The Canadian Experiment for Freeze / Thaw in 2012 or 2013 (CanEx-FT12 or FT13)

Stephane Belair (EC/MRD)
Monique Bernier (INRS-ETE)
Andreas Colliander (JPL)
Thomas Jackson (USDA)
Kyle McDonald (JPL / CCNY)
Anne Walker (EC/CRD)

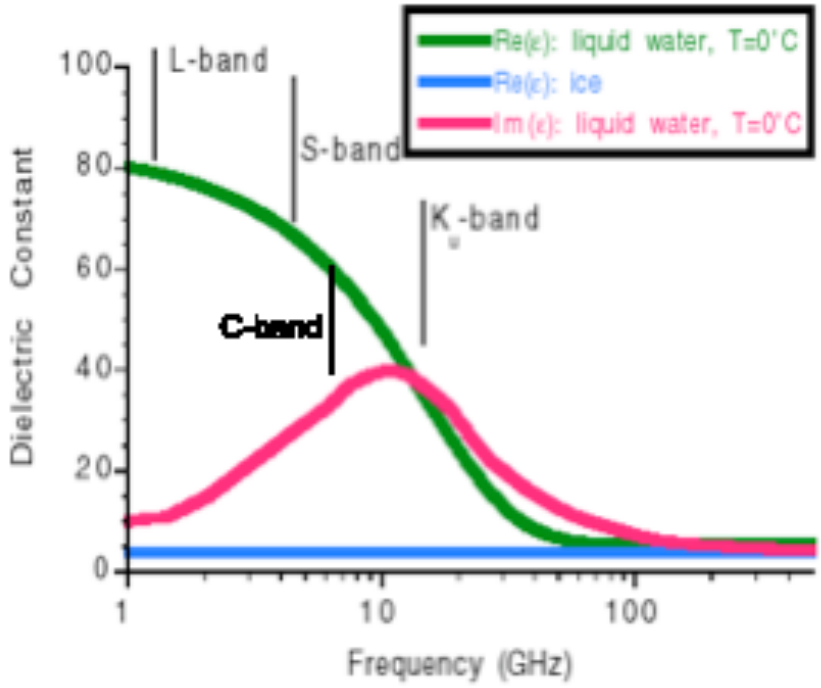
Collaboratively:
Environment Canada (EC)
Institut National de Recherche Scientifique, U. Quebec, Canada (INRS)
Jet Propulstion Laboratory, California Institute of Technology (JPL)
United Stated Department of Agriculture (USDA)
National Aeronautics and Space Administration (NASA)
Canadian Space Agency (CSA)

GENERAL OBJECTIVES

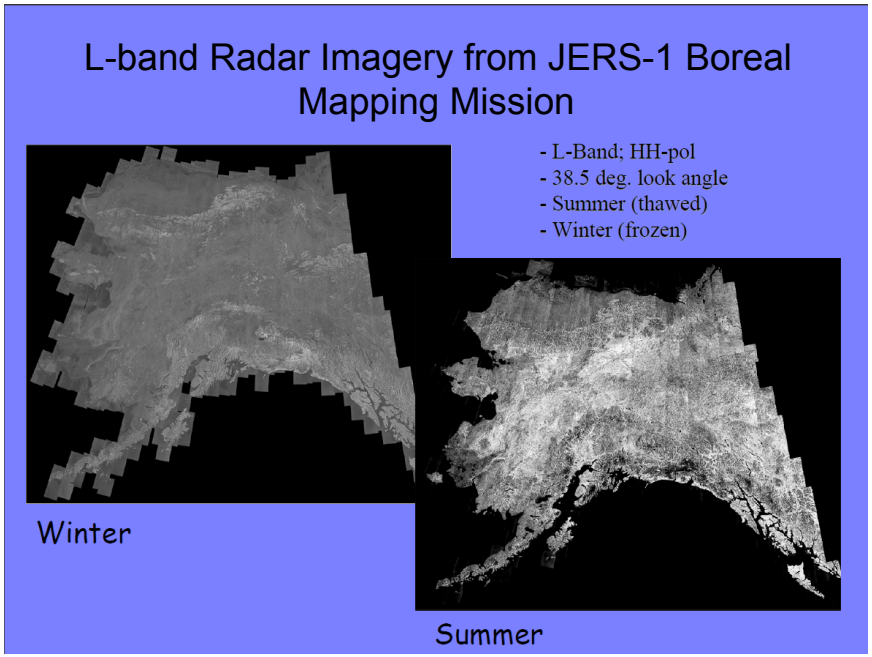
- ***Pre-launch Cal / Val of SMAP F/T products and retrieval algorithms***

- ***Rehearsal for SMAP post launch validation***

L-Band SENSITIVITY to LANDSCAPE F/T



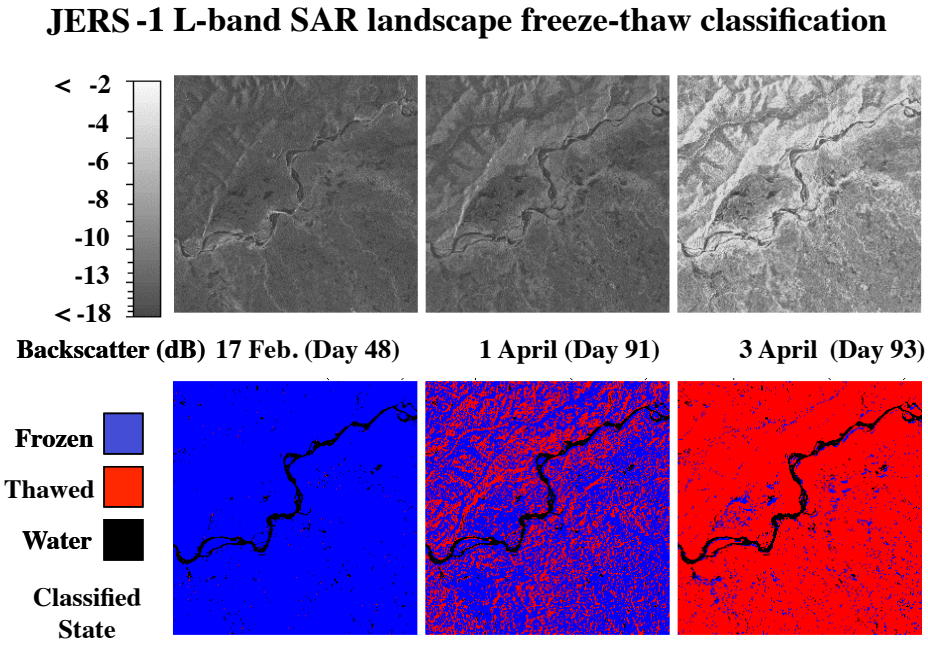
Large (3-7 *dB*) L-band signal response to landscape freeze-thaw events



The basis of the radar freeze-thaw measurement is the large shift in dielectric constant and backscatter (*dB*) between predominantly frozen & thawed conditions. The Dielectric constant of liquid water varies with frequency, whereas that of pure ice is constant (Left);
longer (L-band) frequencies have generally greater soil-vegetation sensitivity & larger freeze-thaw signal relative to higher frequency channels.

(Courtesy of John Kimball)

Bonanza Creek Experimental Forest, Alaska



Seasonal Threshold Algorithm

$$\Delta(t) = [\sigma^0(t) - \sigma^0_{fr}] / [\sigma^0_{th} - \sigma^0_{fr}]$$

σ^0_{fr} = frozen reference

σ^0_{th} = thawed reference

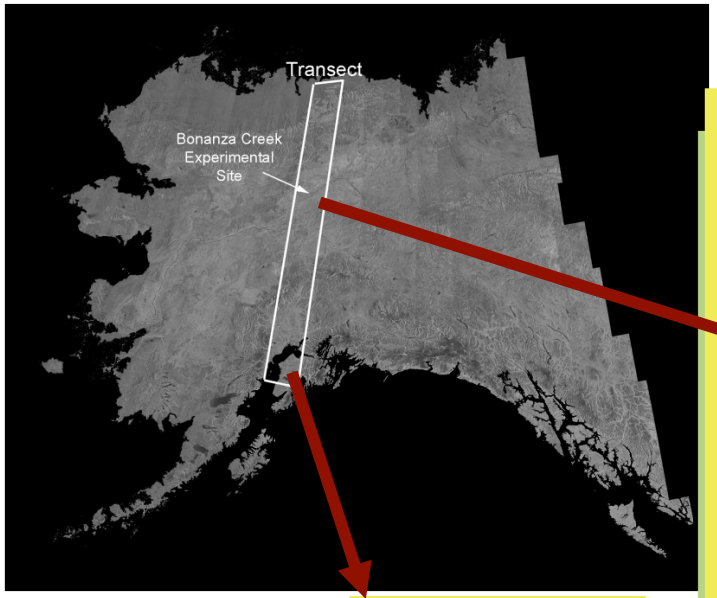
T = threshold

$\Delta(t) > T$ (Thawed)

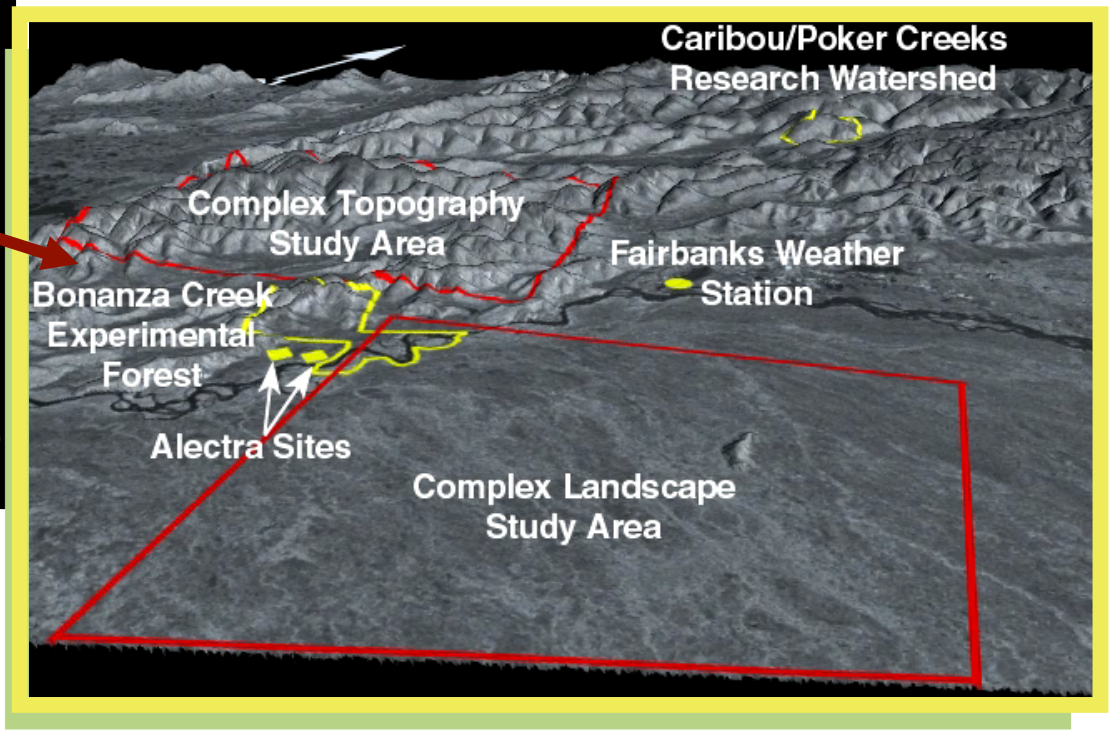
$\Delta(t) \leq T$ (Frozen)

Comparison with in situ data

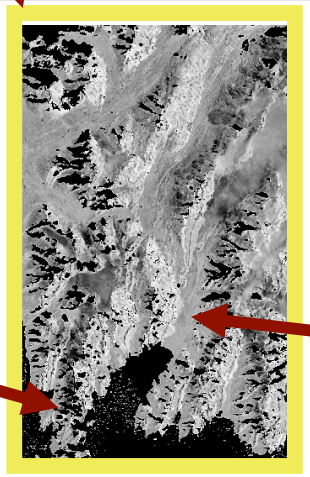
Freeze/Thaw Monitoring: Alaska



Interior Alaska



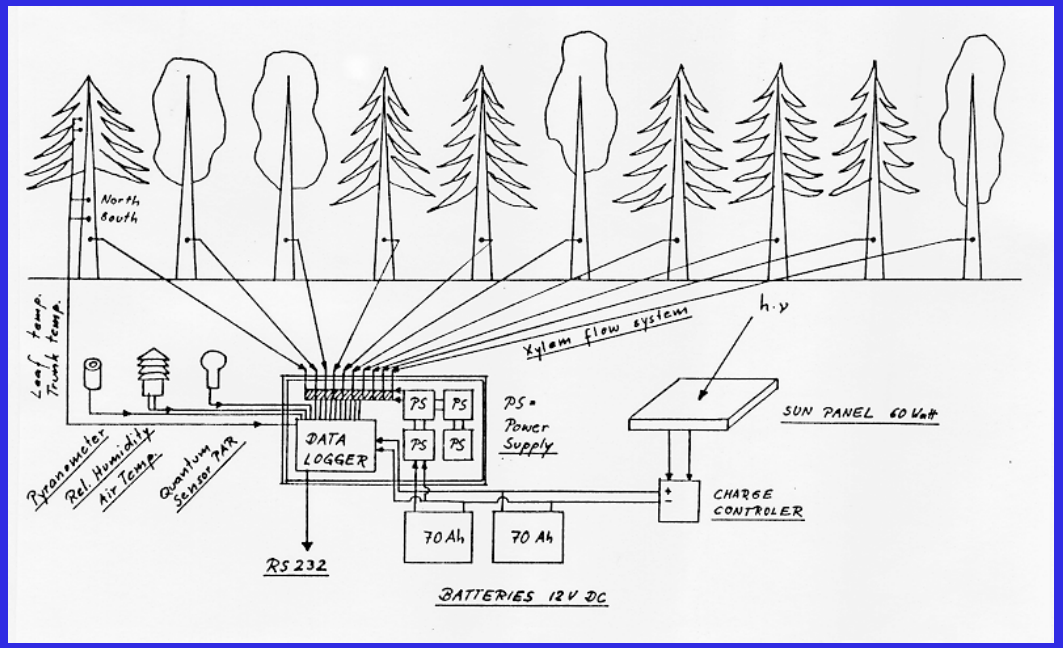
Kenai Peninsula



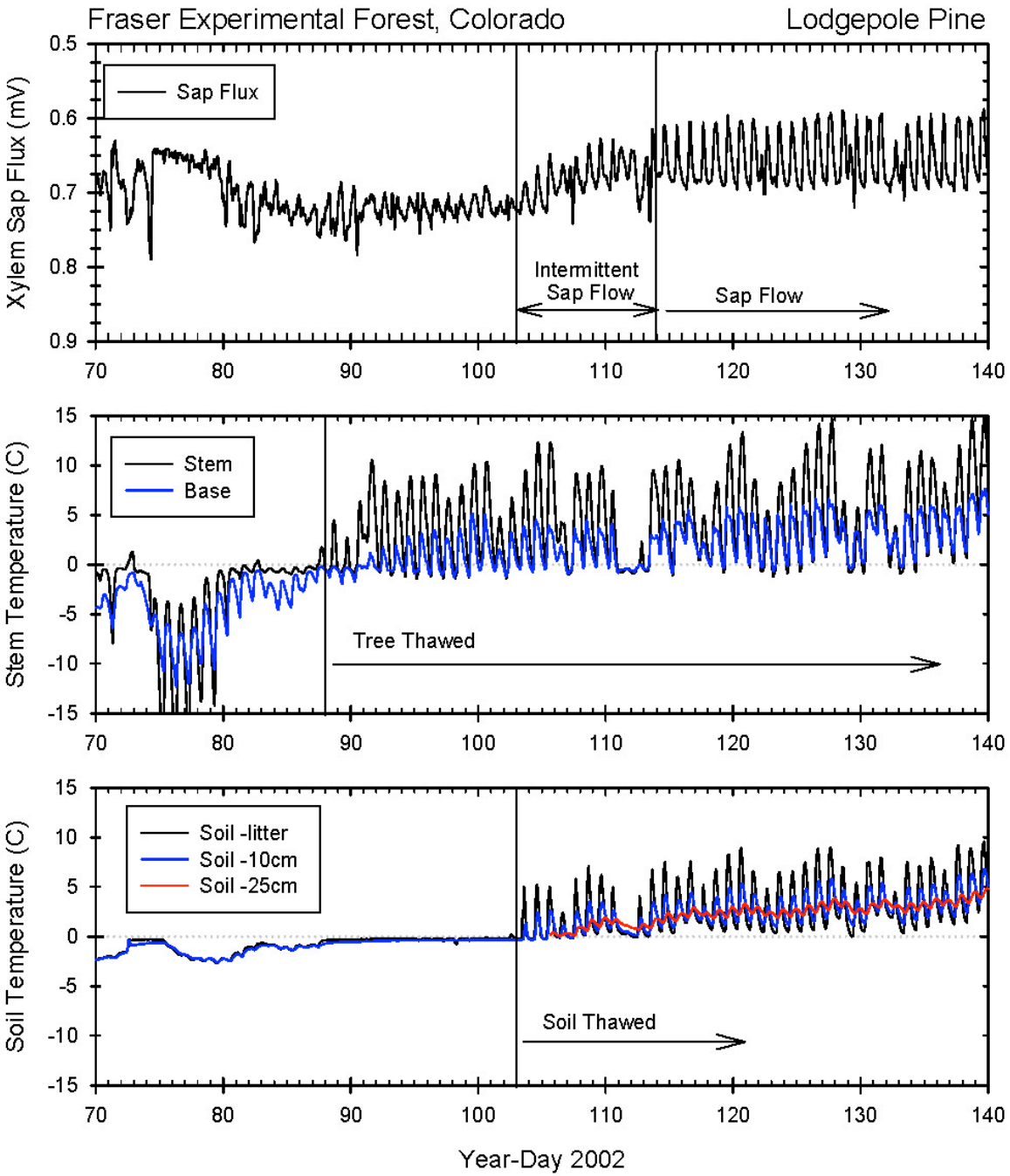
Resurrection Peninsula

Ellsworth Glacier

In Situ Biophysical Measurements

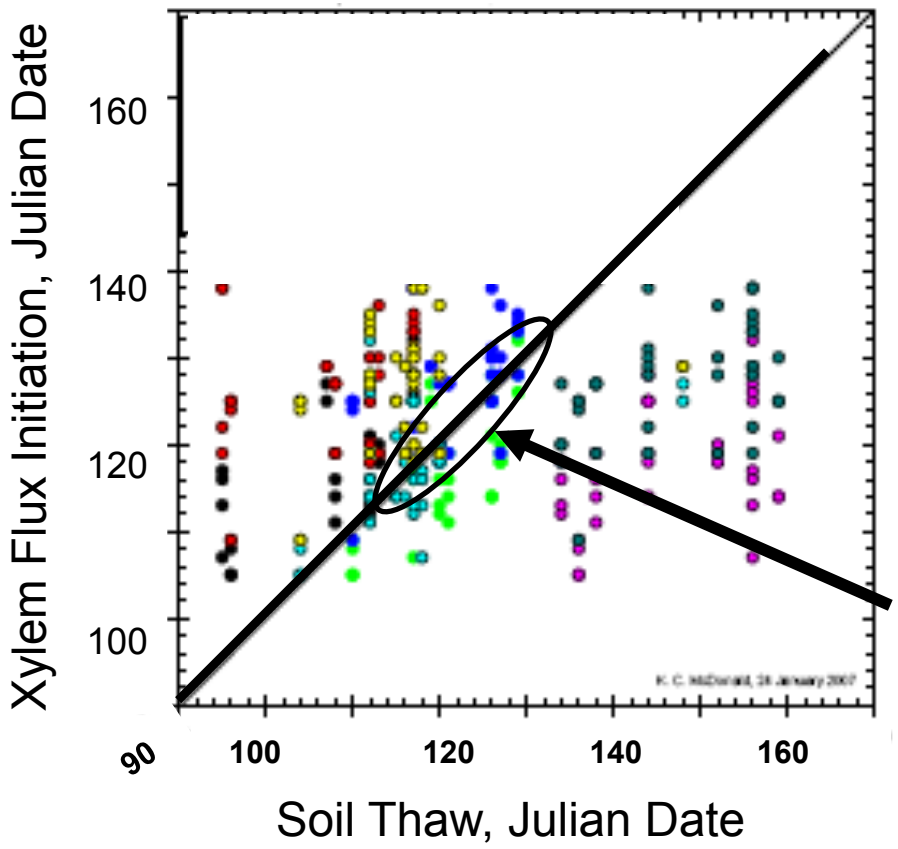


Station Set-up


Fraser Experimental Forest, Colorado
Lodgepole Pine
Xylem Sap Flux (mV)
Sap Flux
Intermittent Sap Flow
Sap Flow
Stem Temperature (C)
Stem
Base
Tree Thawed
Soil Temperature (C)
Soil -litter
Soil -10cm
Soil -25cm
Soil Thawed
Year-Day 2002

K.C.McDonald in prep

BC LTER White Spruce



X=Y line is Best Proxy for onset of growing season (litter, 10cm important)

Xylem Flux

Continuous
Intermittent

Start Finish

Thaw of Litter

Xylem Flux

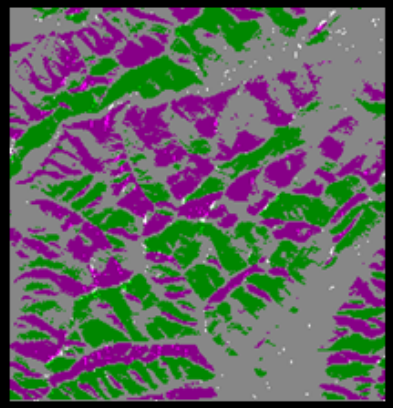
Continuous
Intermittent

Start Finish

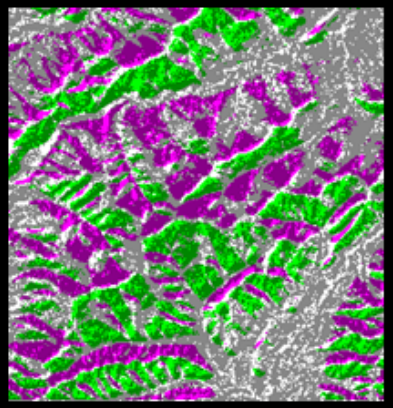
Thaw at 10cm

Freeze/Thaw Monitoring: Enhancements

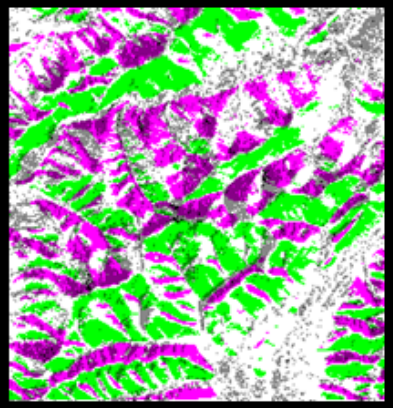
Thaw State Classifier Integrated with Landscape Topography
Bonanza Creek Experimental Forest, Alaska



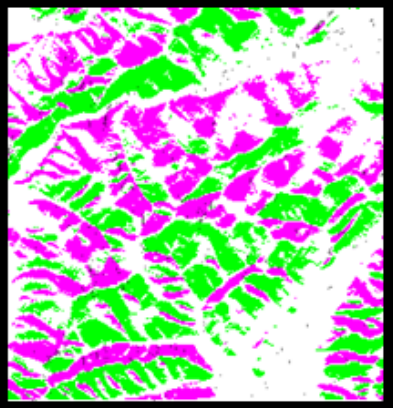
16 Feb 1998



1 April 1998



15 May 1998



28 June 1998

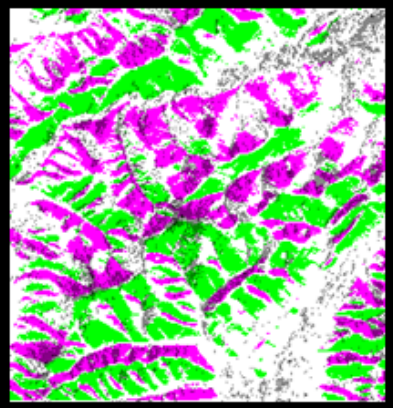
25 km

Frozen Thawed

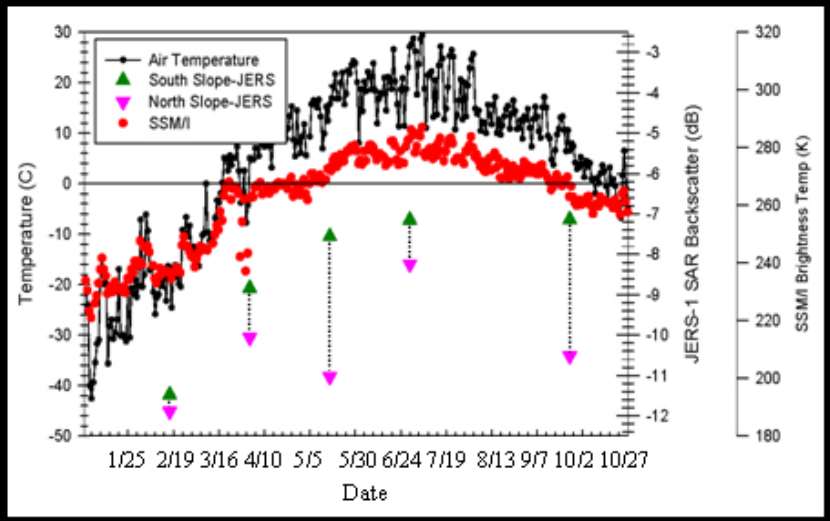
South Facing Slope

North Facing Slope

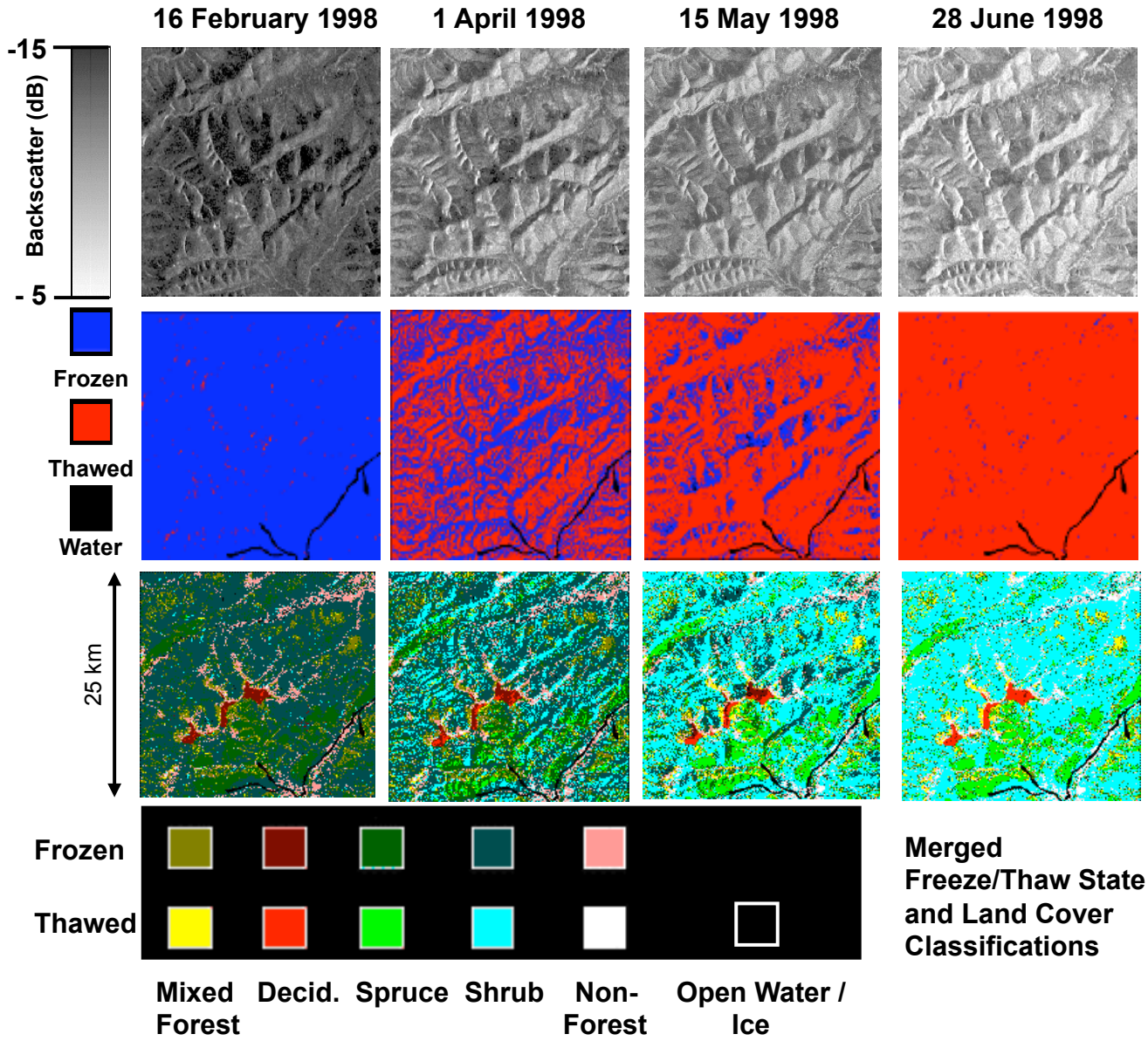
Flat/ Other



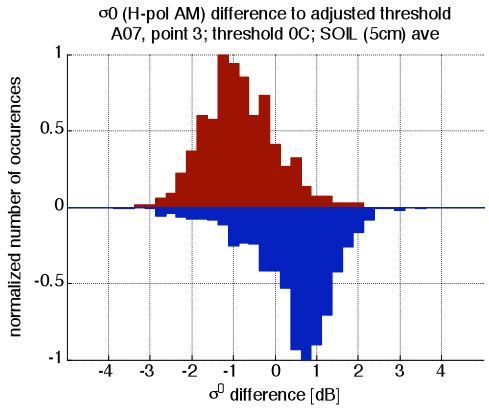
24 Sept 1998



Freeze/Thaw Monitoring: Alaska



ALECTRA and QuikSCAT



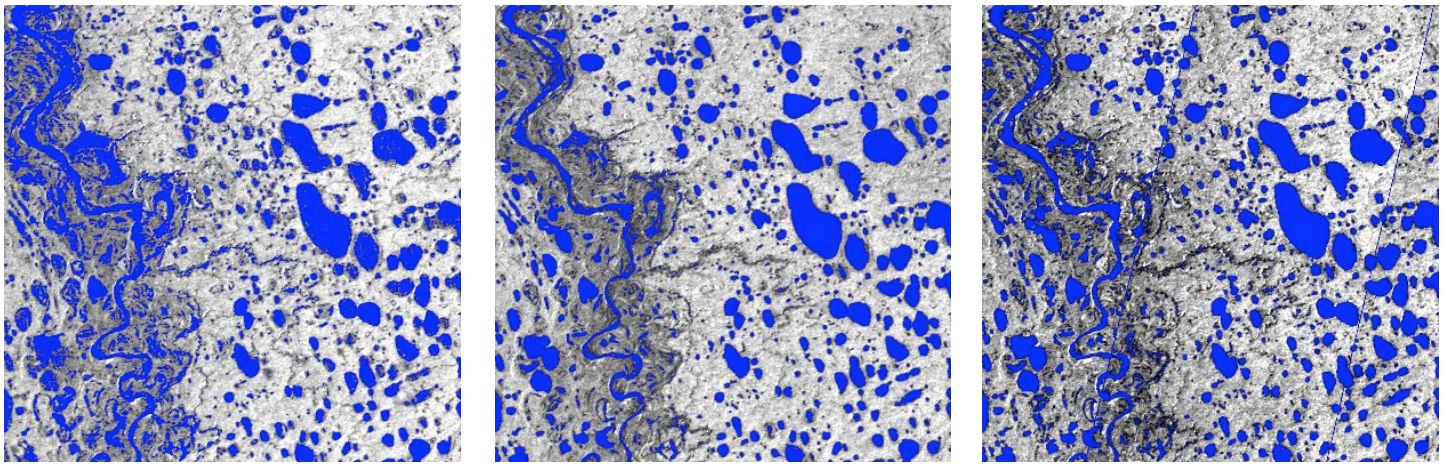
- QuikSCAT backscatter analyzed vs. ALECTRA biophysical network
- Sophisticated ALECTRA data valuable for the planning efforts
- Study indicates the most significant landscape components for explaining QuikSCAT backscatter changes
- Results vary with terrain and land cover conditions which may have implications on validation planning

ST.	SUB	AIR	STEM	BRANCH	SOIL-5	SOIL-10	Type
A01	1	0.23	0.22	0.24	-	0.30	White Spruce
	2	0.25	0.24	-	-	0.31	Black Spruce
	3	-	0.24	-	-	0.24	Poplar
	4	0.29	0.26	0.25	-	0.23	Alder Shrub
A04	1	0.18	0.17	0.16	-	0.25	Sitka Spruce/Poplar
	2	0.17	0.14	0.16	0.21	-	Alder
A05	1	0.26	0.24	-	-	0.37	Open Shrub (Willow)
	2	0.23	0.24	0.25	-	0.23	White Spruce
A06	1	0.29	0.29	0.29	-	0.34	White Spruce/Balsam Poplar
A07	1	0.25	0.24	0.29	0.24	-	Black Spruce bog
	2	0.24	0.25	0.22	0.23	-	Black Spruce, north slope
	3	0.24	0.25	0.22	0.21	-	White Spruce, south slope
	4	0.26	0.25	0.23	0.30	-	Open Shrub/Bog (Willow)
A08	1	0.26	0.26	0.27	0.23	-	White Spruce
	2	0.26	0.29	0.25	0.23	-	Open Shrub (Willow)
	3	0.29	0.26	0.28	0.24	-	Open Shrub, sloped (Willow)
	4	0.26	0.27	0.23	0.29	-	Open Shrub, Sandy soil
A09	1	0.26	0.23	-	-	0.20	Birch, south slope
	2	0.22	0.23	-	-	0.27	Black Spruce/Larch bog
	3	0.22	0.23	-	-	0.21	White Spruce, hill base

(submitted to TGRS)

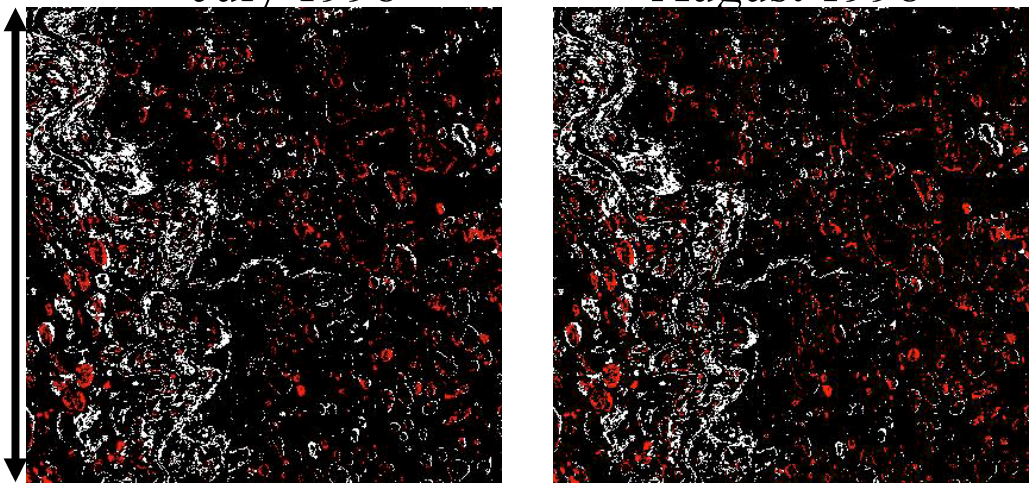
Open Water Change- North Slope, Alaska

The top shows open water overlayed on the JERS image and the bottom shows open water change relative to June.



June 1998 July 1998 August 1998

More open water
Less open water
No change



Open water change June/July

Open water change June/August

Open Water Change Relative to June

	Dryer	Wetter
Jul.	7.7%	2.7%
Aug.	6.9%	3.2%

ISSUES RELATED with such a FIELD CAMPAIGN

- ***Interannual variability of the transition period – need to be sure to capture it... (risk element)***
- ***Spatial heterogeneity (different for the freezing and thawing transitions)***
- ***Open water fractional coverage***
- ***Snow on the ground (possibly melting)***
- ***Freezing and thawing transitions occur differently***
- ***Pre-launch cal-val of an algorithm based on time series***

MORE SPECIFIC OBJECTIVES

- ***Evaluate / calibrate specific elements of the SMAP F/T retrieval algorithm for the subarctic environment.***

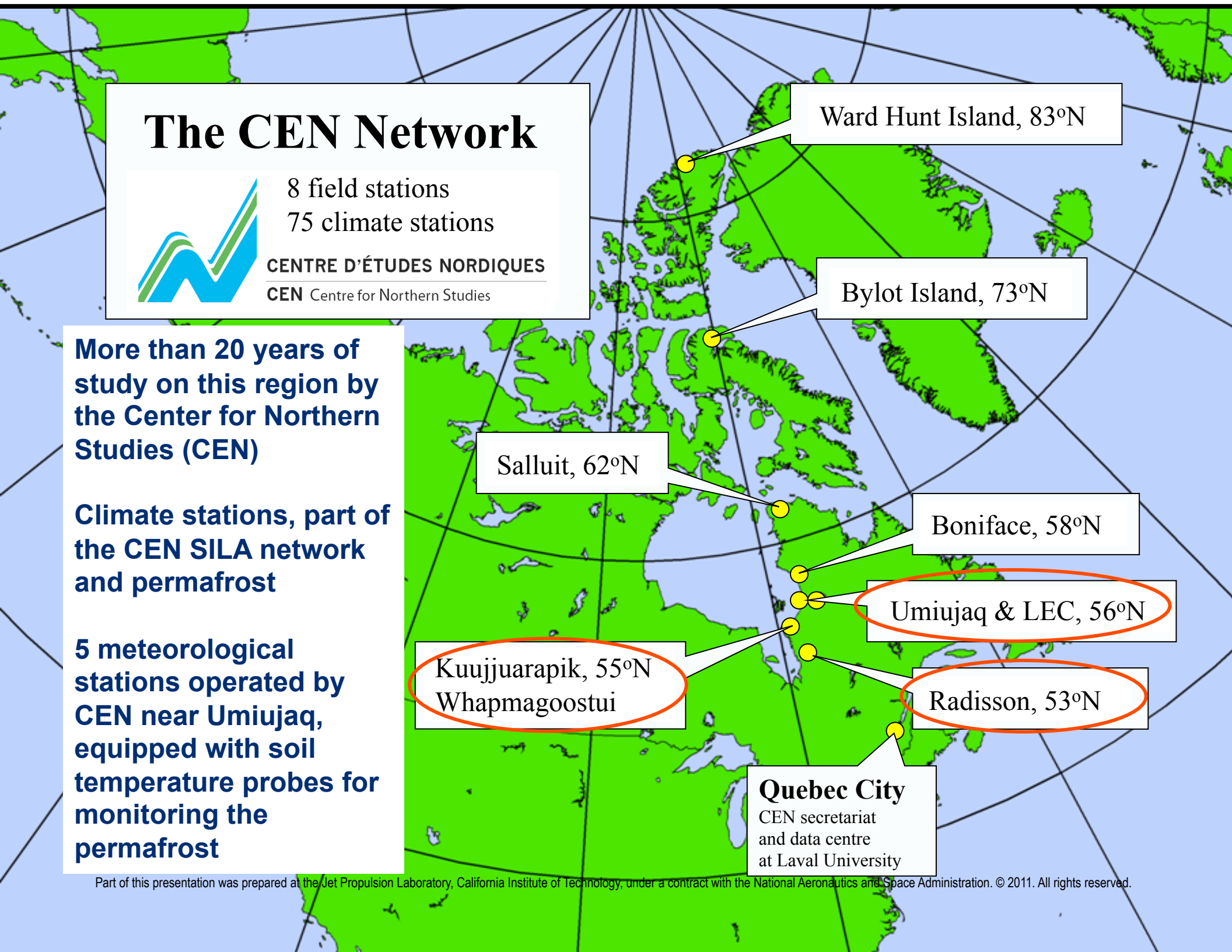
- ***Document errors associated with the SMAP F/T state retrieval based on L-band active data.***

- ***Evaluate algorithms to monitor F/T at medium and low resolution over the Tundra and the Boreal Forest in Canada (based on passive MW measurements).***

STUDY AREA

- *Near the village of Umiujaq, on eastern shore of Hudson Bay (Qc) Canada (56° N, 76.31° O).*
- *Complex landscape, including lakes, wetlands, marine, coastal, riparian, permafrost, streams.*
- *Discontinuous permafrost*
- *Located at the tree line limit.*

Nunavik map
Source : Makivik Corporation



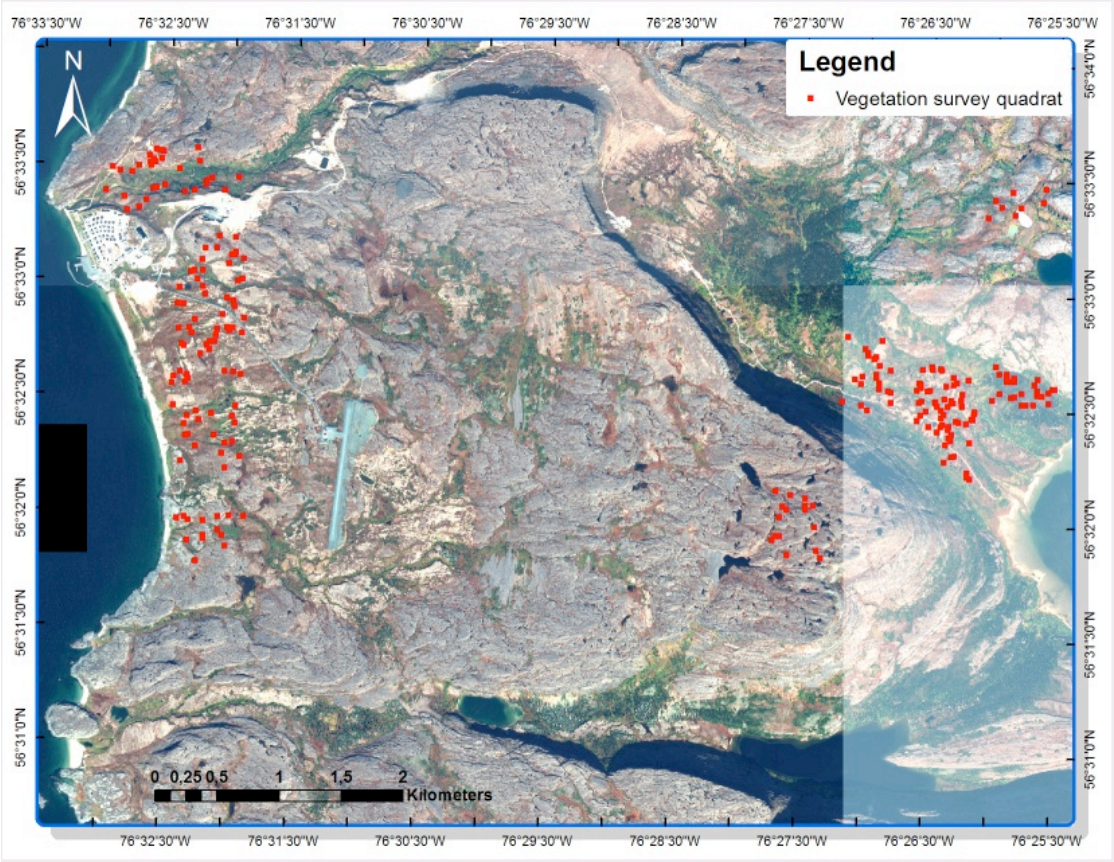
CURRENT CLIMATE over the AREA

- *60 to 80 frost-free days per year*
- *Annual average air temperature: -5.5°C*
- *Annual precipitation of about 500 mm*
- *37% of precipitation as snowfall (in terms of amount)*
- *Annual average wind speed is 20-24 km/h*
- *Windchill as severe as -60°C*

OVERALL OBSERVATIONAL APPROACH

SPACE-BASED	**RADARSAT2, AMSR-E, SMOS, SAOCOM?, Aquarius? ALOS**
AIRBORNE	**NASA UAVSAR L-band radar (Gulfstream-III)** **EC L-band radiometer (Twin Otter or Polar 6)**
GROUND	**Long-term network (soil temperature sensors)** **Additional field-phase ground measurements**

VEGETATION SURVEYS



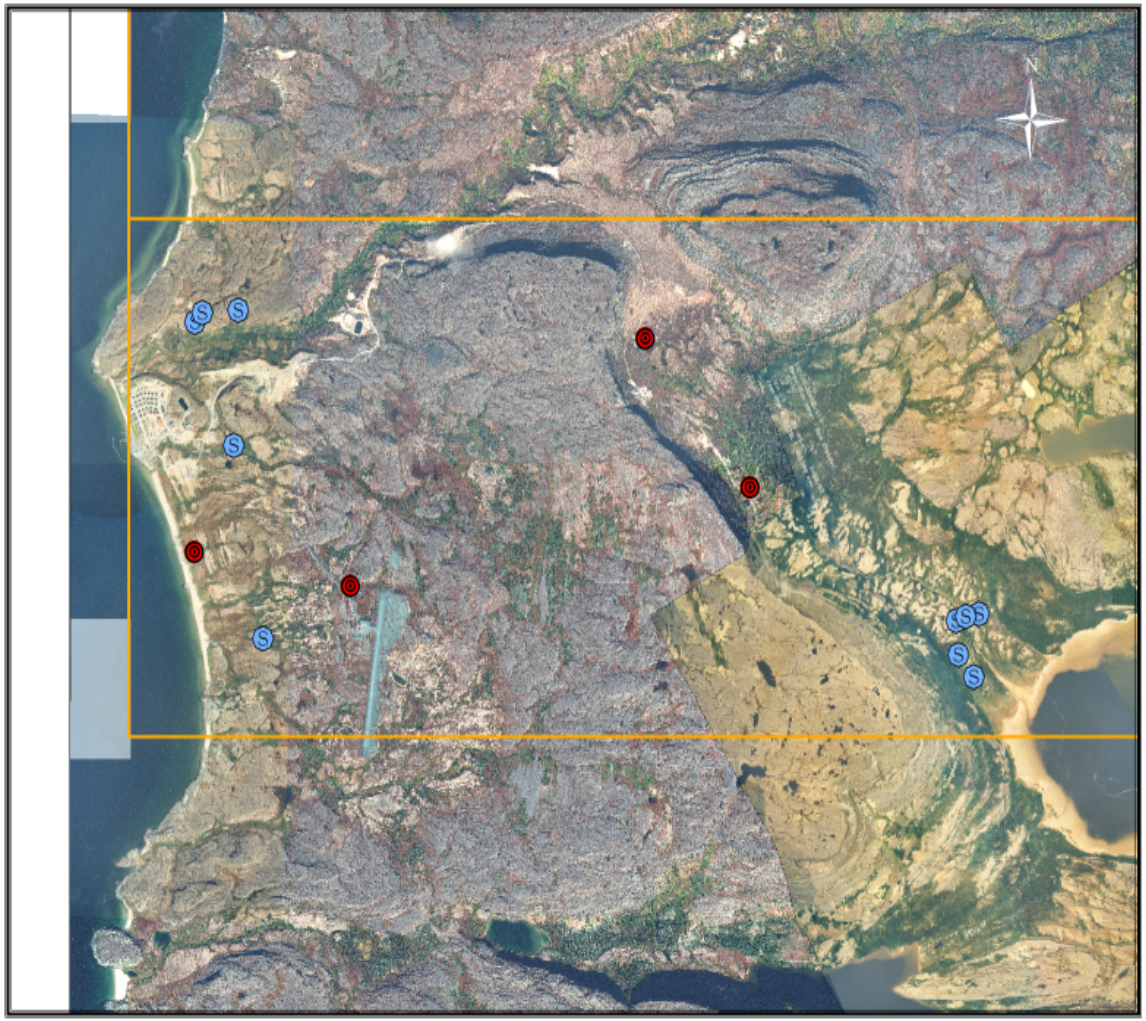
Spatial coverage of the vegetation surveys performed in summer 2008 and 2009 (red dots) near Umiujaq (Hudson Bay area) in Northern Quebec, Canada.

Three sub-arctic (hemi-arctic) environments: a coastal area characterized by sparse tundra vegetation, a valley area covered with shrubby vegetation and black spruce trees, a second valley (north half of the area) dominated by thermokarst lakes and hollows.

A vegetation survey has been done by INRS collaborators (CEN) in summer 2008 and 2009. More than 200 quadrants (5m x 5m) have been inventoried: Vegetation cover %, Habitat, Moisture (qualitative), Substrata types, Topographic position, Vegetation species (20) and Vegetation Height (m)

Satellite data (Ikonos 2005, Geoeye 2009, TerraSAR-X (since 2009), RADARSAT-2 since 2010, DEM) have also been examined.

GROUND NETWORK



Blue: soil temperature sensors (10)
Red: Weather stations (5)

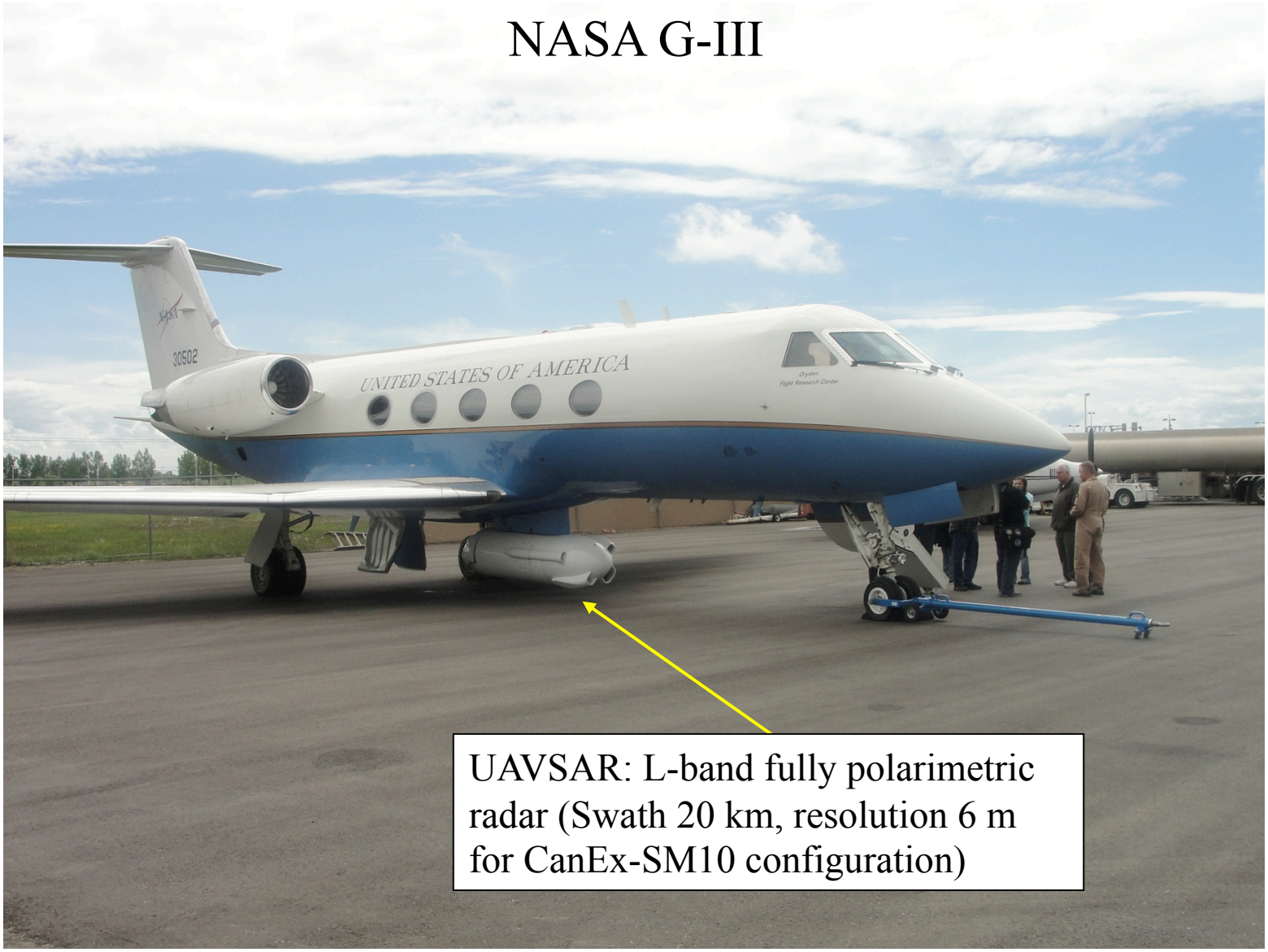
Additional temperature and TDR probes will be installed by INRS in the Sheldrake River watershed during the summer prior to the F/T experiment.

In conjunction with the flights conducted during the field phase of the experiment, field teams will take pictures of the soil and vegetation conditions and will take some measurements on the soil status (frozen or not) and soil characteristics (moisture, density) as well as snow cover depth (number of teams TBD)

Vegetation survey quadrates could be done for the Sheldrake River watershed in summer 2012.

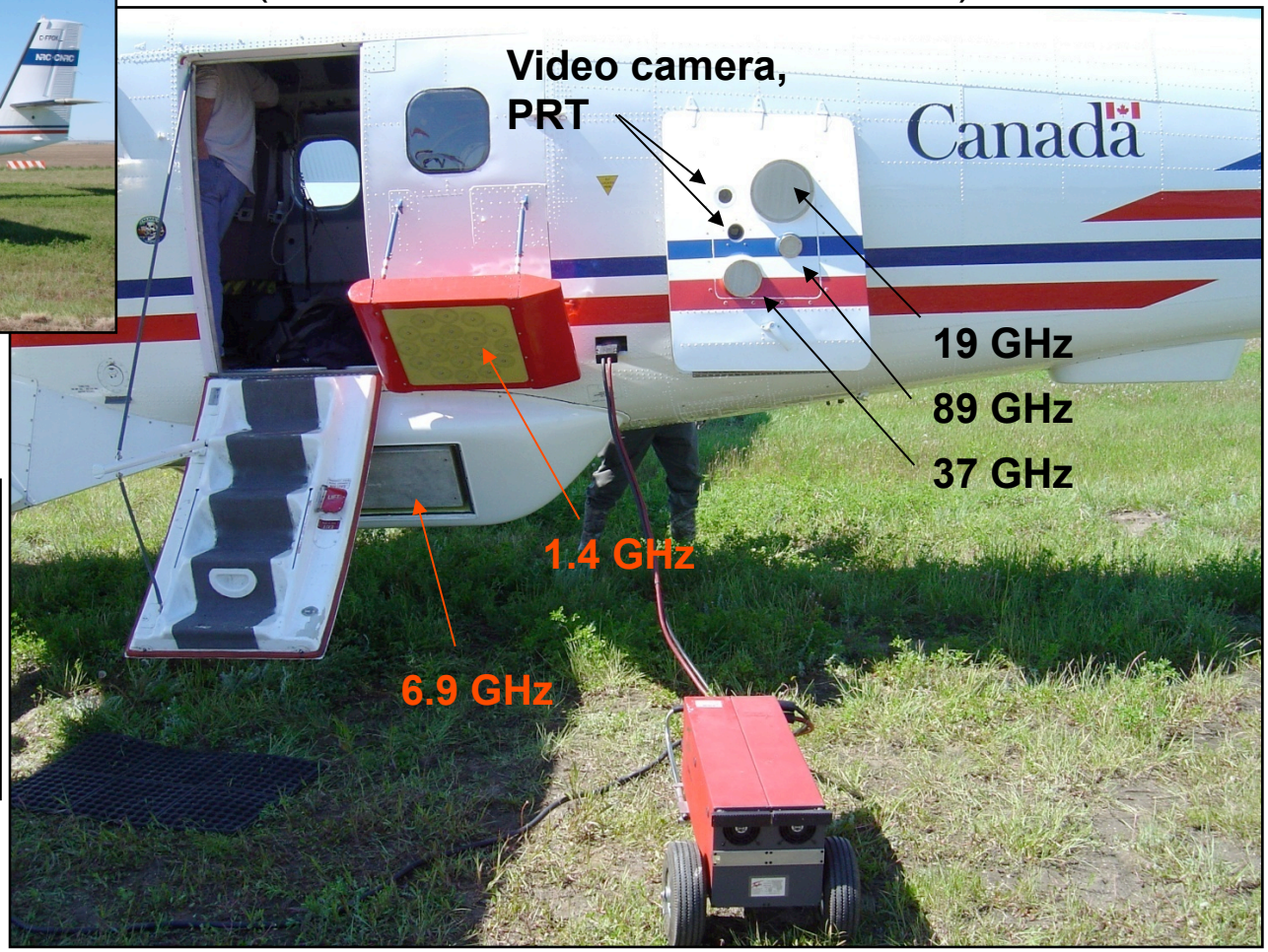
UAVSAR L-Band RADAR

NASA G-III



EC's L-Band RADIOMETER

(As mounted on NRC's Twin Otter)



- **6.9, 19, 37 and 89 GHz → 53° incidence angle**
- **1.4 GHz → 40° incidence angle**

Another aircraft (e.g., Polar 6) may be used for the F/T campaign

PERIOD of the FIELD CAMPAIGN (FALL 2012 vs SPRING 2013)

Freezing (fall) or thawing (spring) portions of the annual cycle?

Fall 2012 could be just after SMAPVEX 2012 (a few months only)

Spring 2013 would be closer to launch. More useful as a rehearsal for the post-launch campaign.

FY13 in the US, FY12/13 or FY13/14 in Canada

Other considerations: aircraft / instrumentation / resources availability, fuel transport for spring campaign.

WEATHER CONSIDERATIONS FOR MICROWAVE RADIOMETER AIRCRAFT OPERATIONS

Summary of Aviation Weather Analysis for Umiujaq Study Site

	Fall Freeze-up Period	Spring Thaw Period
Frequency of cloud ceilings below 10,000 ft	92%	61%
Probability of flight operations (suitable landing conditions)	67% (54% - IFR, 13% - VFR)	87% (48% - IFR, 39% - VFR)

- Spring thaw period has higher chance of flight operations and VFR conditions
- Fall freeze-up period is doable but managing flight operations will be difficult
- More flight hours will be required for fall period due to high probability of IFR conditions – likely not possible to cover Umiujaq study area in one flight
- Use of Polar 5/6 aircraft will allow longer flight times over study area due to longer flight duration (still subject to same landing and operating restrictions as Twin Otter)
- Availability of NRC Twin Otter and Polar-5/6 for Fall 2012 or Spring 2013 is uncertain at this time

EXPECTED DATASETS

Datasets	Description	Provider
UAVSAR	L-band backscatter	T. Jackson (USDA)
EC's radiometers	Tb at 1.4, 6.9, 19, 37, and 89 GHz	A. Walker (EC)
Satellites...	PALSAR, SAOCOM (to be launched), RADARSAT2, AMSR-E, SMOS	
Ground network	Tsoil, soil moisture, soil density, F/T state, vegetation	M. Bernier (INRS-ETE)
Ground measurements	Soil state (F/T), vegetation (photographs), soil density, Tsoil, soil moisture, ...	M. Bernier (INRS-ETE)
Sites characteristics	Vegetation state and characteristics during the experiment, topography, water fractional coverage, roughness	M. Bernier (INRS-ETE) K. McDonald (JPL / CCNY)
Meteorology	Air temperature, humidity, winds, precipitation (snow / rain)	M. Bernier (INRS-ETE) S. Belair (EC)

PARTICIPANTS
(Planification and Implementation)

INRS-ETE (CEN):

- M. Bernier: Coordination field campaign, Algorithms development
- P. Kalantari: Algorithm development for F/T Product, Field work
- J. Poulin: Logistics, field work

Environment Canada (EC):

- A. Walker: Aircraft and instruments
- S. Belair: Coordination

SMAP Project:

- T. Jackson (USDA): UAVSAR, coordination
- K. McDonald (City College of New York / JPL)
- A. Colliander (JPL)

FUNDING PLAN

UAVSAR	**SMAP Project**
RADIOMETERS	**CSA Government Related Initiatives Program**
GROUND ACTIVITIES	**CSA Earth Observation Applications and Utilizations (EOAU) grants programs**

... plus in-kind from the participating organisations.

REMAINING ISSUES

Enough ground observations? Best site in Canada? Too close to Hudson Bay?

Cal / Val of a retrieval algorithm based on long time series (emphasis on preparations for a post-launch validation campaign)

Period of the campaign (Fall 2012 or Spring 2013); need to capture F/T transitions.

Logistical considerations related to northern field studies (fuel transport, road access, accomodations, airport with hangar, de-icing for aircraft).

Weather (for Twin Otter or Polar 6 aircraft measurements).

Collaborations

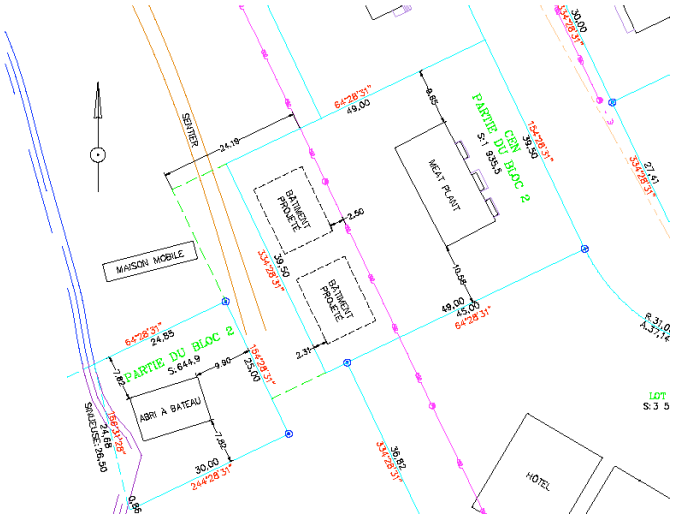
BACKUP SLIDES

WEATHER CONSIDERATIONS FOR MICROWAVE RADIOMETER AIRCRAFT OPERATIONS

- Location of Umiujaq study area along coast of Hudson Bay – complicating weather conditions for flight operations, especially for fall period when Hudson Bay is ice-free (persistent cloud, freezing drizzle, low visibilities)
- Proposed aircraft base – Kuujjuarapik (86 nautical miles south of study area)
- Analysis carried out for 2006-2010 aviation weather conditions during fall freeze-up period (mid-October to mid-November) and spring thaw period (May)
- Ideal operations – minimal cloud below 10,000 ft, Visual Flight Rules (VFR) conditions (visibility > 1 mile)
- VFR operations maximizes flight time available over study area (~3.2 hours with Twin Otter)
- Instrument Flight Rules (IFR) operations, when significant cloud is present, reduces flight time over the study area to 1.5-2 hours due to fuel reserves required for alternate airport landing (100-150 nm southeast of Kuujjuarapik)
- Kuujjuarapik is an uncontrolled, single runway airport therefore pilot may want to keep fuel reserve in case of landing delays (unexpected aircraft, vehicles or animals on runway)
    - Flight time over study site reduced to 2.75 hours (VFR operations)
    - If pilot requires alternate landing airport as contingency, flight time over the study area is further reduced to 2.2 hours (VFR operations)

Umiujaq CEN station, 56°N

house, garage, warehouse



Partnerships:
Kativik Regional Goverment,
Nunavik Research Centre (Makivik Corporation)
Local Anniturvik Land Holding Corporation

LOGISTICS at UMIUJAQ

Local transportation available:

- 4x4 trucks,
- Snowmobiles,
- ATVs.

Fuel Availability via CEN.

Power: Regular commercial.

Nearest Medical Services:

- Health Centre in Umiujaq.
- Hospital in Puvirnituq.

External transport:

- Daily flights available from Montreal (Qc) via Whapmagoostui-Kuujjuarapik
- Helicopter service (charter) available from Radisson

Radisson Ecological Research Station
53°N
La Grande River Airport - CYGL
up to 20 persons (3 houses)

CENTRE D'ÉTUDES NORDIQUES
CEN Centre for Northern Studies

Community Science Centre at Whapmagoostui-Kuujjuarapik 55°N

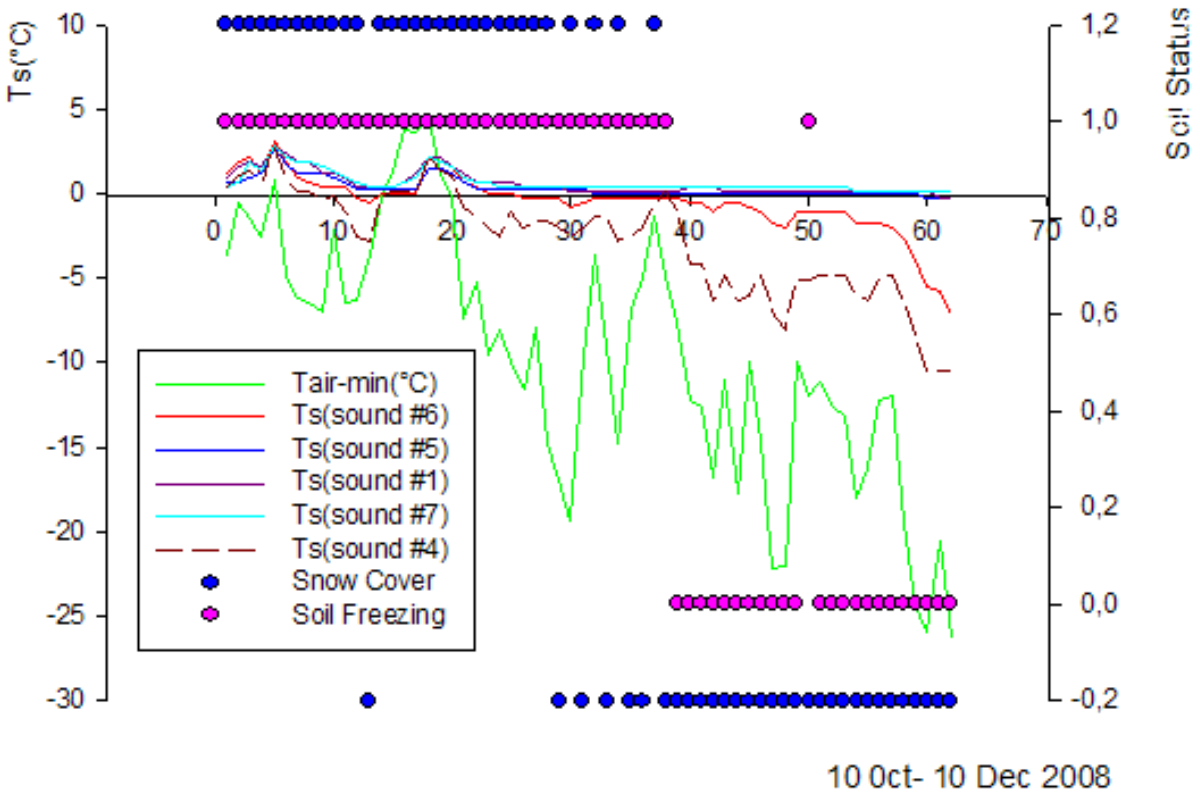
CYGW

Photos: Sept./Oct. 2010

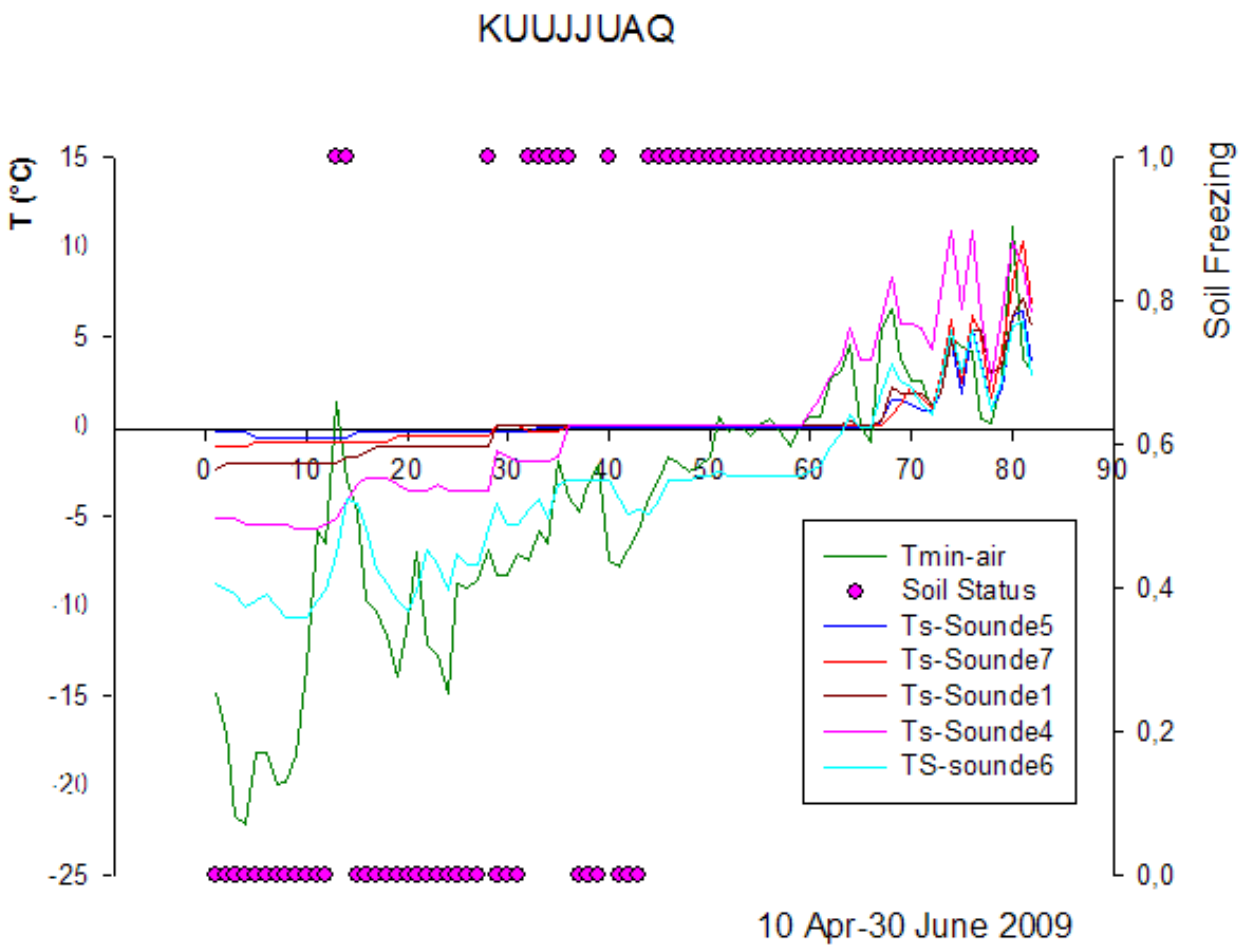
Completion by January 2011

Freezing Fall 2008

Soil temperature sensors have been installed by INRS near the soil surface in summer 2010 for 2010, 2011, and 2012 to monitor soil temperature through the year.



Thawing Spring 2008



SPATIAL VARIABILITY

Field conditions in 2010

Patches of snow on May 7, 2010

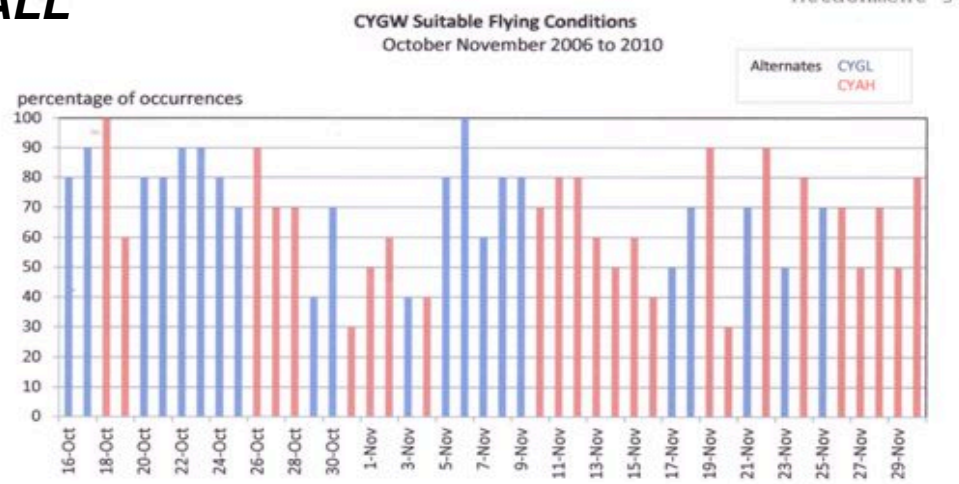
Weather conditions during 2010 winter exceptionally warm... No snow May 4

Frequency of Suitable Flying Conditions (IFR) for Kuujjuarapik

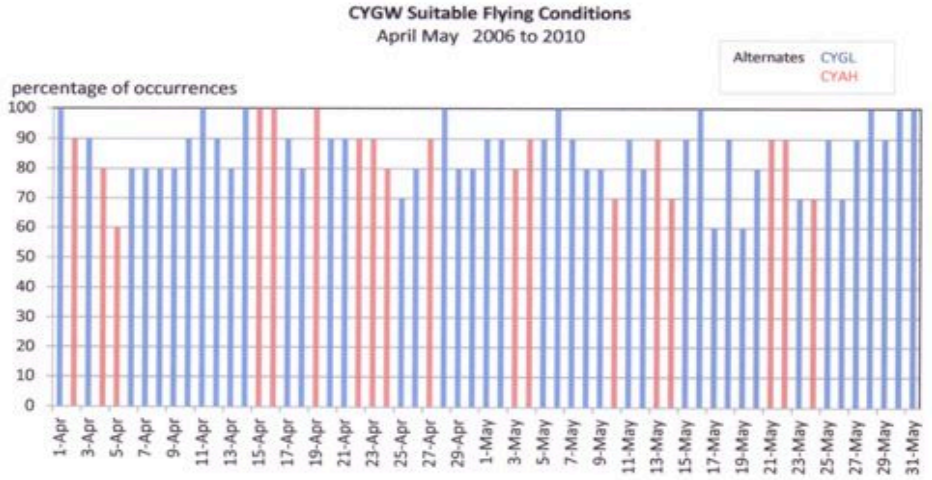
Blue – 1.58 hrs. of flight time over study area
Red – 2 hrs. over of flight time over study area

FALL

Attachment 3



SPRING

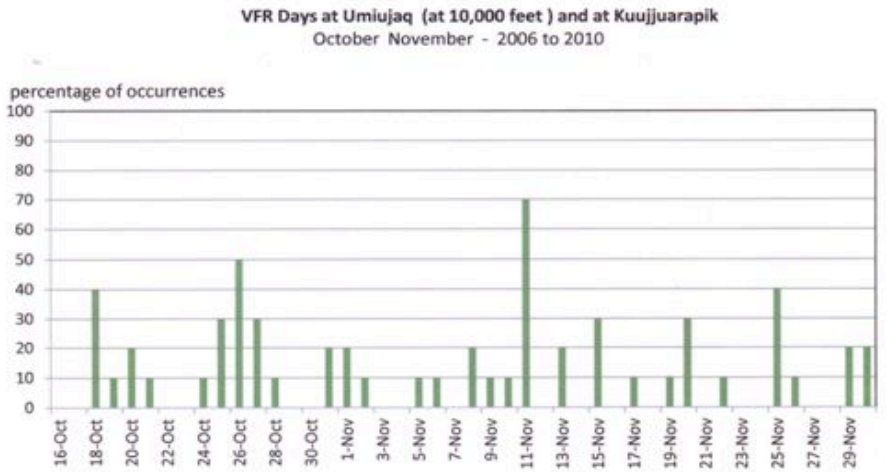


Note: Graphs are for suitable weather conditions from 8:00 am to 7:00 pm at both Kuujjuarapik and the most usable alternate airport.

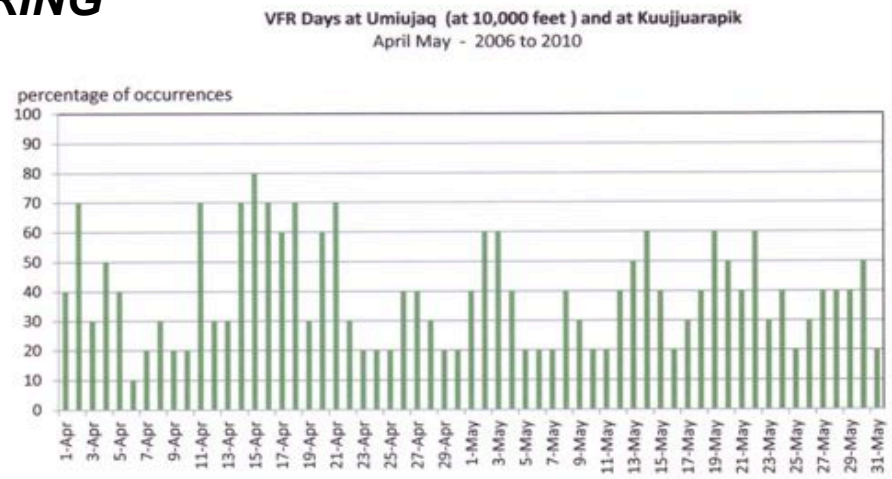
Frequency of VFR Conditions for Flight Operations over Umiujaq Study Area

Attachment 5

FALL



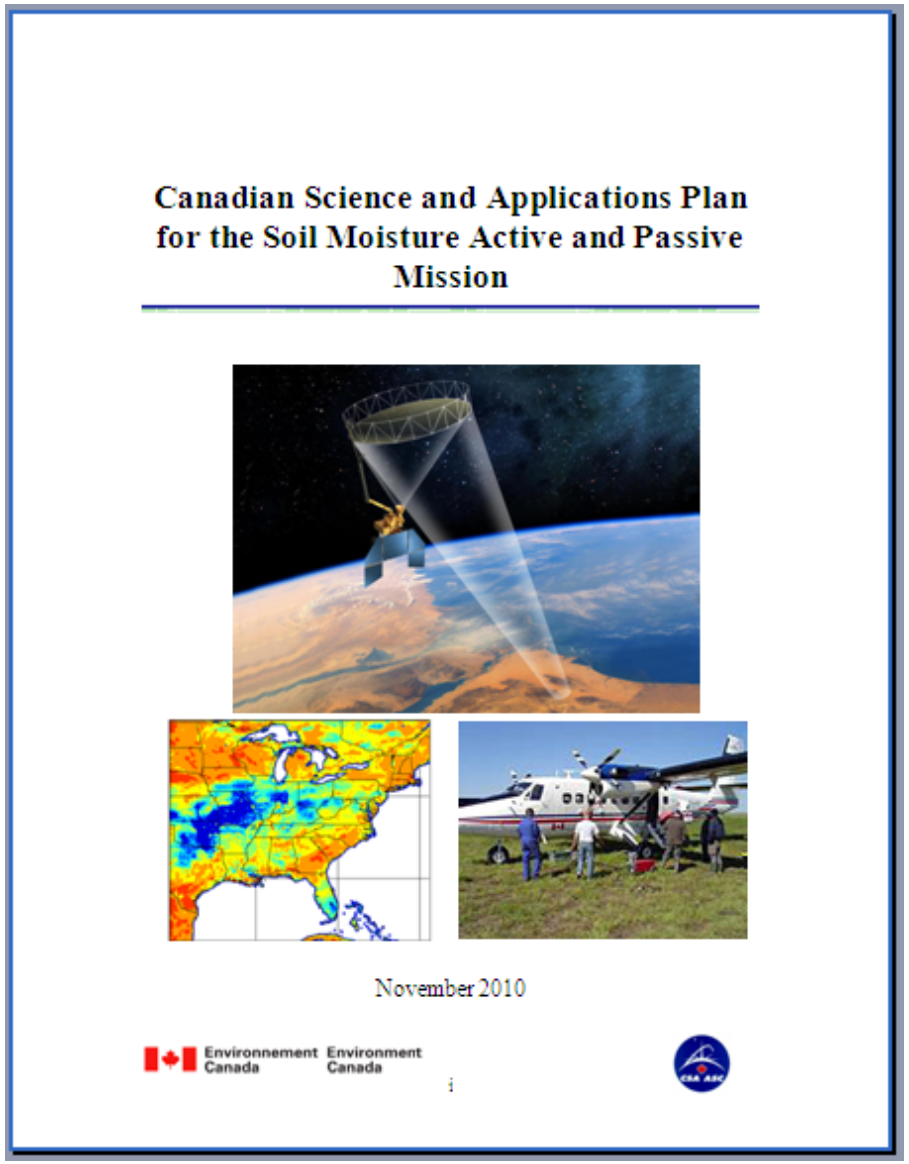
SPRING



REMINDER: SMAP PRODUCTS

Product	Short Description	Resolution/ Grid	Latency	
L1A_S0	Radar raw data in time order	–	12 hours	Instrument Data
L1A_TB	Radiometer raw data in time order	–	12 hours	
L1B_S0_LoRes	Low resolution radar σ_o in time order	5x30 km	12 hours	
L1B_TB	Radiometer T_B in time order	36x47 km	12 hours	
L1C_S0_HiRes	High resolution radar σ_o	1-3 km	12 hours	
L1C_TB	Radiometer T_B	36 km	12 hours	
L2_SM_A	Soil moisture (radar)** [research product]	3 km	24 hours	Science Data (Half-Orbit)
L2_SM_P	Soil moisture (radiometer)	36 km	24 hours	
L2_SM_A/P	Soil moisture (radar/radiometer)	9 km	24 hours	
L3_SM_A	Soil moisture (radar)	3 km	24 hours	Science Data (Daily Composite)
L3_F/T_A	Freeze/thaw state (radar)	3 km	50 hours	
L3_SM_P	Soil moisture (radiometer)	36 km	50 hours	
L3_SM_A/P	Soil moisture (radar/radiometer)	9 km	50 hours	
L4_SM	Soil moisture (surface & root zone)	9 km	7 days	Science Value-Added
L4_C	Carbon net ecosystem exchange (NEE)	9 km	14 days	

CANADIAN PLAN for SMAP



OBJECTIVES:

Cal / Val (SM and FT products)

Research, development, and applications (retrievals, data assimilation, products – for SM, FT, and NEE)

COMPONENTS and PARTICIPANTS:

Cal/Val soil moisture (core sites, campaigns): EC (MRD,CRD,HAL), AAFC, NRC, Guelph, Sherbrooke, SMAP

Cal/Val FT (sites, campaigns): EC (MRD,CRD), NRC, INRS-ETE, SMAP

Soil moisture and FT retrievals: AAFC, Sherbrooke, INRS-ETE

Soil moisture and FT data assimilation: EC(MRD), Guelph

Carbon cycle analysis: EC(MRD,CRD), U. of Toronto

Impacts, products, operations: EC(MRD,MSC)

SMAP F/T ALGORITHM BASELINE

Seasonal threshold Approach (Baseline Algorithm):

$$\Delta(t) = \frac{\sigma(t) - \sigma_{fr}}{\sigma_{th} - \sigma_{fr}}$$

$\Delta(t) > T$ Thawed

$\Delta(t) \leq T$ Frozen

Seasonal threshold Approach (Enhanced Baseline Algorithm):

$$\Delta(t) = \sigma(t) - \left\{\sigma_{fr} + \left(\sigma_{th} - \sigma_{fr}\right)T\right\}$$

$\Delta(t) > 0$ Thawed

$\Delta(t) \leq 0$ Frozen

(Courtesy of John Kimball)

Source: McDonald, K.C, and J.S. Kimball, 2005. Encyclopedia of Hydrological Sciences. DOI: 10.1002/0470848944.hsa059a.