SLAPEX FREEZE/THAW 2015: THE FIRST DEDICATED SOIL FREEZE/THAW AIRBORNE CAMPAIGN

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1. Introduction

Soil freezing and thawing is an important process in the terrestrial water, energy, and carbon cycles, marking the change between two very different hydraulic, thermal, and biological regimes. NASA's Soil Moisture Active/Passive (SMAP) mission [1] includes a binary freeze/thaw data product [2].

While there have been ground-based remote sensing field measurements observing soil freeze/thaw at the point scale, and airborne campaigns that observed some frozen soil areas (e.g., BOREAS), the recently-completed SLAPex Freeze/Thaw (F/T) campaign is the first airborne campaign dedicated solely to observing frozen/thawed soil with both passive and active microwave sensors and dedicated ground truth, in order to enable detailed process-level exploration of the remote sensing signatures and in situ soil conditions. SLAPex F/T utilized the Scanning L-band Active/Passive (SLAP) instrument, an airborne simulator of SMAP developed at NASA's Goddard Space Flight Center, and was conducted near Winnipeg, Manitoba, Canada, in October/November, 2015.

Future soil moisture missions are also expected to include soil freeze/thaw products, and the loss of the radar on SMAP means that airborne radar-radiometer observations like those that SLAP provides are unique assets for freeze/thaw algorithm development.

This paper will present an overview of SLAPex F/T, including descriptions of the site, airborne and ground-based remote sensing, ground truth, as well as preliminary results.

2. Experimental Site Description

The study region for SLAPex F/T was the same as was used during SMAPVEX12. This region is dominated by annual crops, grasslands (pasture), and some deciduous forest (typically dominated by aspen). During the time of SLAPex F/T, the agricultural crops had been harvested and fields consisted of bare soil and residue.
The study domain is located approximately 70km southwest of Winnipeg, Manitoba in the Brunkild sub-watershed of the Red River watershed. This region demonstrates a significant contrast in soil textures ranging from coarse soils (>90% sand content) to very fine soils (>60% clay content). Prior to SMAPVEX12, an *in situ* soil moisture monitoring network, Real-Time In Situ Monitoring for Agriculture (RISMA), was established within the Brunkild watershed.

The RISMA network in Manitoba consists of nine monitoring locations, with the majority of the sites contained within the SLAPex F/T sampling domain. The RISMA stations consisted of Stevens Hydra Probe SDI-12 installed vertically (measuring 0-5.7cm), horizontally centered at 5cm, 20cm, 50cm and 100cm, with each measurement depth measured in triplicate. Stevens Hydra Probe SDI-12 measured real and imaginary dielectric constants, volumetric soil moisture (using a dielectric conversion model) and soil temperature. Wind speed, air temperature, relative humidity and precipitation (rainfall) were measured at all of the locations. Data was collected at 30 minute intervals and was available in near-real time. During station installation, soil cores were removed and a calibration procedure was conducted to ensure accurate site-specific volumetric soil moisture estimates. These stations are permanent installations and will provide data during the SLAPex F/T.

In addition to the RISMA sites, four soil *in situ* monitoring sites were run by the University of Manitoba Department of Soil Science.

3. Measurements

Airborne remote sensing

SLAP consists of passive (radiometer) and active (scatterometer) L-band microwave instruments sharing a thin dual-polarization, dual-frequency antenna configured for 40° conical scan. The SLAP radiometer front-end is an engineering unit of the SMAP radiometer microwave assembly and the digital backend utilizes a clone of the SMAP RFI processor and algorithms, providing the same data products but with increased word lengths to take advantage of SLAP's greater available telemetry bandwidth to achieve a larger dynamic range.

The SLAP instrument's thin antenna design makes aircraft installation simple, and it has successfully flown over 30 flights on both the NASA Langley King Air B-200 and UC-12B. Previous campaigns have included soil moisture measurements over the DelMarVa Peninsula and a NASA/Duke University GPM-related campaign in 2014.

A total of thirteen science flights were flown over the course of seven days, with two flights most days to obtain pre-dawn observations of frozen soil and afternoon observations of thawed soil for comparison. Flights consisted of five low-altitude non-adjacent lines over fields where detailed ground truth was collected as well as two sites with ground-based radiometers plus forest locations. At the end of each flight, the instrument was flown over Lake Manitoba to obtain water calibration data for the scatterometer and radiometer.

Figure 1. SLAP preparing for an early morning flight on a NASA Langley King Air

Three flights were executed to image a single 36 km x 36 km SMAP EASE-grid pixel at maximum resolution (minimum altitude) within the aircraft endurance. These flights successfully demonstrated radiometer and scatterometer imaging for scaling studies. The imaged SMAP pixel contained most of the ground truth sampling locations, making direct comparison to low-altitude flight days possible.

All flights were operated with both scatterometer and radiometer collecting data, allowing for comparison of the freeze-thaw signature between both instruments as well as to enable active-passive algorithm studies. Example active and passive imagery from both types of flights for both frozen and thawed conditions will be presented.

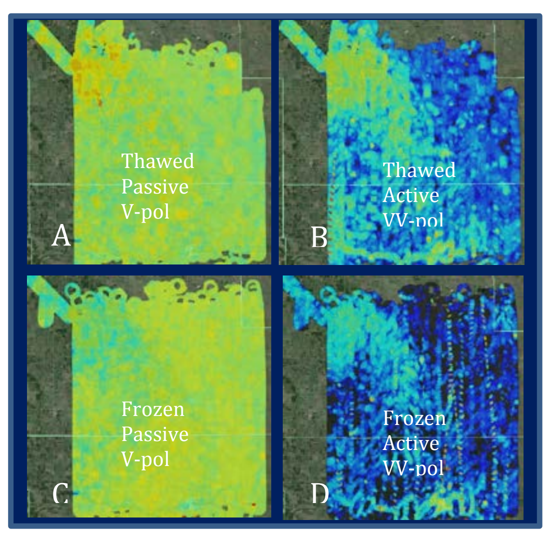

Figure 2. Passive (left panel) and active (right panel) L-band imagery from SLAP airborne sensor. These are quick-look images of brightness temperature (A,C) and radar reflectivity (B,D) superimposed on a Google Earth background image.

In Figure 2, the two passive images (A,C), orange/yellow colors show warmer and/or drier conditions while green/blue colors show cooler and/or wetter areas. In the two active images (B,D), yellow/green colors correspond to stronger radar reflectivity while blue/black colors correspond to lower-reflectivity areas. Note the color scale is arbitrary and independent for each image. Thawed observations (A,B) are from Nov. 8, 2015 and frozen observations (C,D) are from Nov 13, 2015. The imaged area is one 36 x 36 km SMAP grid cell, and spatial resolution is ~300m for passive and ~350m for active, both just around the size of the average farm field. The warmer/drier upper left corner of the thawed passive image (A) corresponds exactly with forested areas, which typically have higher brightness temperatures vs. the low/no vegetation of the bare soil and crops or pasture elsewhere. However, the opposite is seen in the frozen case (C), with a colder response of the forest region.

The passive and active signatures are a function of physical temperature, soil moisture and freeze/thaw state, surface roughness, and the vegetation cover. Field-to-field variations are related to these factors, and the high sensitivity we see indicates that microwave signatures of frozen vs. thawed soil can yield information on the controlling processes and ramifications for the water, energy, and carbon cycles.

Ground-based remote sensing

Two L-band radiometers operated by Environment Canada (EC) and Université de Sherbrooke (UdS) were simultaneously deployed over two different fields and left running continuously at an incidence angle of 40 degrees with an integration time of approximately 1 brightness temperature (TB) measurement every 5 seconds for the 2 week duration of the campaign. The two radiometer sites were located within 7 km of each other, and thus were exposed to the same large-scale weather patterns/conditions throughout the campaign, but had drastically different soil types with the EC system measuring a heavy clay soil, and the UdeS system measuring in a sandy loam soil. At each radiometer survey site, additional automated air (1.5 m above ground) and soil temperature sensors (surface, -1 cm, -2.5 cm below ground) were installed in and around the radiometer footprint, along with several Steven's Hydra Probe soil moisture/permittivity sensors (0-5.7 cm, -2.5 cm, -5 cm below ground). The recording data loggers and were set to record every 5 minutes. In-addition to the automated measurements, manual soil surveys were recorded to document the distributed soil temperatures, moisture and permittivity at different depths around the radiometer footprint and further out into the middle of the agricultural field. The objective of recording these distributed manual soil measurements was to assist in relating the surface-based radiometer TB measurements recorded at the field edge, in a potentially more protected micro-climate compared to the more exposed middle of the field, to the coarser resolution airborne TB that were measured nearby.

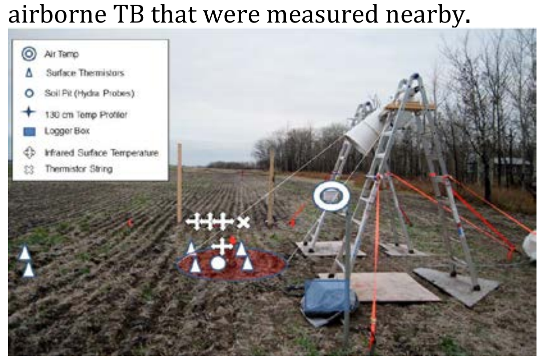

Figure 3. UdeS ground-based radiometer site.

Ground truth

During the 'frozen' overpass of the SLAP instrumentation, ground measurements were collected on up to 18 agricultural fields between 5am and 8am CST. Measurements focussed on the capture of soil temperature and soil permittivity. Temperature measurements consisted of soil and residue surface temperature and soil temperature at depths of 2.5, 5 and 10cm. Measurements were conducted in triplicate at 8 locations in each field following two transects. Soil permittivity was collected using Stevens Hydra probes at 4 times, co-located with temperature measurements. During 'thawed' overpasses, temperature measurements were conducted at 4 points, whereas soil permittivity was collected at 16 points along the same two transects and collected between 11am and 2pm CST. In addition to ground sampling measurements collected during overpass times, a network of in-situ soil moisture probes (Stevens Hydra probes) were installed in each of the fields, with one sensor oriented vertically, measuring an integrated depth of 0-5.7cm, one installed horizontally centered at 5cm and one horizontally at 10cm. In-situ, network measurements were taken every 30 minutes.

Prior to the field campaign soil roughness (rms height and correlation length) was measured at two locations in each field. Measurements were made in the N-S and E-W look directions with 3-m profiles. Also, residue photos were taken at two locations in each field in an attempt to quantify the percent residue cover. Further, at 3 locations in each field residue samples were taken from a 0.5x0.5m area to estimate the dry biomass. Soil texture, bulk density and volumetric water content measurements were determined previously during the SMAPVEX12 field campaign [3,4]. This information was used to calibrate the handheld and in-situ Stevens Hydra probes using field specific calibration equations [4].

Figure 4. 0-5.7cm vertically integrated liquid soil moisture averaged for all of the sites measured with Stevens Hydra probes. The sudden drops are the result of soil freeze events.

Satellite observations

A variety of related satellite data are being collected for use during SLAPex F/T analyses. Examples include SMAP, ASTER, RADARSAT2, and Sentinel.

4. Expected Results

The measurements collected as part of SLAPex F/T are expected to yield an improved process-level understanding of active and passive microwave remote sensing of frozen and thawed soils during the F/T transition period. This, in turn, will lead to the development of more robust F/T algorithms than those currently in use by L-band satellite sensors. And, although it was not a goal of SLAPex F/T, the data will likely be of use for F/T validation for SMAP (and perhaps for SMOS).

6. References

[1] D. Entekhabi, et al. “The Soil Moisture Active Passive (SMAP) mission,” Proc. IEEE, 98 (5), pp. 704–716, May 2010.

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[3] McNairn, H., et al. "The Soil Moisture Active Passive Validation Experiment 2012 (SMAPVEX12): Prelaunch calibration and validation of the SMAP soil moisture algorithms.", IEEE TGARS 53.5 (2015): 2784-2801.

[4] Rowlandson, T, et al. "Evaluation of several calibration procedures for a portable soil moisture sensor." Journal of hydrology 498 (2013): 335-344.