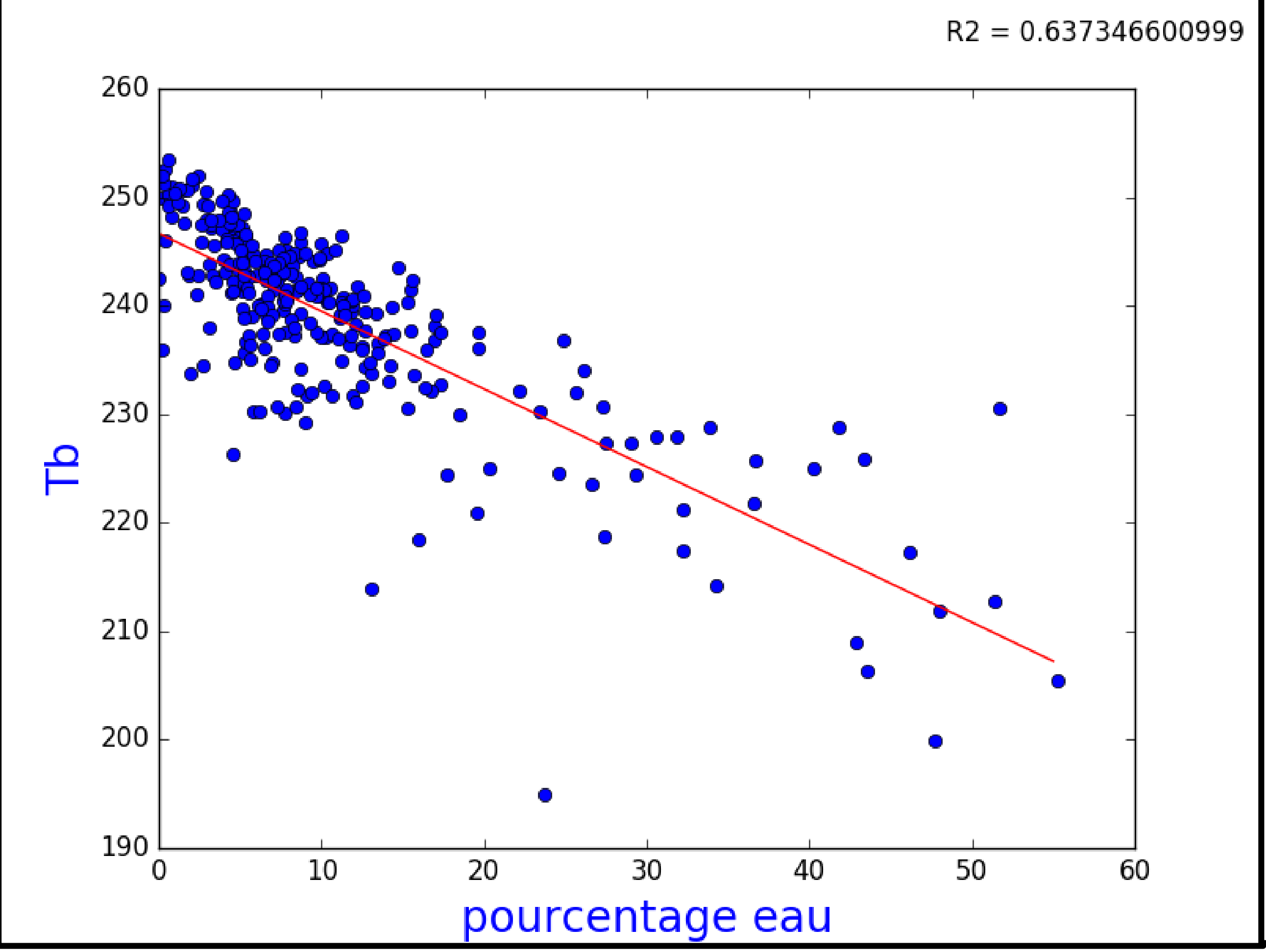
PALSAR Beam Modes				
	Fine Resolution		ScanSAR	Polarimetric
Beam Mode	FBS	FBD	WB1 WB2	PLR
Center Frequency	L-Band (1.27 GHz)			
Polarization	HH or VV	HH+HV or VV+VH	HH or VV	HH+HV+VV+VH
Spatial Resolution	10m	20m	100m	30m
Swath Width	70km	70km	250-350km	30km
Off-Nadir Angle	34.3° (default)		27.1° (default)	21.5° (default)

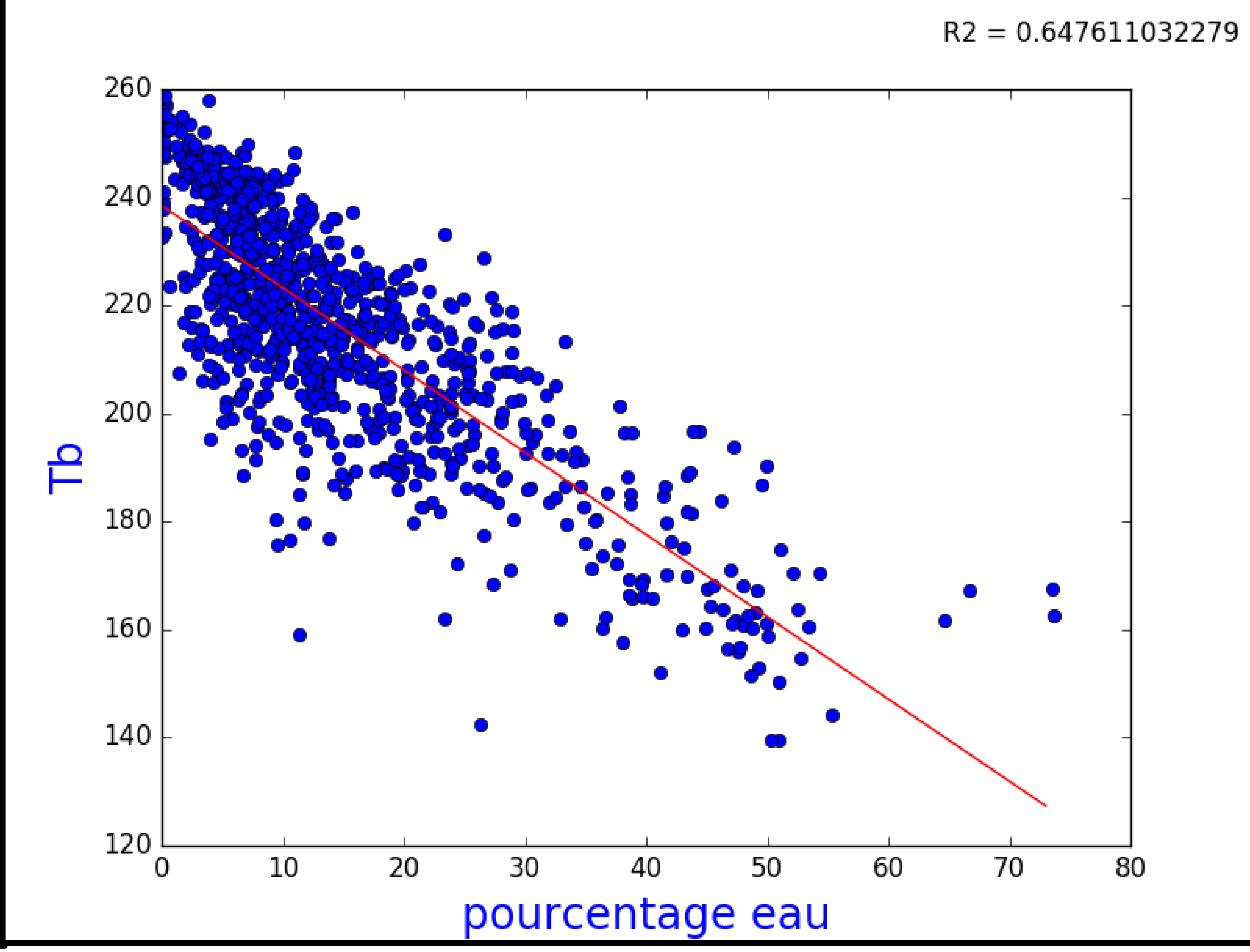
PALSAR (1-2) data



Platform	Soil Moisture Active Passive Observatory
Sensors	SMAP L-Band Radiometer
Spatial Coverage	Global between 85.044'N and 85.044'S
Spatial Resolution	36km
Temporal Coverage	31 March 2015-present
Temporal resolution	49 minutes
Parameters	Brightness Temperatures
Data format	HDF-5

Figure 10. SMAP_L1C, 2016-07-01, Umiujaq, Nunavik





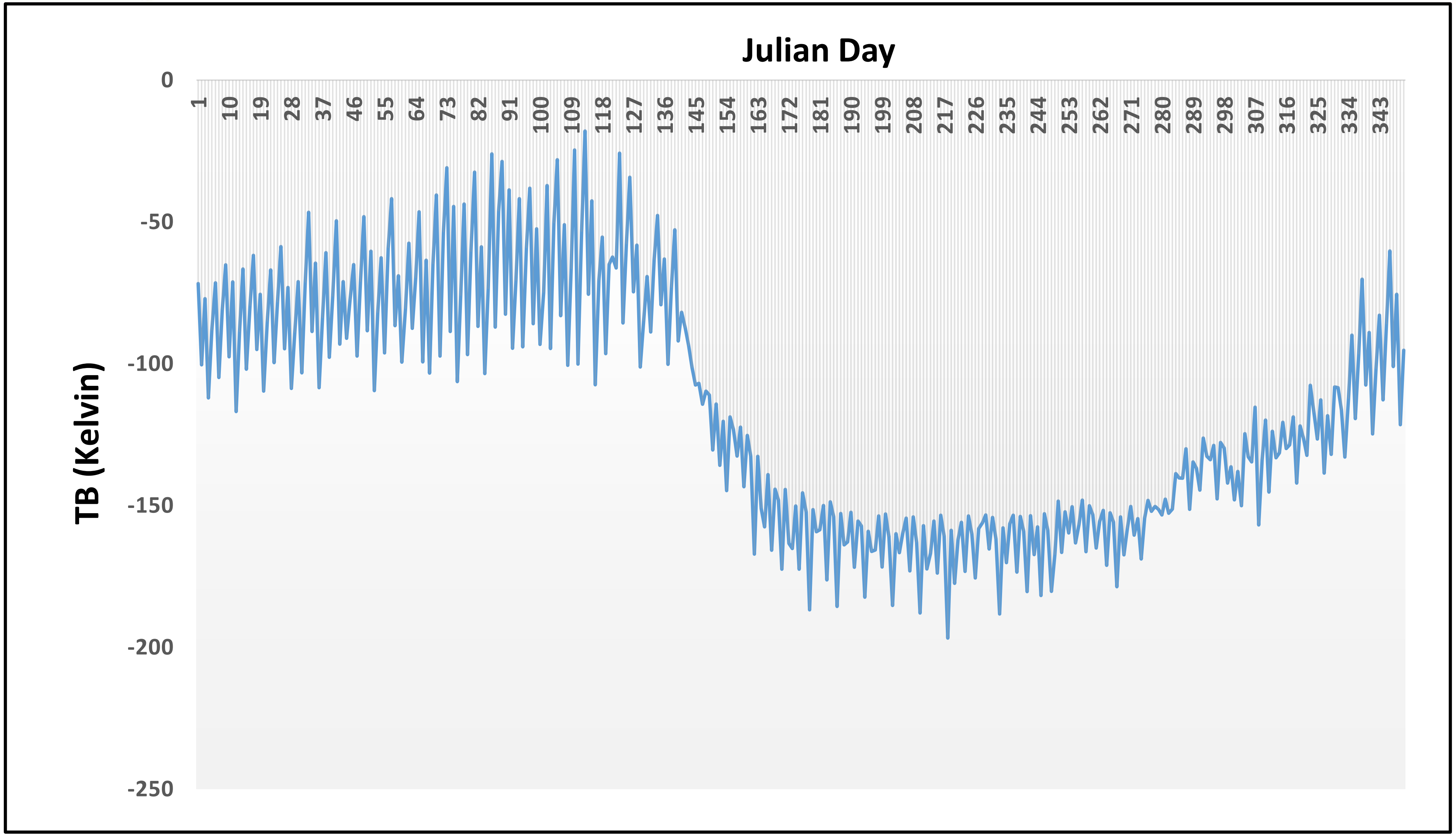
1 Jan 2015 (JJ1)

17 Sep 2015 (JJ260)

Calculate

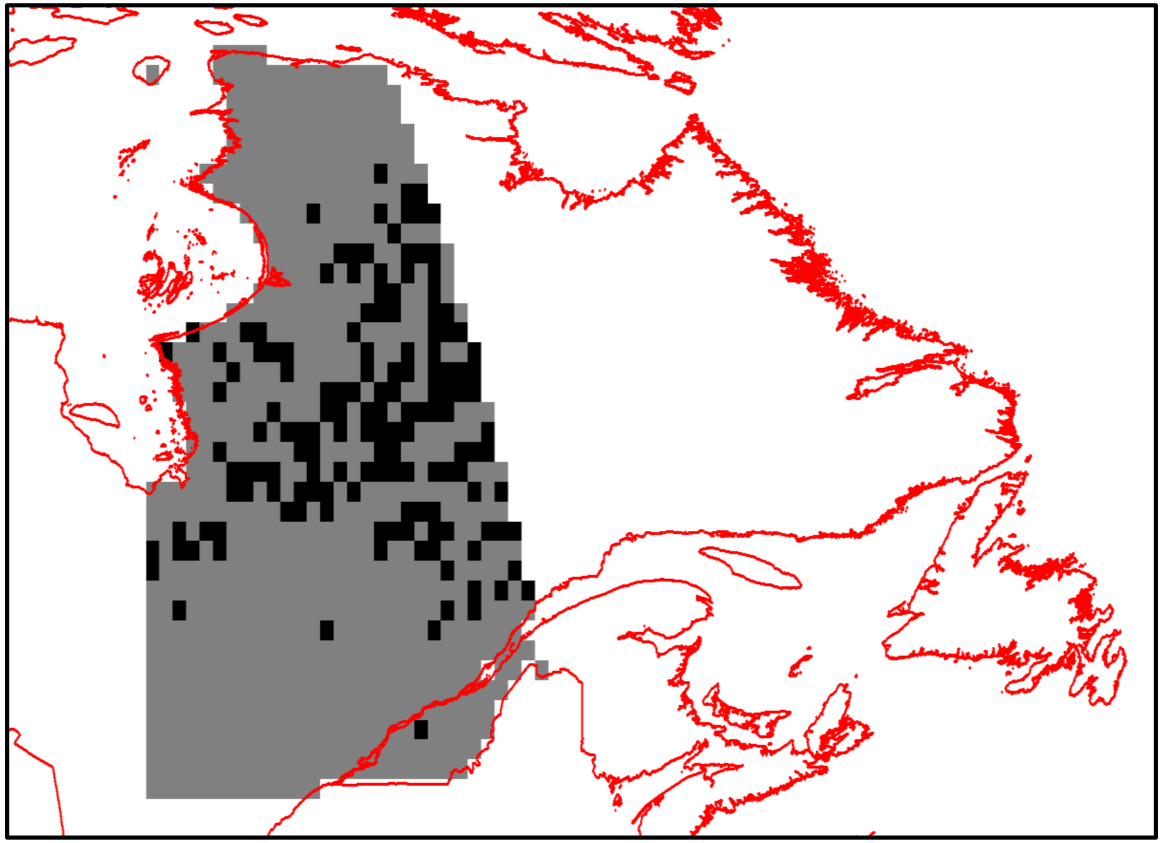
$$a_i = MLR^* P_i$$

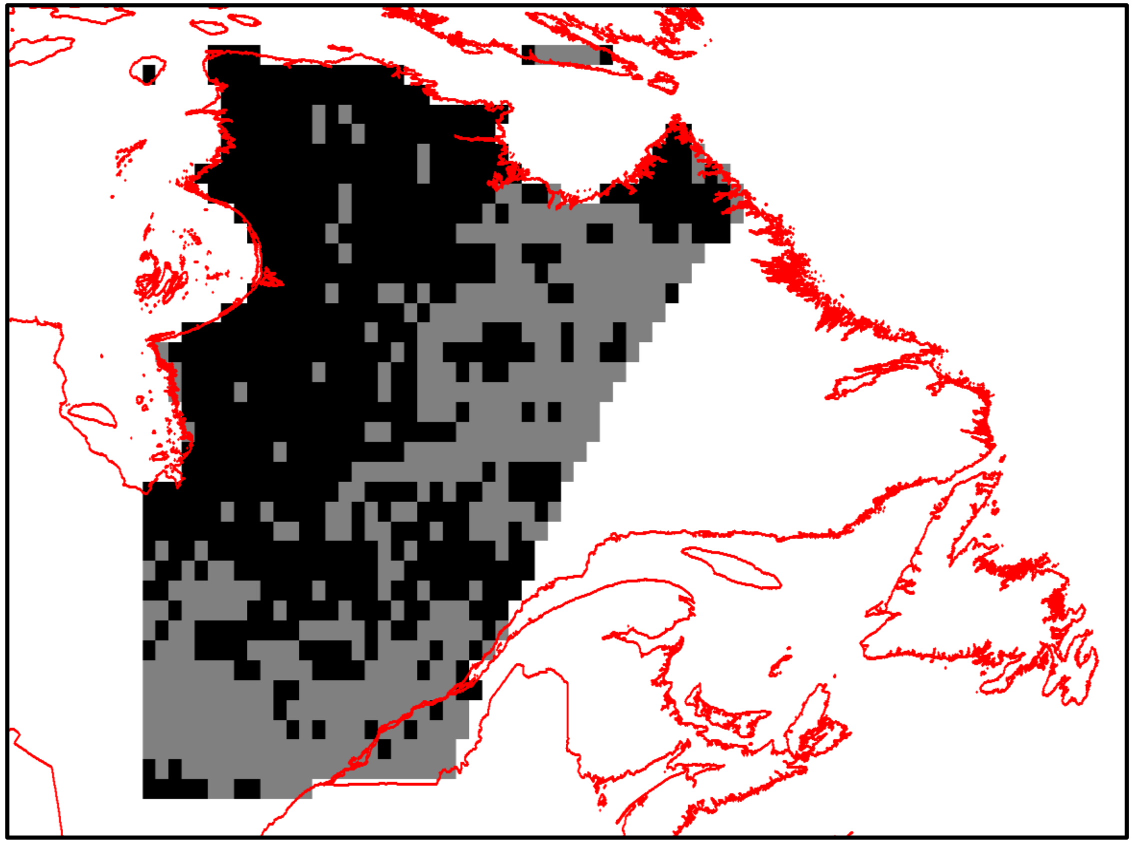
$$CT_{bp}CTbp = Tb\text{-}a_i$$



2016-slope, Umiujaq, Nunavik

Cartography





Freeze pixel

Thaw pixel

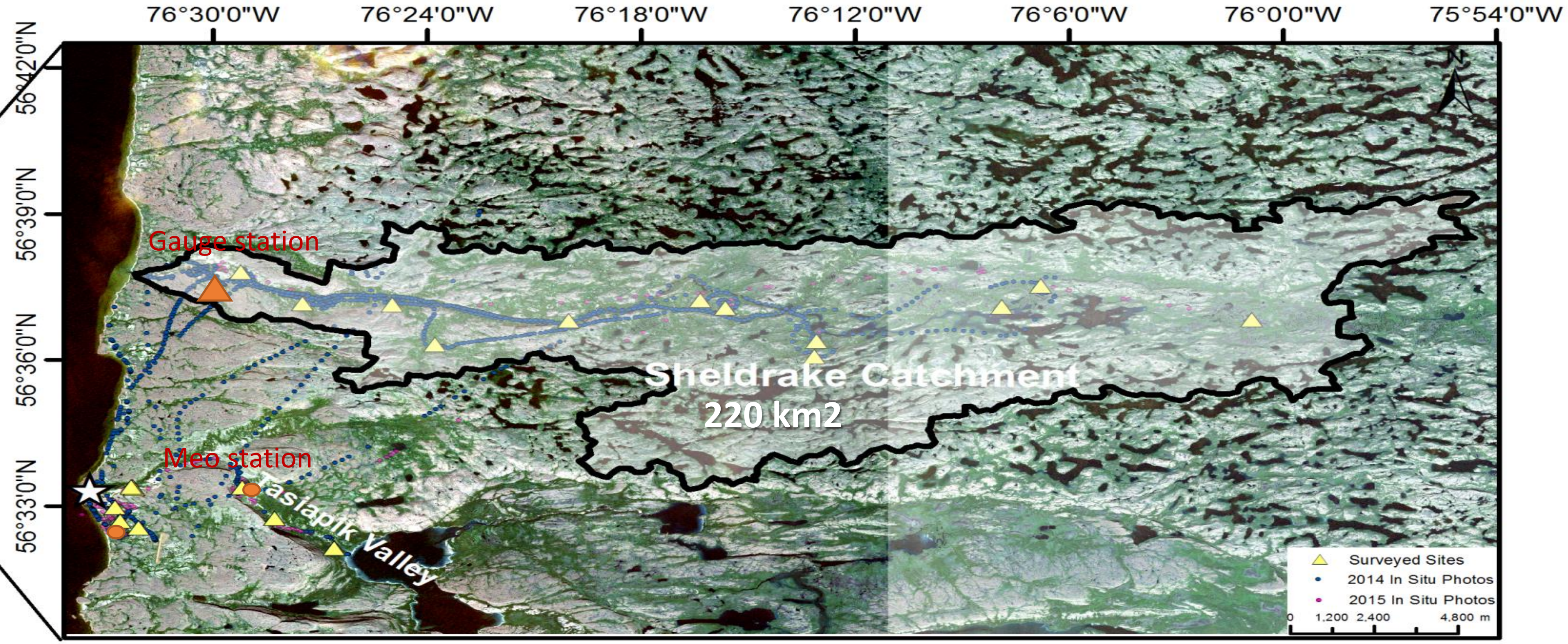
17 Sep 2015 (JJ260)

1 Jan 2015 (JJ1)

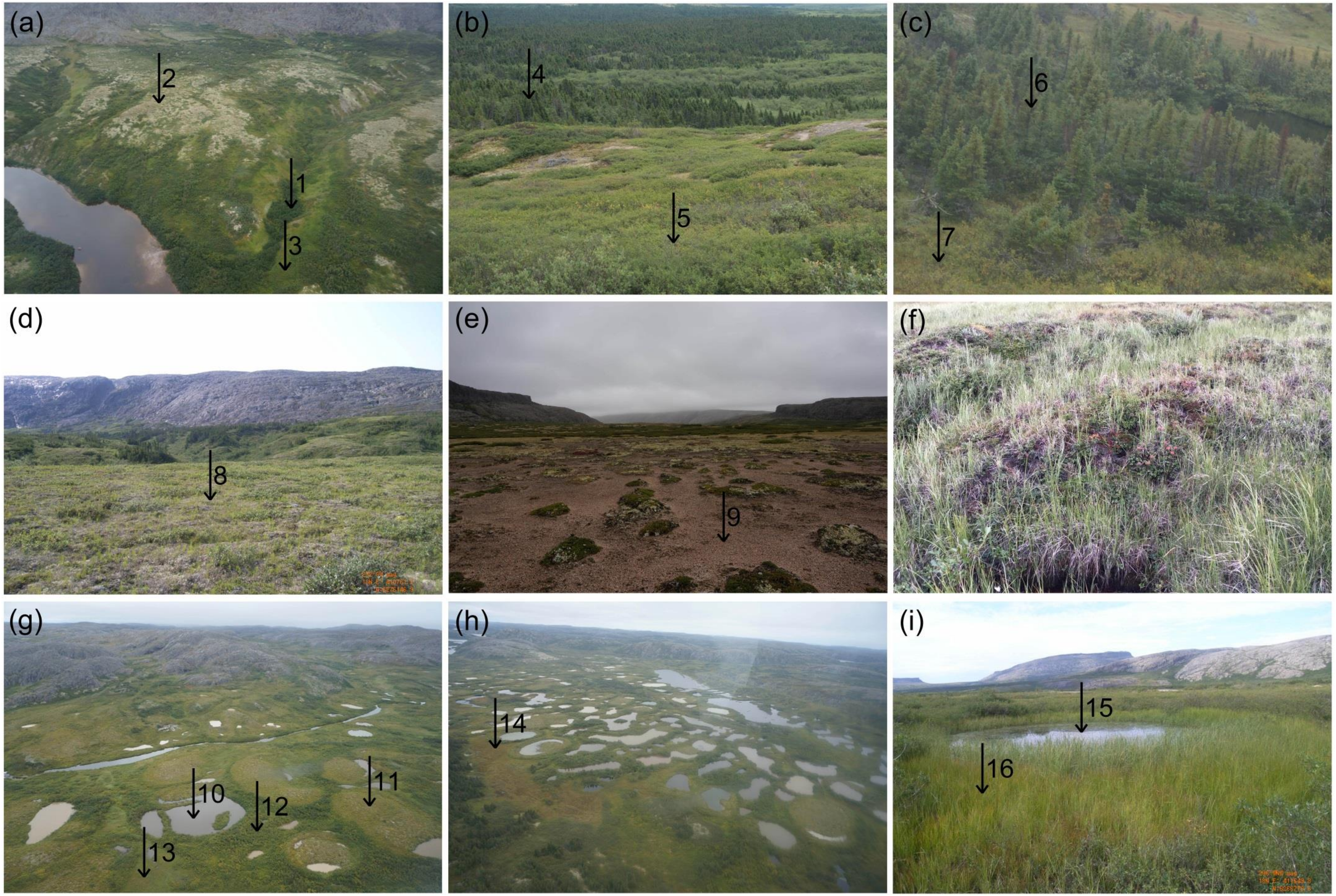
Objective 5

Hydrothermal modeling over the Canadian Tundra



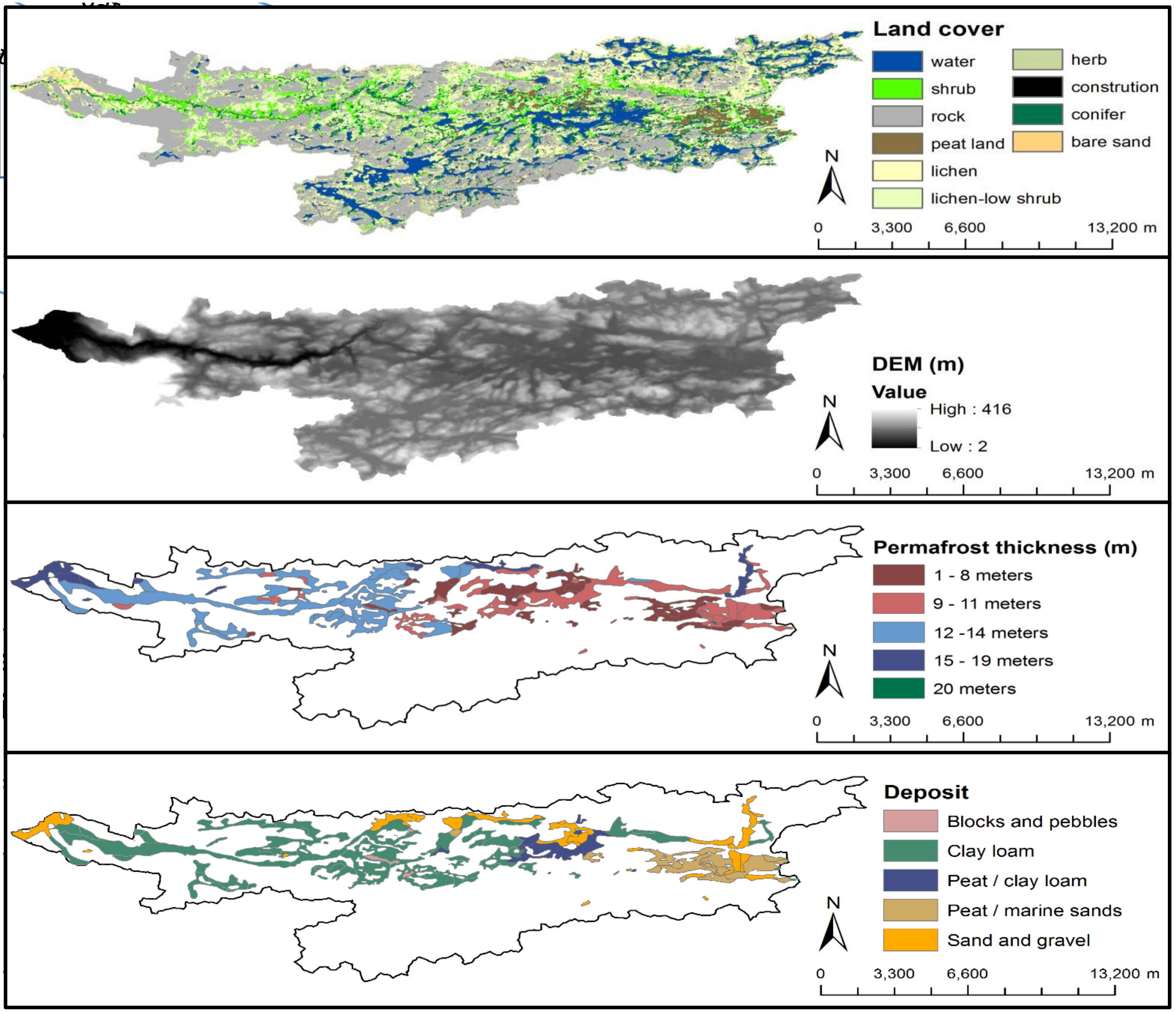



Sheldrake catchment

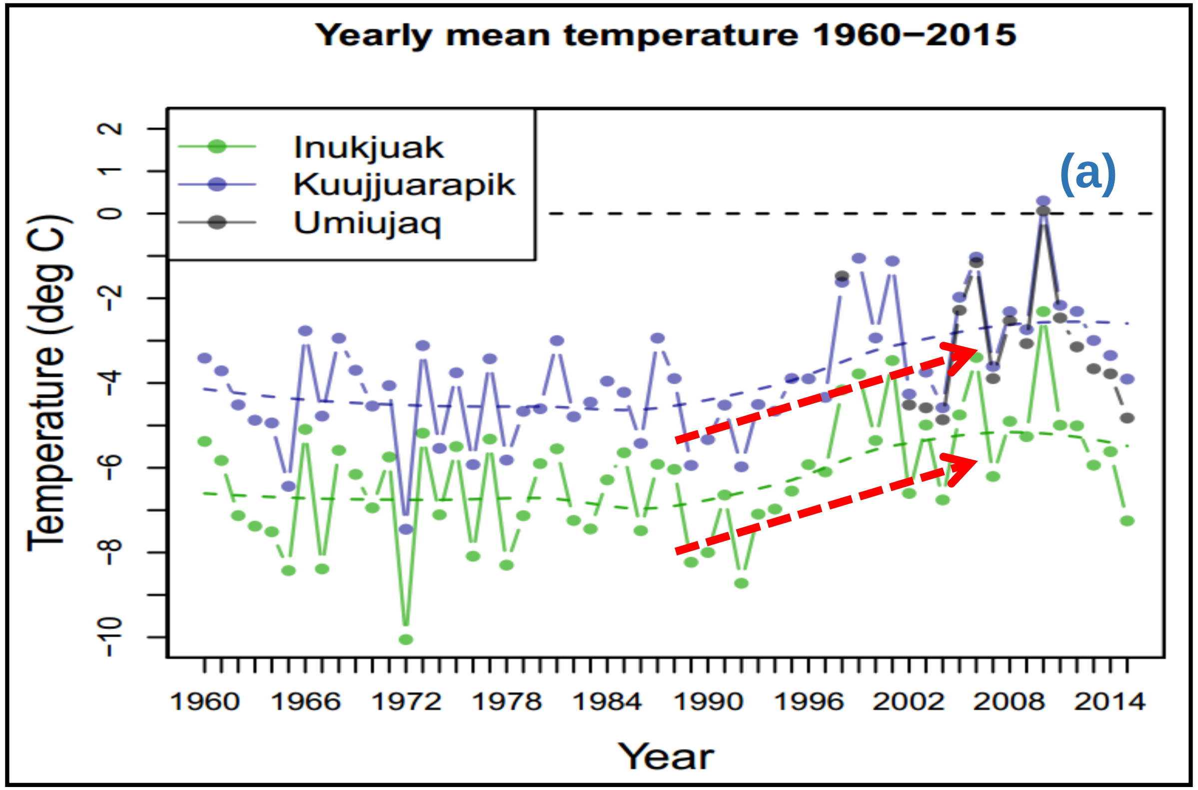


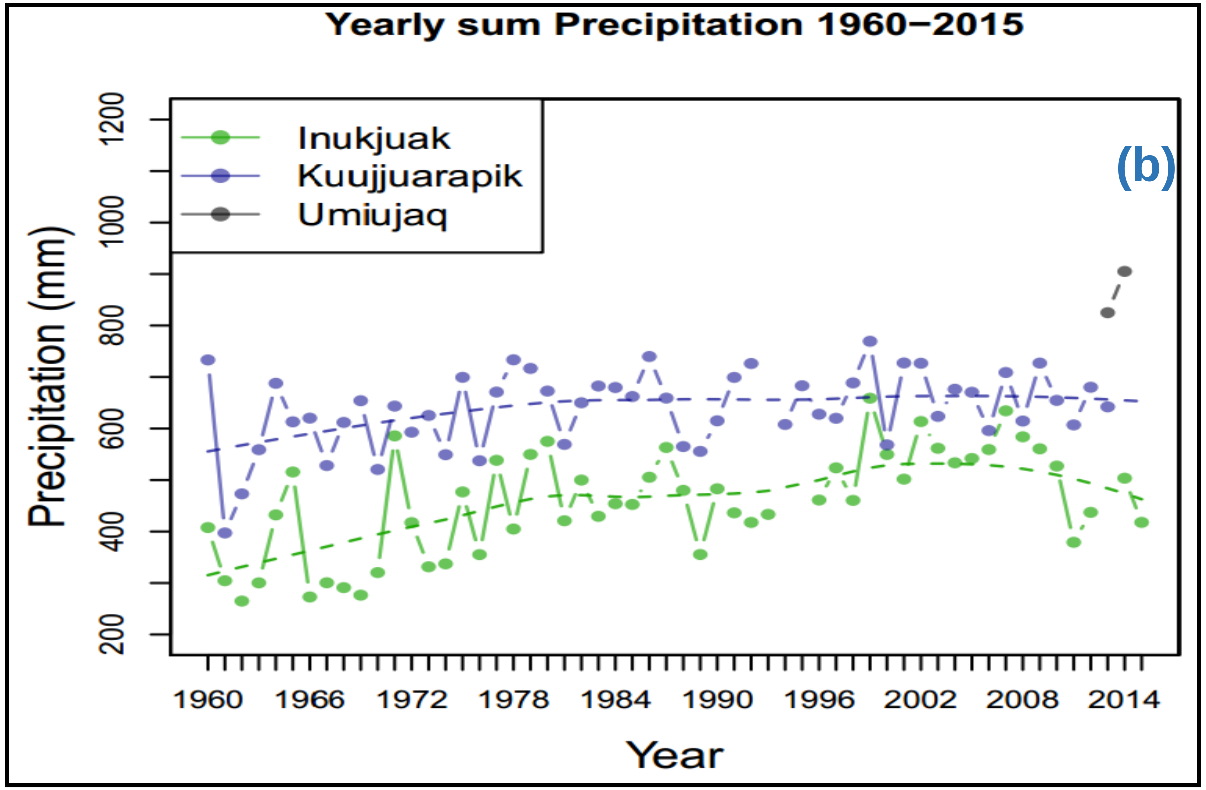
(a)
2
1
3
(b)
4
5
(c)
6
7
(d)
8
(e)
9
(f)
(g)
10
11
12
13
(h)
14
(i)
15
16

1. Database


Land cover
water
herb
shrub
constrution
rock
conifer
peat land
bare sand
lichen
lichen-low shrub
N
0
3,300
6,600
13,200 m
DEM (m)
Value
High : 416
Low : 2
N
0
3,300
6,600
13,200 m
Permafrost thickness (m)
1 - 8 meters
9 - 11 meters
12 -14 meters
15 - 19 meters
20 meters
N
0
3,300
6,600
13,200 m
Deposit
Blocks and pebbles
Clay loam
Peat / clay loam
Peat / marine sands
Sand and gravel
N
0
3,300
6,600
13,200 m

Climate conditions in Nunavik (Inukjuak, Kuujjurapik, Umiujaq)





(a) (b)

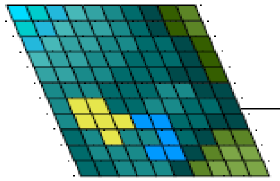
Air temperature (a) and Precipitation (b)

2. WaSiM Framework

For each time step...

input (meteorology)

precipitation correction



cell by cell

interpolation to grid

Shading and exposure adjustment for *R* and *T*

potential evaporation

snow accumulation and melt → Evaporation from snow

~~glacier model (melt and runoff)~~

interception → interception evaporation

infiltration/~~silting-up~~ generation of surface runoff → surface discharge routing

unsaturated zone incl. heat transfer → evaporation/ transpiration; interflow

saturated zone → baseflow

discharge routing incl. lakes and reservoirs

total discharge

Heat transfer model, runs side by side with the Richards equation

meteo-input:
- temperature
- wind speed
- vapour pressure
- radiation
- precipitation etc.

gridded data:
- DEM
- land use
- subcatchments
- soil types
- river network
- others

configuration:
- control file

Other features:
- Solutes transport modelling
- Temperature modelling (soil only)

The model outputs time series (statistics) and grids for all the different modules that run in WaSiM.

3. Model setting

Climate inputs	Spatial data inputs
ERA-Interim 1980-2015	Land cover (satellite image classification, 30m, 5m, dynamic process)
Temperature Precipitation Radiation Relative humidity Wind speed	Soil texture Deposits map + field sampling with lab analysis
	Land surface temperature, air temperature modified by an n-factor/vegetation
	Permafrost distribution (Interpreted from satellite image) -> bottom temperature
	Permafrost depth map -> bottom temperature

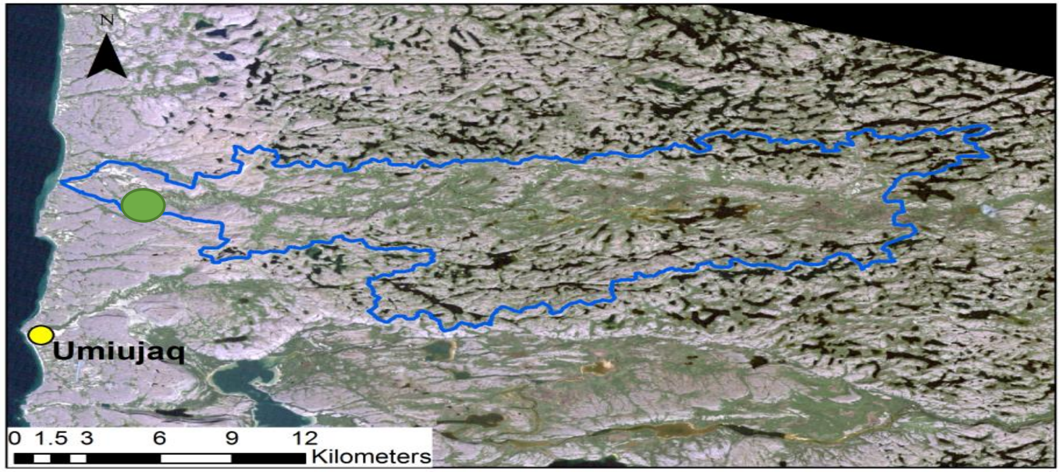
4. Model calibration and validation

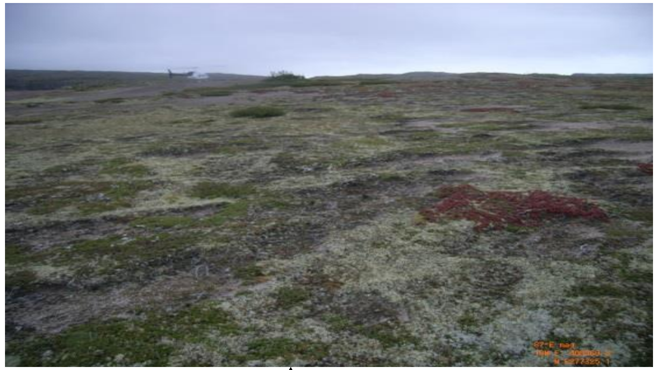
- Hydrological parameters are calibrated and validated through discharge from gauging station in the outlet of catchment from 2009 to 2015.

- Heat module is calibrated by measured active-layer thickness (2012, 2015) also with soil temperature and moisture profiles from monitoring stations in the Sheldrake catchment and also referred from the stations in the Umiujaq region (2012 to 2016).

Model simulation

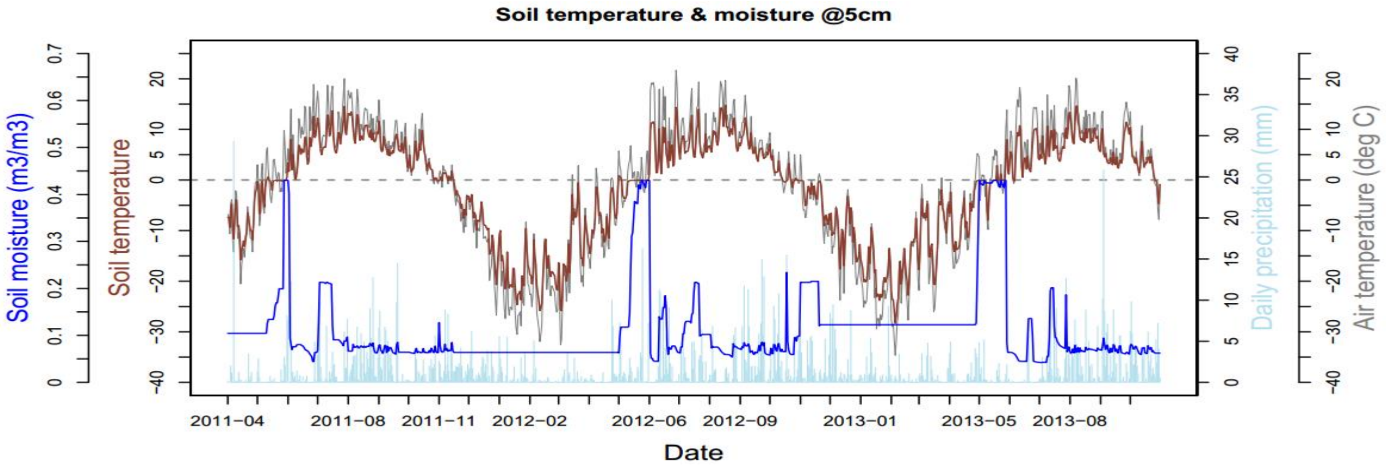
Time series soil moisture and temperature profile

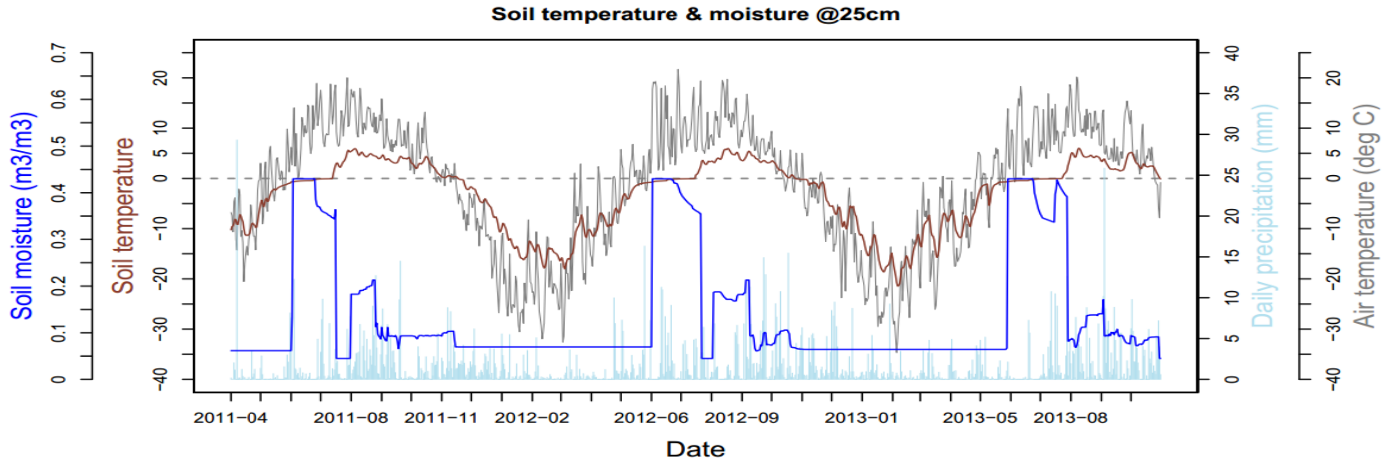


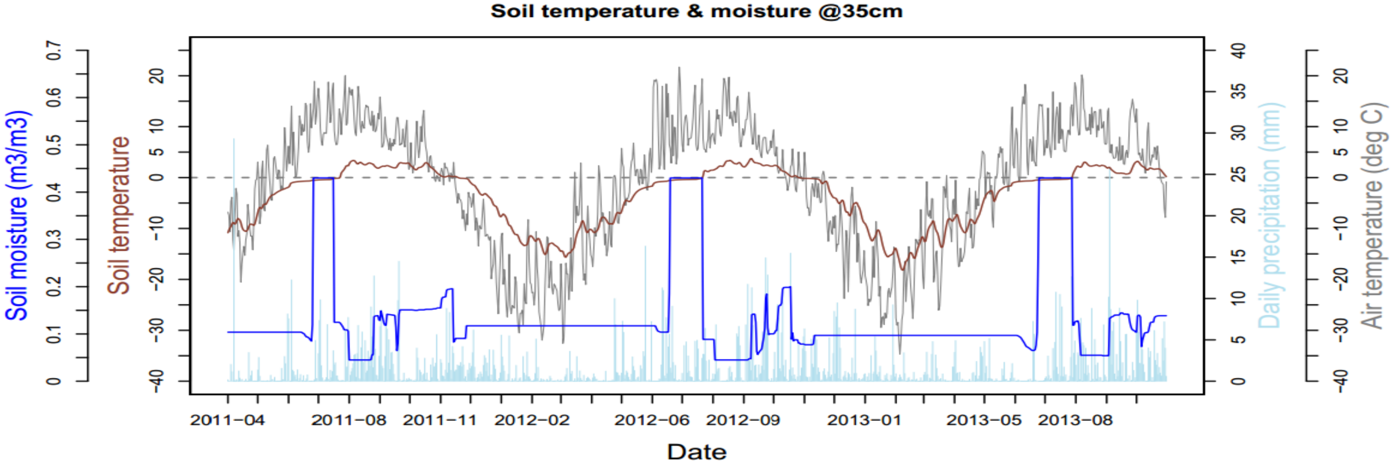


Vegetation:
lichen with prostrate shrub

Soil: coarse sand
With deep permafrost

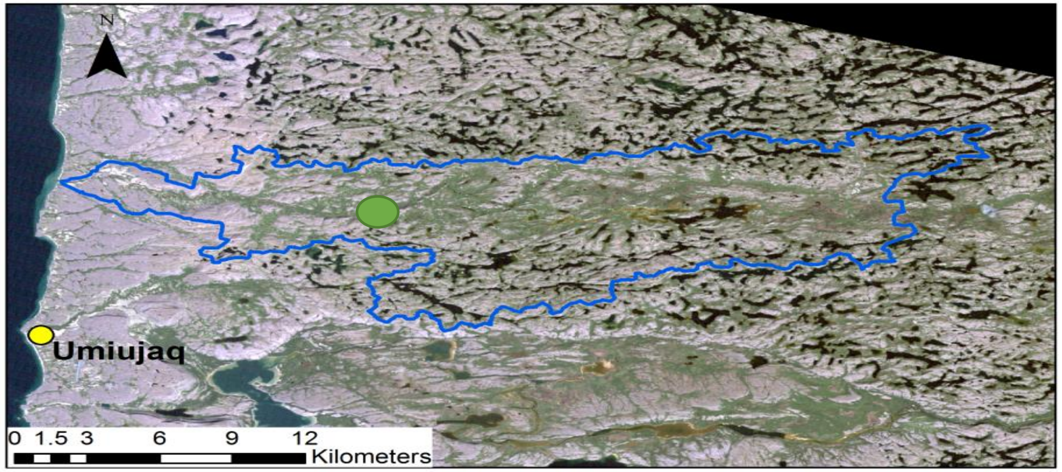


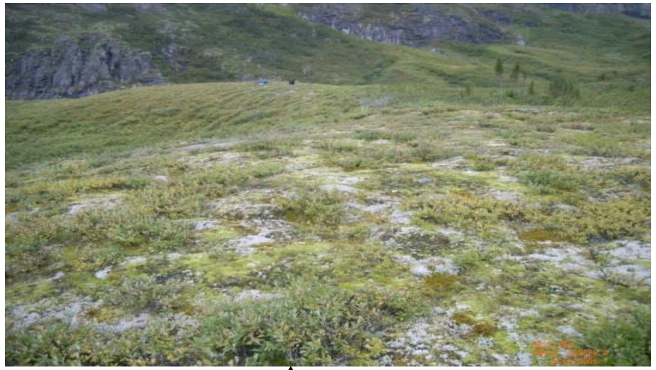




Model simulation

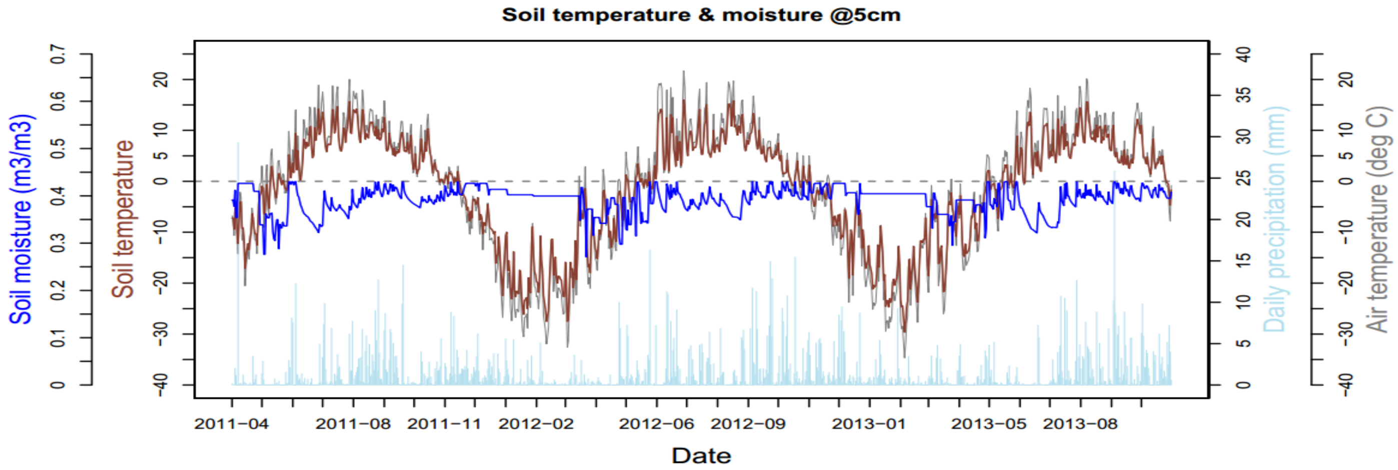
Time series soil moisture and temperature profile

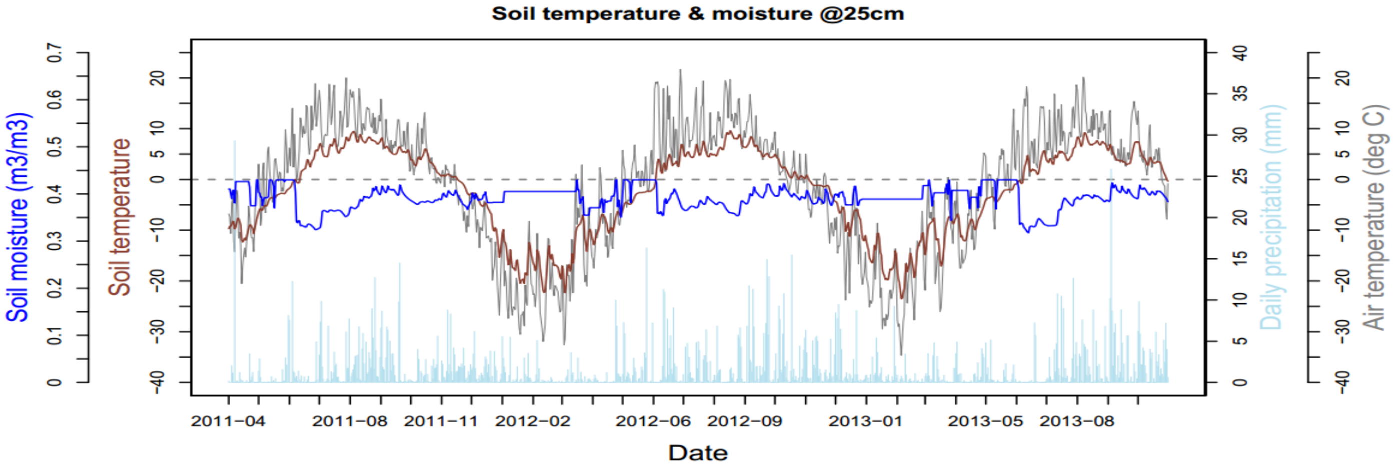


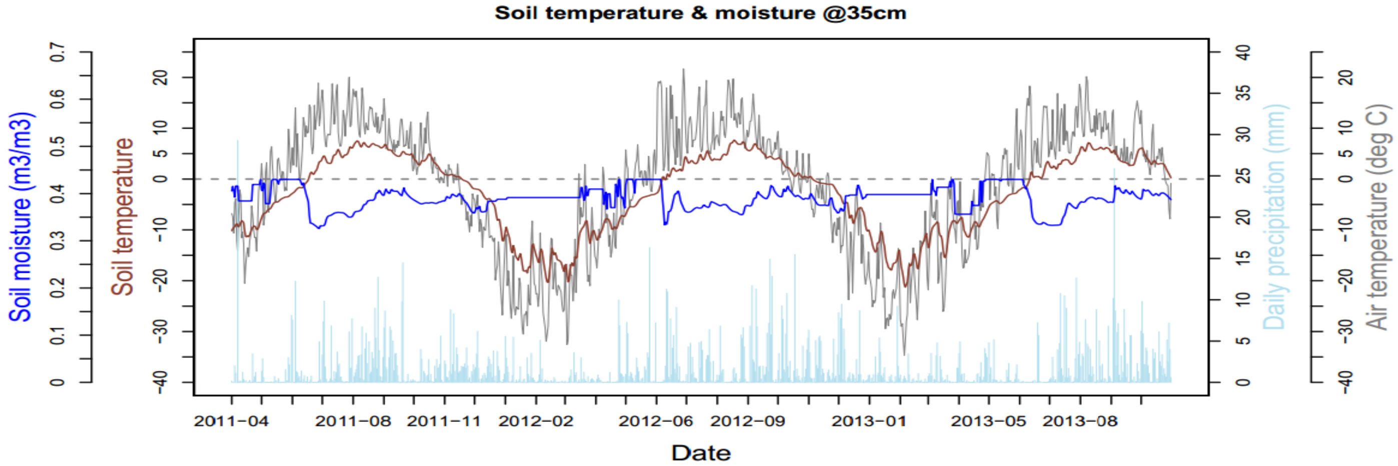


Vegetation:
lichen with prostrate shrub

Soil: Silt clay
With surface permafrost

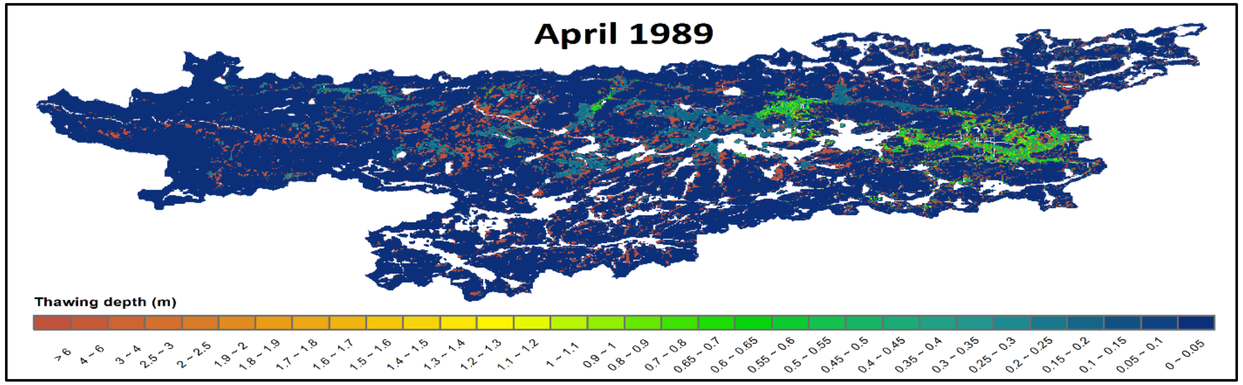


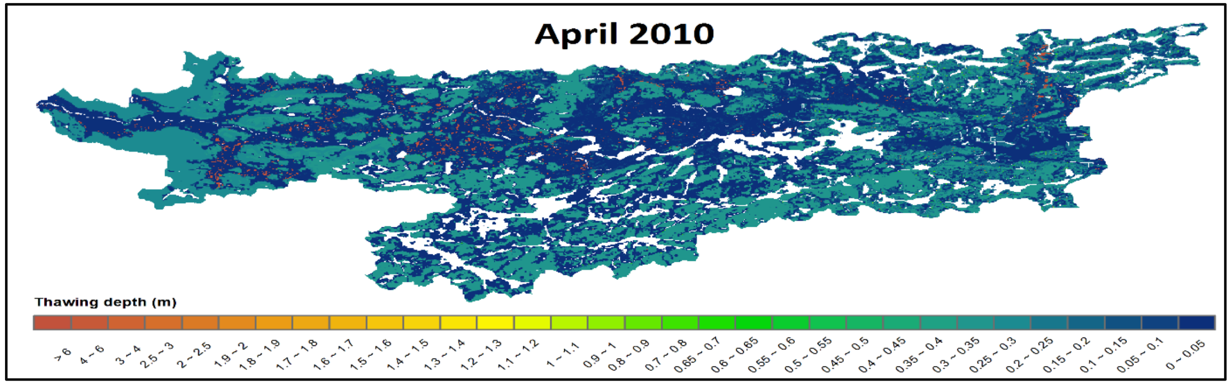


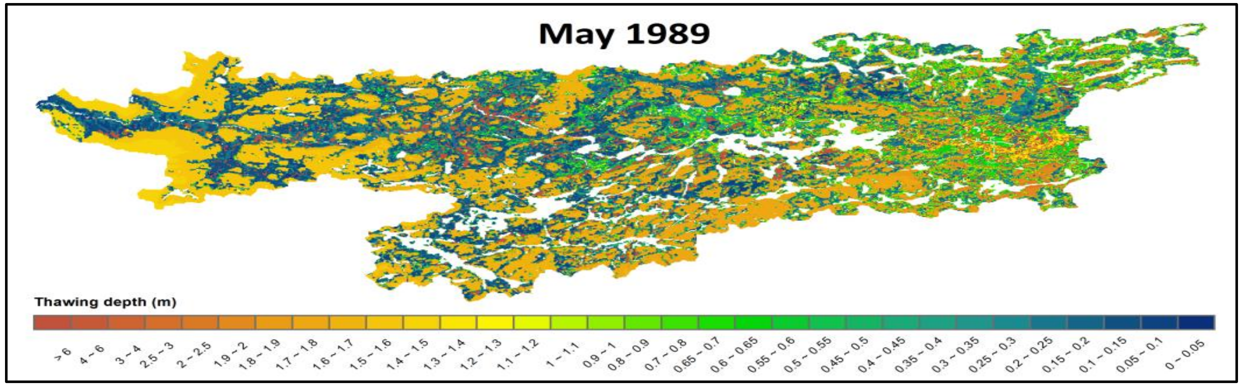


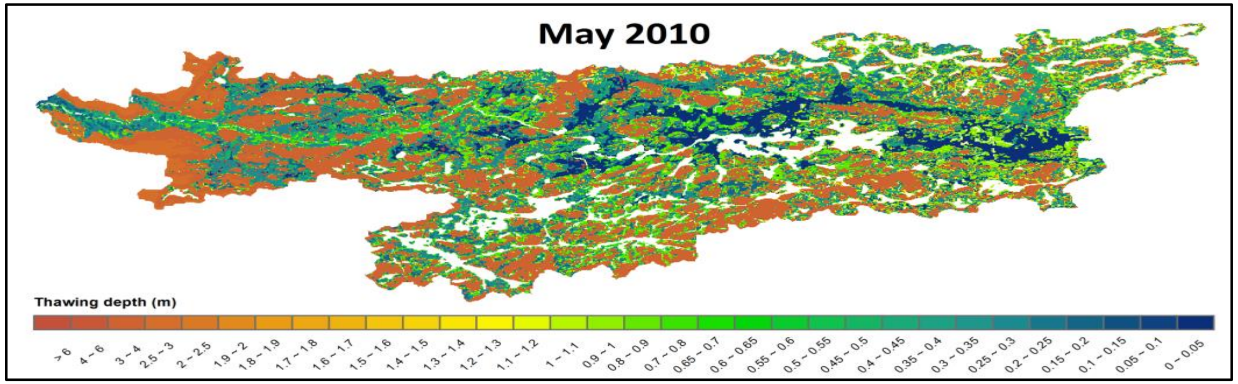
Model simulation

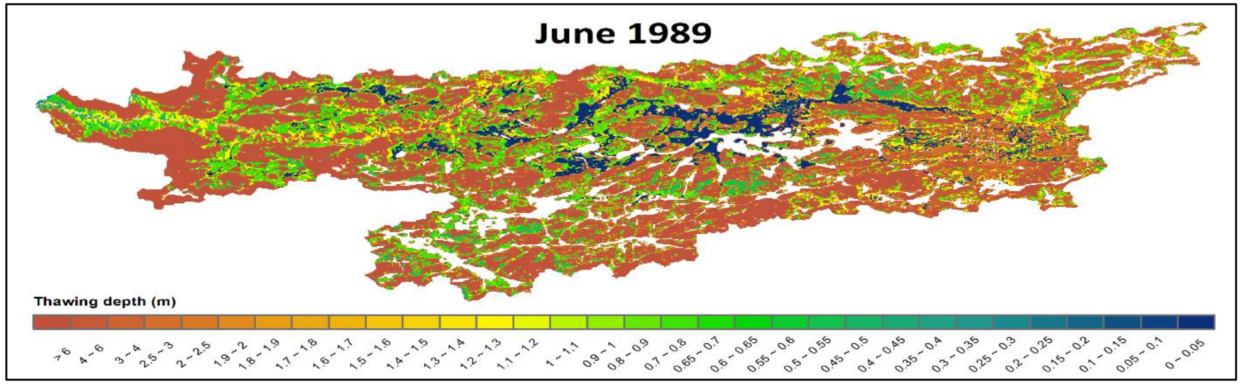
Monthly mean thawing depth

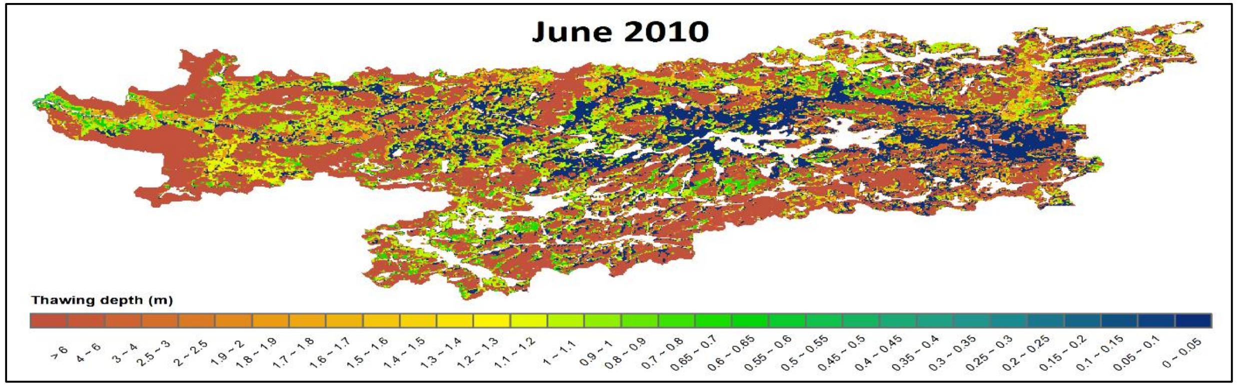


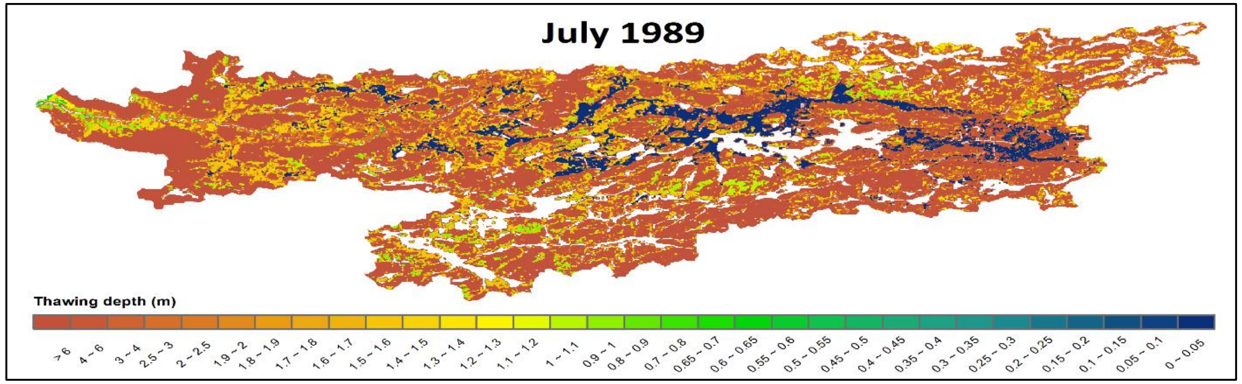


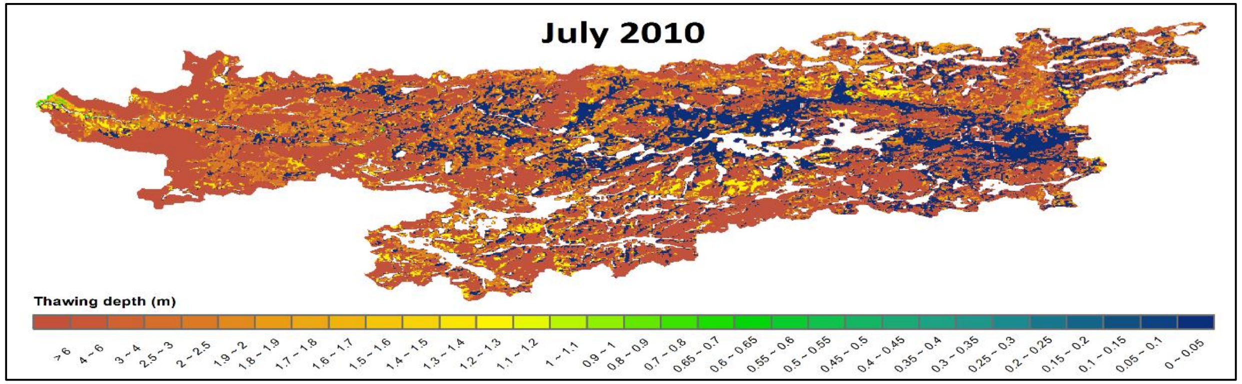





June 1989
Thawing depth (m)
>6
4~6
3~4
2.5~3
2~2.5
1.9~2
1.8~1.9
1.7~1.8
1.6~1.7
1.5~1.6
1.4~1.5
1.3~1.4
1.2~1.3
1.1~1.2
1~1.1
0.9~1
0.8~0.9
0.7~0.8
0.65~0.7
0.6~0.65
0.55~0.6
0.5~0.55
0.45~0.5
0.4~0.45
0.35~0.4
0.3~0.35
0.25~0.3
0.2~0.25
0.15~0.2
0.1~0.15
0.05~0.1
0~0.05

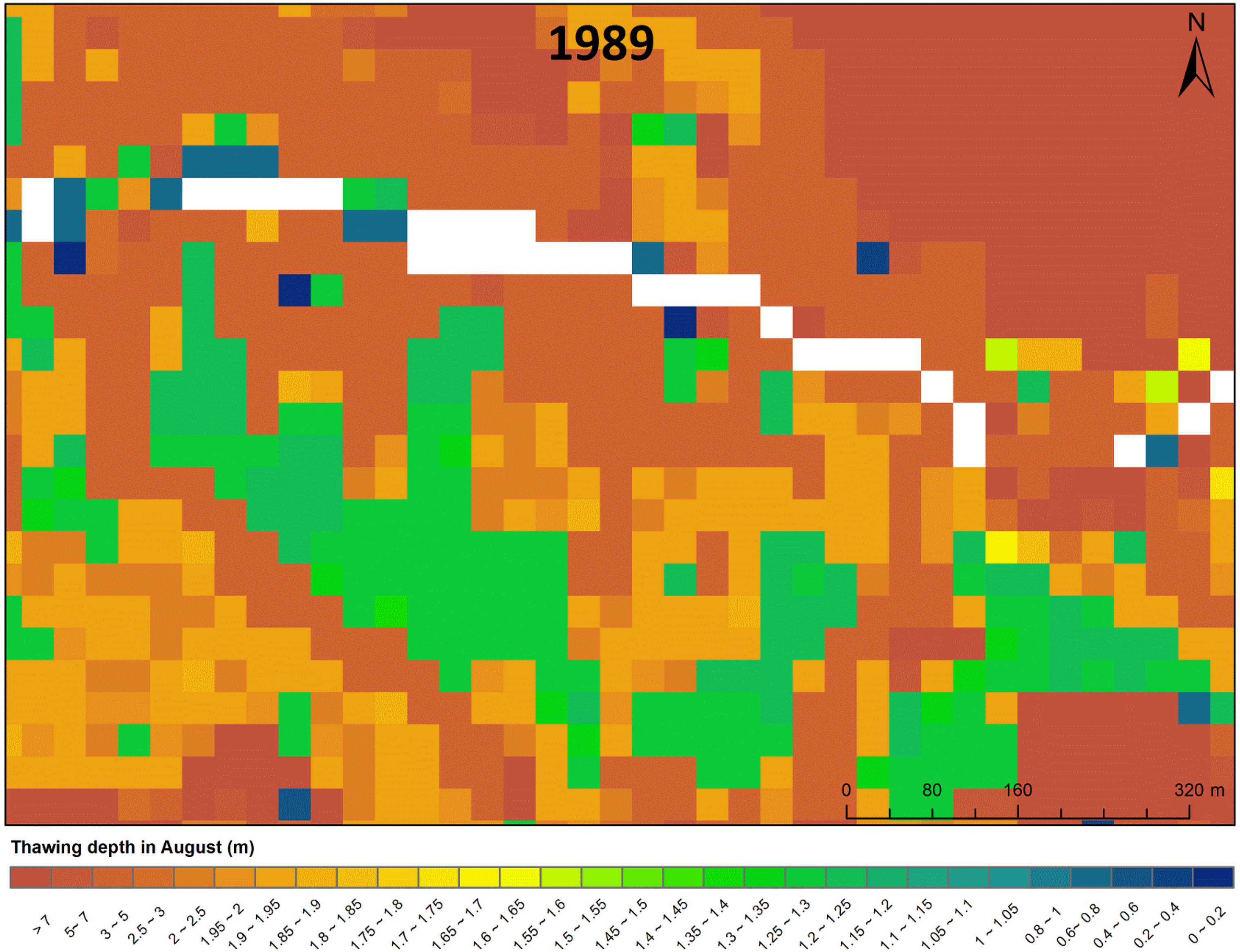

June 2010
Thawing depth (m)
>6
4~6
3~4
2.5~3
2~2.5
1.9~2
1.8~1.9
1.7~1.8
1.6~1.7
1.5~1.6
1.4~1.5
1.3~1.4
1.2~1.3
1.1~1.2
1~1.1
0.9~1
0.8~0.9
0.7~0.8
0.65~0.7
0.6~0.65
0.55~0.6
0.5~0.55
0.45~0.5
0.4~0.45
0.35~0.4
0.3~0.35
0.25~0.3
0.2~0.25
0.15~0.2
0.1~0.15
0.05~0.1
0~0.05


July 1989
Thawing depth (m)
>6
4~6
3~4
2.5~3
2~2.5
1.9~2
1.8~1.9
1.7~1.8
1.6~1.7
1.5~1.6
1.4~1.5
1.3~1.4
1.2~1.3
1.1~1.2
1~1.1
0.9~1
0.8~0.9
0.7~0.8
0.65~0.7
0.6~0.65
0.55~0.6
0.5~0.55
0.45~0.5
0.4~0.45
0.35~0.4
0.3~0.35
0.25~0.3
0.2~0.25
0.15~0.2
0.1~0.15
0.05~0.1
0~0.05


July 2010
Thawing depth (m)
>6
4~6
3~4
2.5~3
2~2.5
1.9~2
1.8~1.9
1.7~1.8
1.6~1.7
1.5~1.6
1.4~1.5
1.3~1.4
1.2~1.3
1.1~1.2
1~1.1
0.9~1
0.8~0.9
0.7~0.8
0.65~0.7
0.6~0.65
0.55~0.6
0.5~0.55
0.45~0.5
0.4~0.45
0.35~0.4
0.3~0.35
0.25~0.3
0.2~0.25
0.15~0.2
0.1~0.15
0.05~0.1
0~0.05

Model simulation

thawing depth in August (m)



Thank you for your attention

Pour Monique

- The Water balance Simulation Model WaSiM (Schulla & Jasper 2006) uses a mixture of conceptual approaches and physically based algorithms to describe hydrological processes. Infiltration of water into the soil and the surface runoff generation is computed after Green & Ampt (1911) using the two step model approach after Peschke (1987). The calculation of the vertical water fluxes in the unsaturated zone is done by the discrete Richards Equation. Soil moisture content is parameterized considering suction head and hydraulic conductivity according to van Genuchten (1976). Interflow is generated in defined different soil layers depending on drainable water content, suction, the hydraulic conductivity and gradient. Surface runoff is routed using a subdivision of the basin into flow time zones. Interception is considered using a simple bucket approach with a leaf area index dependent storage capacity. Evapotranspiration is calculated following the approach of Penman-Monteith (Monteith 1975). WaSiM contains a simple 2D groundwater model which is dynamically coupled to the unsaturated zone.