Inter-Calibration of Low Frequency Brightness Temperature Measurements for a Long-Term Uniform Soil Moisture Record

Mariko S. Burgin¹, Andreas Colliander¹, Chun-Sik Chae¹, Emmanuel Dinnat², Michael Cosh³, Ying Gao⁴, Jeffrey Walker⁴, Todd Caldwell⁵

¹Jet Propulsion Laboratory, California Institute of Technology, USA
²Goddard Space Flight Center, USA, and Chapman University, USA
³USDA-ARS Hydrology and Remote Sensing Laboratory, USA
⁴Department of Civil Engineering, Monash University, Australia
⁵University of Texas at Austin, USA
Motivation

Why?
→ Need for consistent long-term soil moisture is well established
→ Room for improvement over techniques applying statistical matching
→ Address the sensing depth variability (do not leave it up to the user)

Solution?
→ Specifically designed multi-frequency algorithm with brightness temperature inter-calibration and sensing depth normalization
SCIS LOTUS: Satellite Calibration Interconsistency Studies
Long Term Uniform Soil Moisture

Project Overview

PART I
Inter-calibrate L-, C- and X-band TBs

PART II
Apply uniformly designed algorithm to retrieve consistent SM using TB records at different frequencies

PART III
Compensate for different sensing depths of L-, C- and X-band using a model, and derive SM at a uniform depth

- Match instrument observations in space & time over ocean and with respect to cold sky
- Adapt heritage antenna temperature simulator to multi-frequency TB modeling to make L-, C- and X-band TBs consistent across frequencies
  → Temporal overlap of SMOS & AMSR-E, and SMAP & SMOS & AMSR2 is key to make TB records consistent

- Use in-situ SM data as ground truth to parameterize and test the performance of the SM retrieval algorithm
  → Allows to reveal any hidden inconsistencies between the different TB data sets

- Apply near surface SM model to project the SM estimates to the SMAP observation depth

A consistent long-term uniform SM data record

Notation:
SM: soil moisture
TB: brightness temperature

© 2017. All rights reserved.
SCIS LOTUS: Satellite Calibration Interconsistency Studies
Long Term Uniform Soil Moisture

Four Missions

- L-, C- and X-band spaceborne radiometers (AMSR-E, SMOS, AMSR2, SMAP) are used for soil moisture retrieval
- SMOS, AMSR2, SMAP currently in orbit, need AMSR-E to expand the data record back to 2002
- The 4 satellites cover a span from 2002-2017 and will cover 17 years by the end of the project
- The 2 L-band missions overlap since April 2015, the 2 C-/X-band missions do not overlap

<table>
<thead>
<tr>
<th>Year</th>
<th>Available data</th>
<th>Frequency (GHz)</th>
<th>3dB instrument footprint (km)</th>
<th>Temporal Revisit</th>
<th>Incidence angle (°)</th>
<th>Orbit (A: ascending; D: descending)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002-11</td>
<td>AMSR-E</td>
<td>6.93 (C)</td>
<td>75 x 43</td>
<td>~2 days</td>
<td>55</td>
<td>sun-synchronous 1:30 am A / 1:30pm D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.65 (X)</td>
<td>51 x 29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009-17</td>
<td>SMOS</td>
<td>1.4 (L)</td>
<td>27-55*</td>
<td>~3 days</td>
<td>0-55**</td>
<td>sun-synchronous 6am A / 6pm D</td>
</tr>
<tr>
<td>2012-18</td>
<td>AMSR2</td>
<td>6.93 (C)</td>
<td>62 x 35</td>
<td>~2 days</td>
<td>55</td>
<td>sun-synchronous 1:30pm A / 1:30am D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.3 (C)</td>
<td>62 x 35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.65 (X)</td>
<td>42 x 24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015-18</td>
<td>SMAP</td>
<td>1.41 (L)</td>
<td>39-47</td>
<td>~3 days</td>
<td>40</td>
<td>sun-synchronous 6 pm A / 6am D</td>
</tr>
</tbody>
</table>

*Depending on incidence angle; approximately 40 km at 40° incidence angle
**We will interpolate to 40° and 55° incidence angles

© 2017. All rights reserved.
Part I: Inter-Calibration of L-, C-, and X-band TBs

Establish consistency across frequency bands

- Overlapping observation in time & space
  - Temporal overlap of SMOS & AMSR-E, and SMAP & SMOS & AMSR2

- Calibration references:
  - Multi-frequency ocean model (double-difference)
  - Multi-frequency ice sheet emission model (Antarctica)
  - Sky looks of each mission

- Gain & offset adjustment to make the observations consistent
  - Account for temporal trends

An example of SMAP-SMOS TB comparison (top of the atmosphere; homogeneous surfaces)
Part I: Inter-Calibration of L-, C-, and X-band TBs

Multi-frequency ocean model development

- Radiative Transfer model:
  - Emission: 2-scale model
  - Dielectric constant: Meissner and Wentz (2004, 2012)
  - Roughness: Yueh (1997)

- Ancillary data:
  - Sea Surface Temperature: NOAA OI V2
  - Sea Surface Salinity: HYCOM model
  - Wind Speed and Direction: NCEP GDAS

→ Model framework implemented and tested with SMAP L-band and AMSR2 C-band data

→ Dielectric constant and roughness parameterization over frequency on-going (assessment of various model parameterizations)
Part II: Uniformly designed SM algorithm at L-, C-, and X-band

→ In-situ measurement at validation sites around the world allows the tuning of parameters for different types of landscapes and soil types
→ L-, C-, X-band satellite data re-processed to the SMAP EASEv2 grid

**TxSON**
Grassland area in Texas, USA
- Soil moisture: 41 stations measuring at 5, 10, 20, 50 cm
- Weather stations: 6
- LCRA stations: 7

**Yanco**
Semi-arid *cropping & grazing area* in New South Wales, Australia
- Crops: wheat, barley, corn, canola (1/3 irrigated)
- Soil moisture: 24 stations at 0-5 cm
- Soil temperature: 24 stations at 1-5 cm

© 2017. All rights reserved.
Part II: Uniformly designed SM algorithm at L-, C-, and X-band

Comparison of TBs at TxSON: SMAP vs. AMSR2
- L-, C-, and X-band track each other well
- AMSR2-Ascending shows larger dynamic range than AMSR2-Descending
- Smaller difference between SMAP and AMSR2 during July-October

- SMAP, AMSR2 comparison is a natural starting point due to the availability of the data to develop the L/C/X-band relationships
- AMSR-E and SMOS will be added later
Part II: Uniformly designed SM algorithm at L-, C-, and X-band

Comparison of TBs at Yanco: SMAP vs. AMSR2
- L-, C-, and X-band track each other well
- Smaller difference in the dry season during November-March (Southern hemisphere summer) where VWC is smaller

→ SMAP, AMSR2 comparison is a natural starting point due to the availability of the data to develop the L/C/X-band relationships
→ AMSR-E and SMOS will be added later
Forward modelling of TBs: Single Channel Algorithm (SCA)

- TBs for all frequencies re-gridded to 33x33 km SMAP pixel
- Input soil moisture: in-situ station at 0-5 cm
- Soil moisture and temperature aggregated using a Voronoi diagram based weighting
- Input VWC: from MODIS NDVI climatology
- Fixed model parameters for forward simulations at L-, C-, and X-band (at Yanco):

<table>
<thead>
<tr>
<th>Clay%</th>
<th>Sand%</th>
<th>ρ</th>
<th>ω</th>
<th>$Q_{RP}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>25</td>
<td>1.3</td>
<td>0.05</td>
<td>0</td>
</tr>
</tbody>
</table>

- For L-band, use both SMAP default and calibrated $b$ and $h$; for C- and X-band, use calibrated $b$ and $h$
Part II: Uniformly designed SM algorithm at L-, C-, and X-band

TB simulation before/after calibration: SMAP at L-band

- V-pol has a smaller RMSD and mean difference, and higher correlation compared to the H-pol, consistent with previous studies
- Overestimation for wet season (JUL-OCT); underestimation for dry season (NOV-JUN)
- There are avenues to further improve the match, such as tuning of model parameters and improving VWC estimation, etc.
Part II: Uniformly designed SM algorithm at L-, C-, and X-band

TB simulation before/after calibration: ASMR2 at C-/X-band

- V-pol has a smaller RMSD and mean difference, and higher correlation compared to the H-pol, consistent with previous studies
- Underestimation for wet season (JUL-OCT); underestimation for dry season (NOV-JUN)
- There are avenues to further improve the match, such as tuning of model parameters and improving VWC estimation, etc.
Part II: Uniformly designed SM algorithm at L-, C-, and X-band

TB simulation after calibration: Statistics

- V-pol has a smaller RMSD, mean difference and higher correlation as compared to H-pol
- Underestimation of TB at higher values and an overestimation at low values

<table>
<thead>
<tr>
<th>Band, pol</th>
<th>b</th>
<th>h</th>
<th>RMSD</th>
<th>Mean Dif.</th>
<th>ub. RMSD</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-band, H</td>
<td>0.06</td>
<td>0.26</td>
<td>13.3 K</td>
<td>-4.1 K</td>
<td>12.6 K</td>
<td>0.95</td>
</tr>
<tr>
<td>L-band, V</td>
<td>0.05</td>
<td>0.25</td>
<td>7.8 K</td>
<td>-1.5 K</td>
<td>7.7 K</td>
<td>0.96</td>
</tr>
<tr>
<td>C-band, H</td>
<td>0.12</td>
<td>0.71</td>
<td>17.4 K</td>
<td>-13.8 K</td>
<td>10.6 K</td>
<td>0.88</td>
</tr>
<tr>
<td>C-band, V</td>
<td>0.10</td>
<td>0.68</td>
<td>7.6 K</td>
<td>-4.9 K</td>
<td>5.9 K</td>
<td>0.93</td>
</tr>
<tr>
<td>X-band, H</td>
<td>0.15</td>
<td>0.86</td>
<td>14.3 K</td>
<td>-11.4 K</td>
<td>8.5 K</td>
<td>0.89</td>
</tr>
<tr>
<td>X-band, V</td>
<td>0.11</td>
<td>0.78</td>
<td>6.2 K</td>
<td>-3.7 K</td>
<td>5.0 K</td>
<td>0.93</td>
</tr>
</tbody>
</table>
Part III: Derivation of SM at uniform depth

- Most soil moisture installations are installed at a depth of 5 cm
- A set of Hydras installed at depths from 1.5, 2.5, 3, 4, and 5 cm (in triplicate).

Increasing error with increasing depth for a single dry-down; same order as the instrument error for overall comparison, 0.01 m³/m³
- Result applies over this particular site; the outcome will vary by location

Goal: address the difference at 'dry-down scale' even though overall metrics don't necessarily suffer from the depth difference
Thank you for your attention

Mariko S. Burgin
mariko.s.burgin@jpl.nasa.gov