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

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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 Propulsion 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

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)
Seasonal Threshold Algorithm

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

\( \sigma^0_{fr} \) = frozen reference

\( \sigma^0_{th} \) = thawed reference

T = threshold

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

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

Comparison with in situ data
Freeze/Thaw Monitoring: Alaska

Kenai Peninsula

Resurrection Peninsula

Ellsworth Glacier

Interior Alaska

Caribou/Poker Creeks Research Watershed

Complex Topography Study Area

Bonanza Creek Experimental Forest

Fairbanks Weather Station

Complex Landscape Study Area

Alectra Sites
In Situ Biophysical Measurements

Station Set-up
BC LTER White Spruce

Xylem Flux Initiation, Julian Date

Soil Thaw, Julian Date

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

Thaw of Litter

K.C. McDonald in prep
Freeze/Thaw Monitoring: Enhancements

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


Frozen Thawed
South Facing Slope
North Facing Slope
Flat/Other

24 Sept 1998

Temperature (°C)

Date

JERS-1 SAR Backscatter (dB)
Freeze/Thaw Monitoring: Alaska

Mixed Decid. Spruce Shrub Non- Open Water / Forest Forest Ice

Backscatter (dB)

Freeze/Thaw State and Land Cover Classifications


Frozen Thawed Water

25 km

Merged Freeze/Thaw State and Land Cover Classifications
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

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

Open Water Change Relative to June

<table>
<thead>
<tr>
<th></th>
<th>Dryer</th>
<th>Wetter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul.</td>
<td>7.7%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Aug.</td>
<td>6.9%</td>
<td>3.2%</td>
</tr>
</tbody>
</table>
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.
The CEN Network

8 field stations
75 climate stations

CENTRE D’ÉTUDES NORDIQUES
CEN Centre for Northern Studies

More than 20 years of study on this region by the Center for Northern Studies (CEN)

Climate stations, part of the CEN SILA network and permafrost

5 meteorological stations operated by CEN near Umiujaq, equipped with soil temperature probes for monitoring the permafrost

Part of this presentation was prepared at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. © 2011. All rights reserved.
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

<table>
<thead>
<tr>
<th><strong>SPACE-BASED</strong></th>
<th>RADARSAT2, AMSR-E, SMOS, SAOCOM?, Aquarius? ALOS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AIRBORNE</strong></td>
<td>NASA UAVSAR L-band radar (Gulfstream-III)</td>
</tr>
<tr>
<td></td>
<td>EC L-band radiometer (Twin Otter or Polar 6)</td>
</tr>
<tr>
<td><strong>GROUND</strong></td>
<td>Long-term network (soil temperature sensors)</td>
</tr>
<tr>
<td></td>
<td>Additional field-phase ground measurements</td>
</tr>
</tbody>
</table>
Spatial coverage of the vegetation surveys performed in summer 2008 and 2009 (red dots) near Umiujaq (Hudson Bay area) in Northern Quebec, Canada.

VEGETATION SURVEYS

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

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.

Blue: soil temperature sensors (10)
Red: Weather stations (5)
UAVSAR L-Band RADAR

NASA G-III

UAVSAR: L-band fully polarimetric radar (Swath 20 km, resolution 6 m for CanEx-SM10 configuration)
EC’s L-Band RADIOMETER

(As mounted on NRC’s Twin Otter)

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

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

<table>
<thead>
<tr>
<th></th>
<th>Fall Freeze-up Period</th>
<th>Spring Thaw Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of cloud ceilings below 10,000 ft</td>
<td>92%</td>
<td>61%</td>
</tr>
<tr>
<td>Probability of flight operations (suitable landing conditions)</td>
<td>67% (54% - IFR, 13% - VFR)</td>
<td>87% (48% - IFR, 39% - VFR)</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th>Datasets</th>
<th>Description</th>
<th>Provider</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UAVSAR</strong></td>
<td>L-band backscatter</td>
<td>T. Jackson (USDA)</td>
</tr>
<tr>
<td><strong>EC’s radiometers</strong></td>
<td>Tb at 1.4, 6.9, 19, 37, and 89 GHz</td>
<td>A. Walker (EC)</td>
</tr>
<tr>
<td><strong>Satellites...</strong></td>
<td>PALSAR, SAOCOM (to be launched), RADARSAT2, AMSR-E, SMOS</td>
<td></td>
</tr>
<tr>
<td><strong>Ground network</strong></td>
<td>Tsoil, soil moisture, soil density, F/T state, vegetation</td>
<td>M. Bernier (INRS-ETE)</td>
</tr>
<tr>
<td><strong>Ground measurements</strong></td>
<td>Soil state (F/T), vegetation (photographs), soil density, Tsoil, soil moisture, ...</td>
<td>M. Bernier (INRS-ETE)</td>
</tr>
<tr>
<td><strong>Sites characteristics</strong></td>
<td>Vegetation state and characteristics during the experiment, topography, water fractional coverage, roughness</td>
<td>M. Bernier (INRS-ETE) K. McDonald (JPL / CCNY)</td>
</tr>
<tr>
<td><strong>Meteorology</strong></td>
<td>Air temperature, humidity, winds, precipitation (snow / rain)</td>
<td>M. Bernier (INRS-ETE) S. Belair (EC)</td>
</tr>
</tbody>
</table>
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, accommodation, 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)
Community Science Centre at Whapmagoostui-Kuujjuarapik 55°N
CYGW
Photos: Sept./Oct. 2010
Completion by January 2011
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

KUJJUAQ

T (°C)

15
10
5
0
-5
-10
-15
-20
-25

0
10
20
30
40
50
60
70
80
90

1.0
0.8
0.6
0.4
0.2
0.0

Soil Freezing

10 Apr-30 June 2009

Tmin-air
Soil Status
Ts-Sounde5
Ts-Sounde7
Ts-Sounde1
Ts-Sounde4
TS-sounde6
SPATIAL VARIABILITY

Field conditions in 2010

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

Coastal area

Guillaume-Delisle Valley

Patches of snow on May 7, 2010
**Frequency of Suitable Flying Conditions (IFR) for Kuujjuarapik**

**FALL**

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

**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

**FALL**

**SPRING**
### REMINDER: SMAP PRODUCTS

<table>
<thead>
<tr>
<th>Product</th>
<th>Short Description</th>
<th>Resolution/Grid</th>
<th>Latency</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1A_S0</td>
<td>Radar raw data in time order</td>
<td>–</td>
<td>12 hours</td>
</tr>
<tr>
<td>L1A_TB</td>
<td>Radiometer raw data in time order</td>
<td>–</td>
<td>12 hours</td>
</tr>
<tr>
<td>L1B_S0_LoRes</td>
<td>Low resolution radar $\sigma_o$ in time order</td>
<td>5x30 km</td>
<td>12 hours</td>
</tr>
<tr>
<td>L1B_TB</td>
<td>Radiometer $T_B$ in time order</td>
<td>36x47 km</td>
<td>12 hours</td>
</tr>
<tr>
<td>L1C_S0_HiRes</td>
<td>High resolution radar $\sigma_o$</td>
<td>1-3 km</td>
<td>12 hours</td>
</tr>
<tr>
<td>L1C_TB</td>
<td>Radiometer $T_B$</td>
<td>36 km</td>
<td>12 hours</td>
</tr>
<tr>
<td>L2_SM_A</td>
<td>Soil moisture (radar)** [research product]</td>
<td>3 km</td>
<td>24 hours</td>
</tr>
<tr>
<td>L2_SM_P</td>
<td>Soil moisture (radiometer)</td>
<td>36 km</td>
<td>24 hours</td>
</tr>
<tr>
<td>L2_SM_A/P</td>
<td>Soil moisture (radar/radiometer)</td>
<td>9 km</td>
<td>24 hours</td>
</tr>
<tr>
<td>L3_SM_A</td>
<td>Soil moisture (radar)</td>
<td>3 km</td>
<td>24 hours</td>
</tr>
<tr>
<td>L3_F/T_A</td>
<td>Freeze/thaw state (radar)</td>
<td>3 km</td>
<td>50 hours</td>
</tr>
<tr>
<td>L3_SM_P</td>
<td>Soil moisture (radiometer)</td>
<td>36 km</td>
<td>50 hours</td>
</tr>
<tr>
<td>L3_SM_A/P</td>
<td>Soil moisture (radar/radiometer)</td>
<td>9 km</td>
<td>50 hours</td>
</tr>
<tr>
<td>L4_SM</td>
<td>Soil moisture (surface &amp; root zone)</td>
<td>9 km</td>
<td>7 days</td>
</tr>
<tr>
<td>L4_C</td>
<td>Carbon net ecosystem exchange (NEE)</td>
<td>9 km</td>
<td>14 days</td>
</tr>
</tbody>
</table>

*Instrument Data*

*Science Data (Half-Orbit)*

*Science Data (Daily Composite)*

*Science Value-Added*
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)
Seasonal threshold Approach (Baseline Algorithm):

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

\[ \Delta(t) > T \quad \text{Thawed} \]
\[ \Delta(t) \leq T \quad \text{Frozen} \]

Seasonal threshold Approach (Enhanced Baseline Algorithm):

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

\[ \Delta(t) > 0 \quad \text{Thawed} \]
\[ \Delta(t) \leq 0 \quad \text{Frozen} \]

(Courtesy of John Kimball)