DEVELOPMENT OF SMAP (SOIL MOISTURE ACTIVE AND PASSIVE) FREEZE/THAW ALGORITHMS ADAPTED FOR THE CANADIAN TUNDRA.

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ABSTRACT

This study is conducted in the framework of the NASA SMAP mission. The frozen soil mapping would certainly be improved by using the future NASA SMAP instruments which include both a Radiometer and a SAR operating at L-band. SMAP will have the ability to sense the soil conditions through moderate land cover. The radiometric accuracy, the better spatial resolution 40 km passive and 3 km active, and the global coverage of SMAP will make possible the monitoring of the seasonal F/T cycle at a regional scale. The objective of this study is to develop algorithms to track the seasonally F/T over the Tundra and the Boreal Forest. The experimental site is located in Northern Quebec (Nunavik) in Canada. We use available SMOS data from Environment Canada and in situ temperature and soil moisture data measured in different environments of the tundra and taiga.

***Index Terms*—** SMAP, SMOS, Freeze/Thaw, Nunavik

1. INTRODUCTION

The seasonal Freeze/Thaw (F/T) cycle is a major phenomenon in the climate system and plays an important role in ecosystem functioning [2] by influencing the rate of photosynthesis and respiration of the vegetation [11], reducing evaporation, reducing the penetration of water into the soil and altering surface runoff [2,11]. Boreal and arctic regions form a complex land cover mosaic where vegetation structure, condition and distribution are strongly regulated by environmental factors such as soil moisture and nutrient availability, permafrost, growing season length and disturbance. In these seasonally frozen environments, the growing season is determined primarily by the length of the non-frozen period. Variations in both the timing of spring thaw and the resulting growing season length have been found to have a major impact on terrestrial carbon exchange and atmospheric CO2 source/sink strength in boreal regions [13, 7, 8, and 14].

Microwave sensors on board satellite are well adapted tools to monitor the F/T cycle over the Boreal and Arctic regions of North America [8, 14]. Frozen soil behaves like dry soil at the microwave frequencies. Previous F/T cycle studies with low spatial resolution passive microwave sensors like SSMI [14] or AMSR-E [10, 12] have given encouraging results. Further, active microwave sensors (SAR) operating in Ku, C or L band can determine the state of the soil surface, either frozen or thawed [4, 5]. Both RADARSAT-2 C-band (5.4 GHz) data [5] and JERS L band data [3] have given interesting results. The potential of ALOS-PALSAR (1.4 GHz) data for F/T monitoring is presently studied [9]. The frozen soil mapping would certainly be improved by using the future NASA SMAP (Soil Moisture Active and Passive) instruments which include both a Radiometer and a SAR operating at L-band (1.40-1.41 GHz). In fact, SMAP will be able to monitor the frozen soil because of its capability to make coincident measurements of surface emission and backscatter, and with its ability to sense the soil conditions through moderate land cover. The launch of the SMAP mission is scheduled for 2014 or 2015. The radiometric accuracy, the better spatial resolution 40 km passive and 3 km active, and the global coverage of SMAP will make possible a systematic updating of frozen ground maps and monitoring the seasonal F/T cycle at a regional scale.

Then, the main objective of this study is to develop and validate algorithms to monitor F/T over the Tundra and the Boreal Forest for the future SMAP mission using available time series of passive microwave and SAR L-band data. The study area is Northern Quebec (Nunavik) in Eastern Canada. The main field site is located near Umiujaq (56.55° N, 76.55° O). It is a zone of discontinuous permafrost located at the tree line. This site has been the subject of more than 20 years of study by the Center for Northern Studies (CEN).

2. DATA USED

2.1. SOIL MOISTURE AND OCEAN SALINITY MISSION (SMOS)

The European Space Agency (ESA) Soil Moisture and Ocean Salinity (SMOS) mission was launched on November 2, 2009. Providing accurate soil moisture (SM) estimation is one of its main scientific objectives. [6]. SMOS carries a single payload, an L-Band 2D interferometric radiometer in the 1.40–1.43 GHz. This wavelength penetrates well through the atmosphere, and hence the instrument probes the earth surface emissivity. Surface emissivity can then be related to the moisture content in the first few centimeters of soil, and, after some surface roughness and temperature corrections, to the sea surface salinity over ocean.

2.2. IN-SITU MEASUREMENT

We use data from the meteorological network of the Centre for Nordic Studies (CEN), but we need additional data on temperature and soil moisture in different environments of the tundra and taiga. Table 1 gives the type of land cover, soil types and geographic coordinates where the sensors are installed (Umiujaq).

3. METHODS

We are testing different passive microwave algorithms. In particular, we will try the approach proposed by Kim et al. [14] with SMOS L-band data (1.4 GHz) using the followed equation:

$$\Delta T_{bp}\,(x,t) = \frac{(T_{bp}(x,t) - FrozRef\,(x))}{(ThawRef(x) - FrozRef(x))} \qquad (1)$$

Then, the SSM/I landscape F/T status is determined using the following formulas, which define respectively thawed and frozen landscape states.

$$\Delta T_{bp}(x,t) > T(x,t)$$
$$\Delta T_{bp}(x,t) \leq T\,(x,t) \qquad (2)$$

The output is a dimensionless DIM binary state variable designated by zero (0) for frozen and one (1) for non-frozen conditions for each pixel. Also, we will test both emissivity and brightness temperature [1, 12]. The emissivity is derived from the brightness temperature normalized by air and atmosphere. This coefficient correlated better with the weather and the sparse vegetation.

Up to now, we carried out the brightness temperature of SMOS, the values extracted were recorded at 40 degree incident angle as SMAP.

4. RESULTS

4.1. Temporal evolution of soil temperature

Figure 1 shows the place of soil temperature sensors in Umiujaq. Figure 2 shows the soil surface temperature evolution from July 7, 2010 to the end of year 2010, near Umiujaq (Nunavik). For each 12 sensors, the decrease of soil surface temperature and then freezing and thawing dates are different due to the difference in vegetation cover (type and height), in soil texture (sand, humus) and in relief (flat, slope) as given by Table 1.

4.2 SMOS

Figure 3 shows dual and crossed polarization multi-angular brightness temperature observations of SMOS images on November 2010. These brightness temperatures values are in Kelvin. According to this figure, there is a large change on November 23 for both co-polarization VV and HH. In situ data (Figure 2) also shows a decrease of soil temperatures below zero degree for most sensors on November 23, 2010.

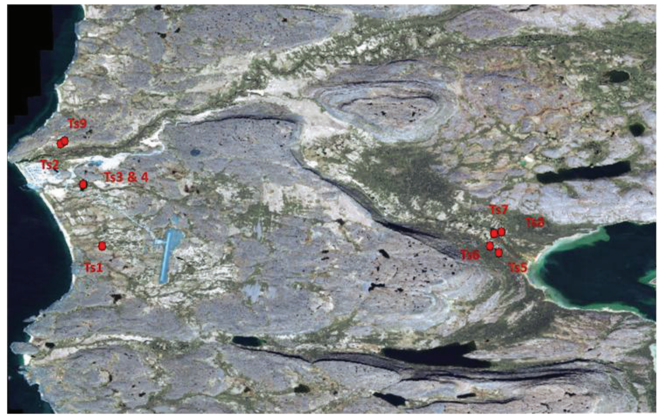

Figure 1: Brightness Temperature Sensor

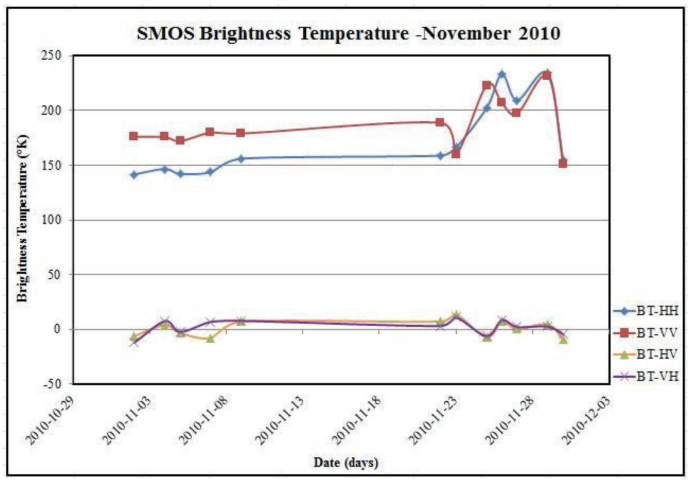

Figure 3: SMOS Brightness Temperature

5. CONCLUSION

Field data shows that freezing and thawing dates vary much spatially at the local scale in the tundra. Therefore, the field validation of the F/T state maps at the regional scale will be very important. Furthermore, the algorithms to be developed should be adapted to take care of the surface subgrid-scale heterogeneity (vegetation, soil, relief) within a given pixel of a few kilometers and the different polarization.

6. REFERENCES

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Table 1: Land Cover and the Soil Texture of each Sensor

Temperature Sensors: Umiujaq 2010-2011						
#Temperature Sensor	GPS Coordinates		Coordinate System	Vegetation	Height/Vegetation Type	Relief/Soil
	X	Y				
Ts-1	-76,53	56,54	WGS84	Yes	55 cm	Dune
Ts-2	-76,54	56,55	WGS84	Yes	60 cm	Flat Area
Ts-3	411541,95	6266926,02	NAD83	Yes	Shrubs	Sand & Hummus
Ts-4	411670,27	6266766,11	NAD83	Yes	Tall Shrubs	Humus
Ts-5	411670,27	6266766,11	NAD83	No	Lichen	±Sand
Ts-6	-76,54	56,56	WGS84	Yes	Shrubs	Sand
Ts-7	-76,54	56,55	WGS84	No	4 cm	Slope
Ts-8	-76,54	56,56	WGS84	No	Lichen	Sand
Ts-9	-76,54	56,56	WGS84	No	Lichen	Sand
Ts-10	-76,53	56,54	WGS84	No	0-1 cm	Dune
Ts-11	-76,54	56,56	WGS84	Yes	Shrubs	Sand
Ts-12	411541,95	6266926,02	NAD83	No	Lichen	Sand

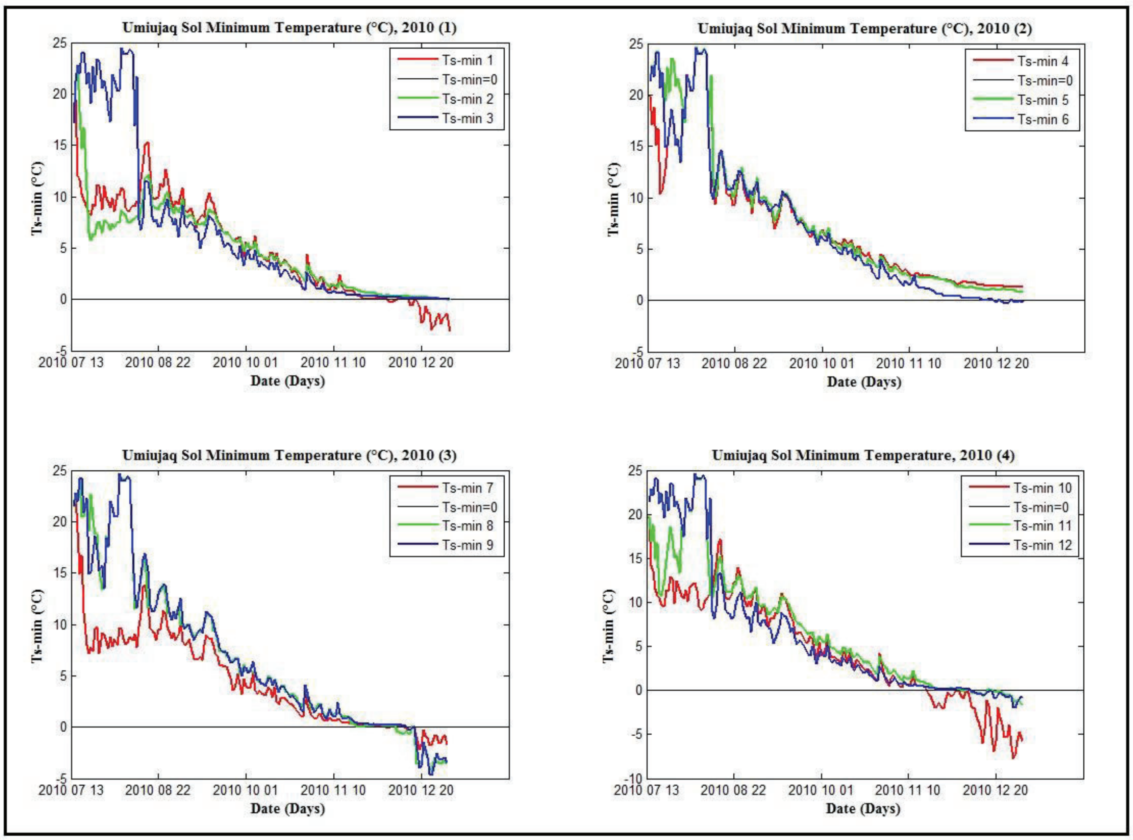

Figure 2: Soil Surface Temperature recorded by 12 different sensors in Umiujaq, 2010