Detection of soil frost in Northern Boreal Forest using space borne SMOS and tower-based ELBARA-II radiometric data

SMOS Validation and Retrieval Team Workshop 2010


* Finnish Meteorological Institute
** European Space Agency, ESTEC
*** Gamma Remote Sensing AG
Objective

• To investigate the feasibility of L-band space-borne radiometry to monitor soil processes at boreal/sub-arctic environment
  - Soil freezing/thawing and other cryospheric processes including the accumulation of snow cover
  - Soil moisture during snow-free conditions
  - Effect of land cover variability to space-borne observations and to data retrieval algorithms

• SMOS CAL-VAL for northern environment
  - Continuous tower-based observations with ESA ELBARA-II reference radiometer at the Sodakylä site, north of the Arctic circle
  - Accompanied with continuous in situ reference data sampling with automatic and manual systems

⇒ Comparison of SMOS observations with reference radiometer and in situ data
L-band passive instruments
FMI Northern Finland test areas

*This study uses test areas of three different scales*

1. **Intensive Observation Area (IOA) in Sodankylä**
   - Tower-based measurements with extensive in-situ observations

2. **SMOS pixel size area around the IOA**
   - Direct comparison between ELBARA and SMOS results

3. **Sodankylä-Pallas testbed**
   - Regional scale test area, size of 150 km x 150 km
   - Well known land classification information
Intensive Observation Area (IOA)

Site typical boreal coniferous forest on mineral soil
Average maximum snow depth: 80 cm
Easy access and technical support

Sodankylä

FMI Arctic Research Centre, Sodankylä, Finland

67°21.712’ N
26°38.270’ E

Meteorological mast measurements

Meteorological ground based measurements
Sodankylä-Pallas testbed with “IOA SMOS pixel”

- For space borne instrument CAL/VAL activities: 150 km x 150 km
- Land class information from Corine Land Cover 2006
First Results

1. ELBARA-II first 9 months
2. Comparison of SMOS and ELBARA-II
3. SMOS results at FMI Sodankylä-Pallas testbed
ELBARA-II: The first 9 months

1.) Cold Winter Period – stable $T_b$
2.) Short Freezing Period – strong correlation $T_b$ vs Soil frost depth
3.) Strong Daily Variations – due to snow melting and freezing
4.) Snow Melt-off
Cold Winter Period

- Stable Tb signature at V-polarization
- Snow layer effect simulated using HUT snow emission model (Pulliainen J. et al., 1999)
- Ground layer surface roughness effects simulated by semiempirical model (Wegmüller & Mätzler, 1999)
- Combined model explains the V-pol behaviour at L-band when surface is assumed ideally smooth
  \[ \Rightarrow \text{effective dielectric constant for soil (} \varepsilon = 4-0.8j) \]
- Typical empirical values for frozen soil (e.g. Hallikainen et al., 1987, Dobson et al., 1987): \( \varepsilon(\text{Re}) = 4...8, \varepsilon(\text{Im}) = 0.5...2 *j \)
Soil frost and snow depth

- Soil frost information from frost tubes (read 3-4 times per month).
- Snow depth: acoustic Campbell SR50 sensor
- Soil temperature sensors at the depth of 5, 10, 20, 30 and 50 cm => additional information on the beginning and end of the frost period on those depths
Effect of increasing soil frost during early winter

- High correlation between the observed brightness temperature and the depth of soil frost during the freezing period
Effect of increasing soil frost during early winter

- High correlation between the observed brightness temperature and the depth of soil frost during the freezing period
Comparison of SMOS and Elbara-II

Both SMOS and Elbara-II show the minimum $T_b$ for the occurrence of snow clearance.

Directly after snow melt-off:
Soil temperature starts to rise from 0°C level, top-soil dries quickly and frozen soil below the top-soil layer starts to melt (from the top and the bottom).
SMOS results at FMI Sodankylä-Pallas testbed I

- Test area 150 x 150 km
- Land classes reduced to 4: Water, Forests, Bogs, and Other
- SMOS isea grid was oversampled to 10 x 10 km grid => further averaged to 50 x 50 km grid
- => Nine samples, each having unique land class distribution
- => 4 unknowns, 9 equations => Brightness temperature values for each land class was solved
SMOS results at FMI Sodankylä-Pallas testbed II

Four land cover classes at 45 deg incidence angle

Elbara-II and SMOS results at IOA

- Water
- Forest
- Bog
- Other

Date in dd/mm:
15/04, 26/04, 07/05, 19/05, 30/05, 10/06, 22/06

Date dd/mm:
15/04, 26/04, 07/05, 19/05, 30/05, 10/06, 22/06
Conclusions

- L-band radiometry has a clear potential for boreal/sub-arctic terrestrial regions
  - Even using instruments with a coarse spatial resolution, such as SMOS with its ~40 km spatial resolution

- Potential applications for the monitoring of cryospheric processes
  - Soil freezing and depth of soil frost during early winter
  - Snow melt period processes including snow freeze-melt cycles and snow clearance related melt of seasonal soil frost
Thank You for Your Attention!