Soil Moisture: Algorithms

Eni Njoku
Jet Propulsion Laboratory
California Institute of Technology

Soil Moisture Active and Passive (SMAP) Mission Workshop
Arlington VA, July 9-10 2007
### SMAP Primary Data Products Table

<table>
<thead>
<tr>
<th>Data Product</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1B_S0_LoRes</td>
<td>Low Resolution Radar $\sigma^o$ in Time Order</td>
</tr>
<tr>
<td>L1C_S0_HiRes</td>
<td>High Resolution Radar $\sigma^o$ on Earth Grid</td>
</tr>
<tr>
<td>L1B_TB</td>
<td>Radiometer $T_B$ in Time Order</td>
</tr>
<tr>
<td>L1C_TB</td>
<td>Radiometer $T_B$ on Earth Grid</td>
</tr>
<tr>
<td>L3_SM_HiRes</td>
<td>Radar Soil Moisture on Earth Grid</td>
</tr>
<tr>
<td>L3_F/T_HiRes</td>
<td>Freeze/Thaw State on Earth Grid</td>
</tr>
<tr>
<td>L3_SM_40km</td>
<td>Radiometer Soil Moisture on Earth Grid</td>
</tr>
<tr>
<td>L3_SM_A/P</td>
<td>Radar/Radiometer Soil Moisture on Earth Grid</td>
</tr>
<tr>
<td>L4_GPP</td>
<td>Gross Primary Productivity on Earth Grid</td>
</tr>
<tr>
<td>L4_4DDA</td>
<td>Soil Moisture Model Assimilation on Earth Grid</td>
</tr>
</tbody>
</table>
SMAP Candidate Ground System Architecture

Hydros Heritage
Science Algorithm Roadmaps

Algorithm Roadmaps (Hydros Heritage)

• Mission data products are based on algorithms (baseline and enhancements) that consist of the equations and processing steps used to generate the products.

• Algorithm roadmaps describe the procedures for developing and testing the algorithms to ensure the data products meet the mission requirements.

• The algorithms and computational software derived from them are developed by the science team to be used in generation of the data products.

• Each science data product has a target accuracy, spatial resolution, spatial gridding (posting), global repeat, and latency requirement.

• Roadmap documents were developed for each Hydros data product during Hydros Phase A.
Soil Moisture Algorithms: Heritage R&A Investments

Evolution of Soil Moisture Mapping

- Ground and aircraft development and verification of theory (1-10m resolution)
- Improved soil moisture algorithms
- Spaceborne demonstration
- Global soil moisture mapping

- Field Experiments
- AIRSAR (POLSAR)
- PBMR
- ESTAR, PALS
- SIR-C
- SMOS
- SMAP
- AMSR
- PALSAR
- Aquarius
- Hydros
- NPOESS

Time Period

Soil-Vegetation Surface Microwave Model

Ionosphere, Atmosphere

Surface
(Composite soil/vegetation)

Emission
(Radiometer)

\[ T^t_{Bp} = T^s_{Bp} L_p + T^v_{Bp} + T^{sv}_{Bp} \] (Emission)

\[ \sigma^t_{pq} = \sigma^s_{pq} L^2_{pq} + \sigma^v_{pq} + \sigma^{sv}_{pq} \] (Backscatter)

- Subscripts \( p, q \): polarization (h or v)
- \( L_{pq}, L_p \): one-way vegetation attenuation factor, \( \exp(-\tau_o / \cos \theta) \)
- Superscripts \( t, s, v, \) and \( sv \) indicate total, soil, vegetation, and soil-vegetation interaction terms, respectively
Supporting Field Campaigns

**Soil Moisture Science and Algorithm Development**

*Multi-scale soil moisture field experiments (1990-2005) using satellite, airborne, and in-situ sensing*

- Coordinated by NASA and USDA/ARS Hydrology Laboratory
- Included flights of ESTAR, PALS and AIRSAR L-band sensors
- Participation by university faculty and students in field measurements and data analysis

**SMEX04/North American Monsoon Experiment (NAME)**

**SMEX U.S. Sites**

*Validation Field Site at Alabama A&M with University Students Participation*

*NCAR C-130 Aircraft*

*SMEX Airborne soil moisture mapping*

*In-situ Sampling*

*600+ High-Schools*

Students collect ground-truth soil moisture data. Classroom access linkages developed for soil moisture mission data.
PALS-II: Combined Active and Passive L-band Instrument

- **PALS-II Characteristics**
  - Polarimetric radiometer (1.41 GHz)
    - V, H, +45, and -45 degree polarizations
    - Three-noise-diode design, similar to Aquarius and Hydros’
  - Polarimetric radar (1.26 GHz)
    - VV, HH, VH and HV
    - Parallel V and H receivers
  - Companion nadir-looking IR and video cameras

- **CLASIC campaign on the Twin Otter in summer 2007**

- **High Wind Ocean Salinity Campaign for hurricanes of opportunity on the NASA P-3 in summer 2008**
Field Campaign Retrieval Results

Retrievals and Validation

- Soil moisture retrieval algorithms have been developed and validated during an extensive history of microwave modeling and field experiments (using ground-based, airborne and Shuttle instruments)
  - MacHydro’90, Monsoon’91, Washita’92, FIFE, HAPEX, SGP’97, ‘99, SMEX’02, ‘03, ‘04, ‘05
  - Radiometric retrieval accuracy is greater than radar in vegetated conditions, achieving better than 4% volumetric accuracy for vegetation water contents up to ~5 kg m$^{-2}$ (mature corn crop)
  - Radar can achieve higher spatial resolution than radiometry using synthetic aperture processing
Soil Moisture and Freeze/Thaw Algorithm Processing

(Hydros Heritage)
Retrieval Simulation and Sensitivity Studies

- Observing System Simulation Experiments (OSSE) designed for Hydros can be improved and extended to continental and global scales for SMAP
  - *Improved geophysical and microwave models*
  - *Improved instrument and orbit simulations*
  - *Essential for informed instrument design trades and algorithm development*

Legend:
- $x_i$ geophysical variables
- $+$ simulated sensor product resolution (radar and radiometer)
- $++$ combined retrieval resolution
- $*$ estimated (retrieved variables)
Model-Simulated Soil Moisture
Red-Arkansas River Basin (Crow et al.)

Start Date: May 26, 1994 (Wet)
End Date: June 28, 1994 (Dry)

Soil moisture distributions at start and end of simulation

Basin-averaged soil moisture and precipitation time series
Simulated Soil Moisture Retrievals
(Radiometer, Radar, and Combined Spatial Resolutions)

Hydros OSSE
• Soil Moisture Requirements for a spaceborne mission were articulated in NASA-sponsored community workshop (SMMWG) in Irvine in the 1990s and have not changed significantly since then - recently reconfirmed by the SMMWG meeting in March 2006

• SMAP soil moisture algorithms (Hydros heritage) were further developed during the Hydros Risk-Reduction phase and reviewed at the Hydros open science meeting (Phoenix, AZ, May 2005)

• Recent progress in soil moisture radar science and algorithms was presented and reviewed at the Hydros International Radar Workshop (Santa Barbara, CA, October, 2005)

• Soil moisture and freeze/thaw algorithms are robust - additional research will help refine and extend these algorithms for the SMAP mission