Anticipated Impacts of Soil Moisture Active Passive (SMAP) Mission Measurements on Hydrologic Applications

The SMAP Science Definition Team (SDT)

Remote Sensing and Hydrology 2010 Symposium (IAHS)
September 2010
Talk Outline

1. SMAP mission and the *Earth Science Decadal Survey*
2. Traceability of measurement requirements to hydrologic applications
3. Pathways of soil moisture influence on weather and climate
4. Applications to:
   - Drought monitoring and seasonal climate prediction
   - Water availability from snowmelt outlooks
   - Flood monitoring and forecasting
5. Data products and latencies
SMAP is one of four missions recommended by the NRC “Decadal Survey” for launch in the 2010–2013 time frame.

- Feb 2008: NASA announces start of SMAP project
- SMAP is a directed-mission with heritage from Hydros
- Hydros risk-reduction performed during Phase A (instrument, spacecraft dynamics, science, ground system)
  Cancelled 2005 due to NASA budgetary constraints

<table>
<thead>
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<th>Tier 1: 2010–2013 Launch</th>
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<td>Soil Moisture Active Passive (SMAP)</td>
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<td>GRACE-II</td>
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<td>3D-WINDS</td>
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## Science Requirements

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<th>Application</th>
<th>Science Requirement</th>
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<td>Weather Forecast</td>
<td>Initialization of Numerical Weather Prediction (NWP)</td>
<td>Hydrometeorology</td>
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<td>Climate Prediction</td>
<td>Boundary and Initial Conditions for Seasonal Climate Prediction Models</td>
<td>Hydroclimatology</td>
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<td>Testing Land Surface Models in General Circulation Models</td>
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<tr>
<td>Drought and Agriculture Monitoring</td>
<td>Seasonal Precipitation Prediction</td>
<td>Hydroclimatology</td>
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<td>Regional Drought Monitoring</td>
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<td>Crop Outlook</td>
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<td>Flood Forecast Improvements</td>
<td>River Forecast Model Initialization</td>
<td>Hydrometeorology</td>
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<td>Flash Flood Guidance (FFG)</td>
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<td></td>
<td>NWP Initialization for Precipitation Forecast</td>
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<td>Human Health</td>
<td>Seasonal Heat Stress Outlook</td>
<td>Hydroclimatology</td>
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<td>Near-Term Air Temperature and Heat Stress Forecast</td>
<td>Hydrometeorology</td>
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<td>Disease Vector Seasonal Outlook</td>
<td>Hydroclimatology</td>
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<tr>
<td></td>
<td>Disease Vector Near-Term Forecast (NWP)</td>
<td>Hydroclimatology</td>
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<tr>
<td>Boreal Carbon</td>
<td>Freeze/Thaw Date</td>
<td>Freeze/Thaw State</td>
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### Baseline Mission

<table>
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<tr>
<th>Requirement</th>
<th>Hydro-Meteorology</th>
<th>Hydro-Climatology</th>
<th>Carbon Cycle</th>
<th>Baseline Mission</th>
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<tr>
<td></td>
<td>Resolution</td>
<td>Refresh Rate</td>
<td>Accuracy</td>
<td>Soil Moisture</td>
</tr>
<tr>
<td>Resolution</td>
<td>4–15 km</td>
<td>2–3 days</td>
<td>4–6%**</td>
<td>10 km</td>
</tr>
<tr>
<td>Refresh Rate</td>
<td>50–100 km</td>
<td>3–4 days</td>
<td>4–6%**</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td></td>
<td>2–3 days(1)</td>
<td>80–70%*</td>
<td>4%**</td>
</tr>
</tbody>
</table>

(*%) % classification accuracy (binary Freeze/Thaw)

(**) [cm³ cm⁻³] volumetric water content, 1-sigma

(1) North of 45N latitude
Mission Science Objective

Global mapping of Soil Moisture and Freeze/Thaw state to:

- Understand processes that link the terrestrial water, energy & carbon cycles
- Estimate global water and energy fluxes at the land surface
- Quantify net carbon flux in boreal landscapes
- Enhance weather and climate forecast skill
- Develop improved flood prediction and drought monitoring capability
May 10  Dry soil, clear, mild winds. (LE≈H)
May 18  90 mm Rain
May 20  Moist soil, clear, mild winds. (LE>H)

Pathways of Land Surface Influence on Weather and Climate

Key Determinants of Land Evaporation

Latent heat flux (evaporation) *links* the water, energy, and carbon cycles at the surface.

Closure relationship, yet virtually unknown.

Lack of knowledge of soil moisture control on evaporation causes uncertainty in land surface and atmospheric models.

\[
\beta = \frac{E}{E_p}
\]

Source: Cahill et al., *J. Appl. Met.*, 38
What Do We Do Today?

**NOAH**

model grid cell and

\[
\beta = \left( \frac{\Theta_l - \Theta_w}{\Theta_{\text{ref}} - \Theta_w} \right)^f
\]

(7)

represents a normalized soil moisture availability term where \(\Theta_w\) is the wilting point and \(\Theta_{\text{ref}}\) is the field capacity.

**CLM**

functional type and the soil water potential of each soil layer

\[
\beta_i = \sum w_i \gamma_i \geq 1 \times 10^{-10}
\]

(8.10)

where \(w_i\) is a soil dryness or plant wilting factor for layer \(i\), and \(\gamma_i\) is the fraction of roots in layer \(i\).

The plant wilting factor \(w_i\) is

\[
w_i = \begin{cases} 
\frac{\psi_{\text{max}} - \psi_i}{\psi_{\text{max}} + \psi_{\text{sat},i}} & \text{for } T_i > T_f \\
0 & \text{for } T_i \leq T_f
\end{cases}
\]

(8.11)

Atmospheric model representations of this function are essentially “guesses”, given scarcity of soil moisture and evaporation data.
American Meteorological Society (AMS) Statement

Drought is often grouped into four basic types: 1) meteorological, 2) agricultural, 3) hydrological, and 4) socioeconomic.

**Meteorological drought** … magnitude [and duration] of a precipitation shortfall

**Agricultural drought** is largely the result of a deficit of soil moisture…

**Hydrological droughts** are concerned with shortfall on surface or subsurface water supply…Rootzone, vegetation and streams response
Agricultural drought (deficit of soil moisture) cannot necessarily be inferred from precipitation deficit.

The Standardized Precipitation Index (SPI) for July 2010.

Palmer Drought Severity Index (PDSI) for July 2010.
“Compared with the WWII drought, multi-year averages of rainfall and subsurface soil moisture during the Big Dry are not as low, but the sensitivity of soil moisture to rainfall decline is over 80% higher.

We show that a relationship exists between subsurface soil moisture variations and fluctuations of temperature not associated with rainfall over eastern Australia in all seasons, and over SEA in austral spring and summer.”

Root-zone soil moisture dynamics may contribute to prolonged drought conditions.

Conditions are similar to those expected under global change.

Multi-model consensus view of land contribution to air temperature forecasts.

JJA Skill contribution at the 30-day lead (days 31-45).


Seasonal Climate Prediction: 50 km Resolution
Initialize rootzone moisture

**Global Change and Water Cycle**

**Future Climate and Water Cycle:** Soil moisture influence on precipitation intensifies the regional water cycle response to global change.

Mean Summer (JJA) soil moisture feedback parameter on precipitation among 19 IPCC models [cm/month]

Global average monthly precipitation over land is ~8 cm/month

Soil moisture information can contribute skill to streamflow forecasts

Linear regression analysis examining observed streamflow, snow, climate and soil moisture:

“This study demonstrates that available macroscale estimates of soil moisture have the potential to enhance streamflow prediction...”
(Berg and Mulroy, Hydro. Sci., 51, 642-654, 2006)

Contribution ($r^2$) of Jan. 1 soil moisture initialization to MAM streamflow prediction.

Synthetic analysis showing where soil moisture initialization may improve streamflow prediction at seasonal timescales. Results are supported by available streamflow observations.
(Mahanama et al., in preparation)
Soil Moisture Information Enhances Water Resource Availability Predictions

Koster et al., 2010: Skill in streamflow forecasts derived from large-scale estimates of soil moisture and snow”, *Nature-Geoscience*, in press.

May-July streamflow forecasts

(a) CTRL: Forcings, initial snow & SM known (not true forecasts)
(b) Exp1: Initial snow, initial SM known
(c) Exp2: Initial snow known
(d) Exp3: Initial SM known

Skill ($r^2$) vs. observations
1) Characterization of pre-storm soil moisture
2) Accurate real-time rainfall monitoring (in large basins)
3) Numerical weather prediction of extreme rainfall
4) Monitoring inundation
Characterization of Pre-Storm Soil Moisture

Current: Empirical soil moisture indices based on filtering precipitation time-series at county resolution (~50 km)

Future: Direct observations: SMAP at 10 km
Characterization of Pre-Storm Soil Moisture

Red – Remote Sensing Only (TRMM TMI)
Black – Model Only
Blue – Remote Sensing/ Model KF Combined

(>30^2 km^2 MOPEX Basins in Southern US)
Characterization of Pre-Storm Soil Moisture

Red – Remote Sensing Only (TRMM TMI)

Black – Model Only

Blue – Remote Sensing/ Model KF Combined

SMAP will:
- Lead to more added skill.
  (Here: X-band, SMAP: L-band)
- Allow for implementation in finer-scale basins.
  (Here: >1000 km², SMAP: >100 km²)

(>30² km² MOPEX Basins in Southern US)
Accurate Rainfall Monitoring

Crow et al. (2009), JHM, 10(1), 199-212.

\[ R_{value} = 0.791 \]
\[ N = 130 \]

\( R_{value} = 0.791 \)
\( N = 130 \)
Accurate Rainfall Monitoring

Improvement in TRMM 3B40RT 3-day accumulation skill

Crow et al. (2009), JHM, 10(1), 199-212.
Accurate Rainfall Monitoring

**Improvement in TRMM 3B40RT 3-day accumulation skill**

a) RMSE

b) R2

SMAP will:

- Enhance correction in vegetated areas. (Here: X-band, SMAP: L-band)
- Allow for implementation at finer space scales. (Here: ~10,000 km², SMAP: 100 km²)

Crow et al. (2009), JHM, 10(1), 199-212.
Prediction of Extreme Rainfall

Flash flood event near Fort Collins
July 13, 1996
Chen et al. (2001), JAS, 58, 3204-3223.
SMAP provides 3 km resolution dual-polarization radar data with 2-3 days revisit (all-weather and regardless of illumination)

\[ \gamma = \frac{\sigma_{vv}}{\sigma_{hh}} \]
In situ Soil Moisture Network Coverage: Adequate?

Significant spatial variability between point measurements!

An airborne campaign US SGP

10 km Scale

Significant spatial variability between point measurements!
SMAP Mission Concept

• L-band unfocused SAR and radiometer system, offset-fed 6 m light-weight deployable mesh reflector. Shared feed for
  ➢ 1.26 GHz dual-pol Radar at 1-3 km (30% nadir gap)
  ➢ 1.4 GHz polarimetric Radiometer at 40 km
• Conical scan, fixed incidence angle across swath
• Contiguous 1000 km swath with 2-3 days revisit
• Sun-synchronous 6am/6pm orbit (680 km)
• Launch November 2014
• Mission duration 3 years
Soil moisture retrieval algorithms are derived from a long heritage of microwave modeling and field experiments:

MacHydro’90, Monsoon’91, Washita92, Washita94, SGP97, SGP99, SMEX02, SMEX03, SMEX04, SMEX05, CLASIC, SMAPVEX08, CanEx10

- **Radiometer** - High accuracy (less influenced by roughness and vegetation) but coarser spatial resolution (40 km)

- **Radar** - High spatial resolution (1-3 km) but more sensitive to surface roughness and vegetation

- **Combined Radar-Radiometer** product provides optimal blend of resolution and accuracy to meet science objectives
## SMAP Data Products

<table>
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<tr>
<th>Product</th>
<th>Short Description</th>
<th>Resolution</th>
<th>Latency</th>
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<tbody>
<tr>
<td>L1A_S0</td>
<td>Radar raw data in time order</td>
<td>–</td>
<td>12 hours</td>
</tr>
<tr>
<td>L1A_TB</td>
<td>Radiometer raw data in time order</td>
<td>–</td>
<td>12 hours</td>
</tr>
<tr>
<td>L1B_S0_LoRes</td>
<td>Low resolution radar $\sigma_o$ in time order</td>
<td>5x30 km</td>
<td>12 hours</td>
</tr>
<tr>
<td>L1B_TB</td>
<td>Radiometer $T_B$ in time order</td>
<td>36x47 km</td>
<td>12 hours</td>
</tr>
<tr>
<td>L1C_S0_HiRes</td>
<td>High resolution radar $\sigma_o$</td>
<td>1-3 km</td>
<td>12 hours</td>
</tr>
<tr>
<td>L1C_TB</td>
<td>Radiometer $T_B$</td>
<td>36 km</td>
<td>12 hours</td>
</tr>
<tr>
<td>L2_SM_A</td>
<td>Soil moisture (radar)</td>
<td>3 km</td>
<td>24 hours</td>
</tr>
<tr>
<td>L2_SM_P</td>
<td>Soil moisture (radiometer)</td>
<td>36 km</td>
<td>24 hours</td>
</tr>
<tr>
<td>L2_SM_A/P</td>
<td>Soil moisture (radar/radiometer)</td>
<td>9 km</td>
<td>24 hours</td>
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<tr>
<td>L3_F/T_A</td>
<td>Freeze/thaw state (radar)</td>
<td>3 km</td>
<td>36 hours</td>
</tr>
<tr>
<td>L3_SM_P</td>
<td>Soil moisture (radiometer)</td>
<td>36 km</td>
<td>36 hours</td>
</tr>
<tr>
<td>L3_SM_A/P</td>
<td>Soil moisture (radar/radiometer)</td>
<td>9 km</td>
<td>36 hours</td>
</tr>
<tr>
<td>L4_SM</td>
<td>Soil moisture (surface &amp; root zone)</td>
<td>9 km</td>
<td>7 days</td>
</tr>
<tr>
<td>L4_C</td>
<td>Carbon net ecosystem exchange (NEE)</td>
<td>9 km</td>
<td>14 days</td>
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- **Instrument Data**
- **Science Data (Half-Orbit)**
- **Science Data (Daily Composite)**
- **Science Value-Added**
Interested in joining the SMAP Working Group?


1. Algorithms Working Group (AWG)
2. Calibration & Validation Working Group (CVWG)
3. Radio-Frequency Interference Working Group (RFIWG)