MULTI-SCALE L-BAND BRIGHTNESS TEMPERATURE ANALYSIS FOR SOIL FREEZING AND THAWING PROCESS STUDY

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Surface Freeze/Thaw

Rational:

* Surface energy balance
* Net carbon fluxes in boreal and sub-arctic regions
* Permafrost monitoring
* Hydrological applications

Over one-third of the global land area undergoes a seasonal transition between predominantly frozen and non-frozen conditions each year. Closely linked to:

- timing and length of the vegetation growing season
- seasonal evolution of land-atmosphere carbon dioxide exchange
- interactions between soil processes and snow melt

The land surface F/T state acts as a natural on/off switch for hydrological and biospheric processes over northern land areas and at high elevations.

Average non-frozen period (top) and (bottom) standard deviation of the non-frozen period [days yr\(^{-1}\)] derived from SSM/I data(1988–2007)
SMOS F/T product

- FT estimates derived from SMOS 1.4 GHz L-band radiometer measurements
- 45 km spatial resolution
- Less sensitive to snow & vegetation; RFI poses a challenge

Rautiainen et al., RSE, 2014

Example FT classification derived from SMOS measurements
L-Band Spaceborne Radiometers

<table>
<thead>
<tr>
<th>Mission</th>
<th>LRD</th>
<th>Measurement</th>
<th>Instrument Complement</th>
<th>Radiometer Resolution/Revisit</th>
<th>Incident Angle (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMOS</td>
<td>Nov. 2009 –</td>
<td>Soil Moisture, Ocean Salinity</td>
<td>L-band radiometer</td>
<td>50 km / 3 days</td>
<td>0-65</td>
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<td>(1)</td>
<td>…</td>
<td></td>
<td></td>
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<tr>
<td>Aquarius</td>
<td>Aug. 2011 –</td>
<td>Ocean Salinity, Soil Moisture</td>
<td>L-band radiometer, Scatterometer</td>
<td>100 km / 7 days</td>
<td>Beam 1: 29.2</td>
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<tr>
<td>(2)</td>
<td>Jun. 2015</td>
<td></td>
<td></td>
<td></td>
<td>Beam 2: 38.4</td>
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<td></td>
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<td>Beam 3: 46.3</td>
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<tr>
<td>SMAP</td>
<td>Apr. 2015 –</td>
<td>Soil Moisture Freeze/Thaw state</td>
<td>L-band radiometer</td>
<td>40 km / 2-3 days</td>
<td>40</td>
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<td>(3)</td>
<td>…</td>
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</table>

(1) SMOS Weekly averaged from daily reconstructed TB (L3TB) (www.catds.fr/sipad/)
(2) Aquarius weekly-polar gridded TB version 3.0 (Brucker et al., The Cryosphere, 2014)
(3) SMAP NSIDC : LC1, TB Ease Grid 36 km
Objective #1
SMOS and Aquarius F/T

* Evaluate Normalized Polarization Ratio (NPR)-based F/T detection algorithm
  * SMOS
  * Aquarius

\[ NPR = \frac{TB_V - TB_H}{TB_V + TB_H} \]

Relative Frost Factor (FFrel)

\[ FFrel = \frac{NPR(t) - NPR_{fr}}{NPR_{th} - NPR_{fr}} \]

\[ FFrel < \Delta \rightarrow \text{freeze} \quad \text{and} \quad \text{if} \quad FF(t) > \Delta \rightarrow \text{thaw} \]

* Evaluate the influence of land cover and sensor configuration (angle) on F/T detection

Soil and air temperatures and snow measurements
7 tundra, 8 boreal forest and 35 prairie sites
Ancillary Data

* Surface temperature: weekly binary (F/T) datasets
  * In situ soil temperature (2 to 5 cm)
  * In situ air temperature
  * Cloud free MODIS land surface temperature ($\text{MODIS}_{\text{LST}}$)
    
    if majority of $X <= 0 = \text{frozen week}$

* Cloud free MODIS snow cover area ($\text{MODIS}_{\text{SCA}}$)
  
  if majority of $\text{SCA} > 10\% = \text{frozen week}$
Objective 1: Results
Threshold (Δ) evaluation with Aquarius

Accuracy = # correct predictions / total weeks (%)

• Best Accuracies with $T_{\text{air}}$
• Best accuracies over Tundra and worst over Prairies
• Tundra: broad range in the threshold (0.3 to 0.7)
• Optimized threshold at 38.4°: forest = 0.46; Prairies = 0.39
• For SMOS: best Accuracies with higher incidence angle (60°) $\rightarrow$ larger V-H at Brewster
Objective 1: Results
Tundra temporal series (Salluit) SMOS & Aquarius

- Clear NPR F/T signal in tundra
- SMOS at 55-60° and Aquarius at 38.9°
Objective 1: Results

Tundra temporal series (Cambridge Bay) SMAP F/T

- Latitude = 69.13 N
- Good F/T signal
- Influence of lakes (TB drop in July)

SMAP NSIDC: LC1, TB Ease Grid 36 km
Objective 1: Results
Boreal Forest temporal series (Kuujjuarapik)

- Smoother F/T transition (vegetation soil continuum)
- SMOS at 55-60° and Aquarius at 38.9°
Objective 1: Results
Boreal Forest temporal series (Baie-James) SMAP F/T

- Soil barely frozen (even with $T_{\text{air}} < -40^\circ\text{C}$)
- More thaw with Asc passes / more freeze with Dsc passes
- Clear signal with the presence of snow
- Differences between fore- and aft-look

SMAP NSIDC: LC1, TB Ease Grid 36 km
Objective 1: Results
Prairies temporal series (Alberta)

- F/T signal is less clear
- TB increase during summers → seasonal crop growth cycle
- Many melt events in winter
- SMOS at 55-60° and Aquarius at 38.9°
Objective 2: Spatial variability

Freeze onset and Freeze ends maps (SMOS)

Freeze onset in weeks (Fall)

2011

Freeze end in weeks (Spring)

2011

2012
Objective 2: Spatial variability
Snowmelt effect (Great Bear Lake)

- Pure lake pixel (Great Bear Lake)
- High NPR and low TB in summer (water)
- Low NPR and higher TB in winter (ice)
- Higher TB during spring snowmelt (wet snow)
Objective 2: Spatial variability
Surface-based vs SMOS $T_B$ (Prairies)

Mean surface-based radiometer $T_B$ and standard deviation for 7 sites over the Kenaston region, Prairies within the same SMOS pixel (2 bare soil, 1 grass, 1 pasture, 3 crop stubble)
Conclusion

- L-band NPR is sensitive to F/T
- But do not use the full potential of SMOS (weekly vs 3 days TB and version 243)
- Applications for SMOP in progress...

- Better correlation with $T_{\text{air}}$ (with the limitation of point measurements)
  - Snowmelt signal in spring
  - Soil temperature (2 to 5 cm) = delay
  - Sensitive to surface freezing
- Vegetation-soil continuum signal in boreal forest
- Need a better understanding/decoupling of FT signal in boreal forest (vegetation phenology vs soil FT)

- Interesting spatial pattern of F/T variability (Rain-On-Snow events)
- Good agreement between SBR and SMOS TB, excepted at 60°

Overall accuracy for F/T detection:
- 90.8% Aquarius
- 87.8% SMOS
Thanks to *In situ* data providers

* Centre d’Études Nordiques (CEN)
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* Peter Lafleur (Daring Lake)
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* Agriculture Alberta (ACIS)

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Thanks for your attention