Soil Moisture Active Passive (SMAP) Mission

Peggy E. O’Neill [NASA GSFC]
Canadian SMAP Science Meeting
November 16, 2010
SMAP is one of four Tier-1 missions recommended by the U.S. NRC Earth Science Decadal Survey

“Earth Science and Applications from Space: National Imperatives for the next Decade and Beyond”
(National Research Council, 2007) http://www.nap.edu

• SMAP was initiated by NASA as a new start mission in February 2008
• SMAP leverages work done under Hydros (including Canadian contributions) & Aquarius
• SMAP now in Phase B – PDR scheduled for Mar 2011
• The target launch date for SMAP is November 2014
SMAP will provide high-resolution, frequent-revisit global mapping of soil moisture and freeze/thaw state to enable science and applications users to:

• Understand processes that link the terrestrial water, energy and 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

SMAP data will also be used in applications of societal benefit that range from agriculture to human health.
### SMAP Level 1 Science Requirements

#### Science Discipline Measurement Need

<table>
<thead>
<tr>
<th>Hydro-Meteorology</th>
<th>Hydro-Climatology</th>
<th>Carbon Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>4–15 km</td>
<td>50–100 km</td>
<td>1–10 km</td>
</tr>
<tr>
<td>2–3 days</td>
<td>3–4 days</td>
<td>2–3 days</td>
</tr>
<tr>
<td>.04–.06 cm³/cm³</td>
<td>.04–.06 cm³/cm³</td>
<td>80–70%</td>
</tr>
</tbody>
</table>

#### Level 1 Science Measurement Requirements

<table>
<thead>
<tr>
<th></th>
<th>Baseline Mission</th>
<th>Threshold Mission</th>
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</thead>
<tbody>
<tr>
<td><strong>Science Discipline</strong></td>
<td><strong>Soil Moisture</strong></td>
<td><strong>Freeze/Thaw</strong></td>
</tr>
<tr>
<td>Hydro-Meteorology</td>
<td>10 km</td>
<td>3 km</td>
</tr>
<tr>
<td>Hydro-Climatology</td>
<td>10 km</td>
<td>10 km</td>
</tr>
<tr>
<td>Carbon Cycle</td>
<td>3 days</td>
<td>2 days</td>
</tr>
<tr>
<td></td>
<td>3 days</td>
<td>3 days</td>
</tr>
<tr>
<td></td>
<td>.04 cm³/cm³</td>
<td>80%</td>
</tr>
<tr>
<td></td>
<td>.06 cm³/cm³</td>
<td>70%</td>
</tr>
</tbody>
</table>

### Mission Duration Requirement:
3 Years Baseline; 18 Months Threshold

1. Volumetric soil moisture content (1-sigma);
2. % classification accuracy (binary Freeze/Thaw)
3. North of 45° N latitude

### Derived from models and decision-support tools used in areas of application identified by decadal survey for SMAP

<table>
<thead>
<tr>
<th>DS Objective</th>
<th>Application/Discipline</th>
<th>Science Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather Forecast</td>
<td>Initialization of Numerical Weather Prediction (NWP)</td>
<td>Hydrometeorology</td>
</tr>
<tr>
<td>Climate Prediction</td>
<td>Boundary and Initial Conditions for Climate Models</td>
<td>Hydroclimatology</td>
</tr>
<tr>
<td></td>
<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></td>
<td>Regional Drought Monitoring</td>
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<tr>
<td></td>
<td>Crop Outlook</td>
<td></td>
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<tr>
<td>Flood Forecast</td>
<td>River Forecast Model Initialization</td>
<td>Hydrometeorology</td>
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<tr>
<td></td>
<td>Flash Flood Guidance (FFG)</td>
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<tr>
<td></td>
<td>NWP Initialization for Precipitation Forecast</td>
<td></td>
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<tr>
<td>Human Health</td>
<td>Seasonal Heat Stress Outlook</td>
<td>Hydroclimatology</td>
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<tr>
<td></td>
<td>Near-Term Air Temperature and Heat Stress Forecast</td>
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<tr>
<td></td>
<td>Disease Vector Seasonal Outlook</td>
<td>Hydroclimatology</td>
</tr>
<tr>
<td></td>
<td>Disease Vector Near-Term Forecast (NWP)</td>
<td>Hydroclimatology</td>
</tr>
<tr>
<td>Boreal Carbon</td>
<td>Freeze/Thaw Date</td>
<td>Freeze/Thaw State</td>
</tr>
</tbody>
</table>
Measurement Approach

• **Instruments:**
  - **Radiometer: L-band (1.4 GHz)**
    - V, H, 3\textsuperscript{rd} & 4\textsuperscript{th} Stokes parameters
    - 40 km resolution
    - Moderate resolution soil moisture (high accuracy)
  - **Radar: L-band (1.26 GHz)**
    - VV, HH, HV polarizations
    - 3 km resolution (SAR mode); 30 x 5 km resolution (real-aperture mode)
    - High resolution soil moisture (moderate accuracy) and Freeze/Thaw state detection
  - **Shared Antenna**
    - 6-m diameter deployable mesh antenna
    - Conical scan at 14.6 rpm
    - Constant incidence angle: 40 degrees
    - 1000 km-wide swath
    - Swath and orbit enable 2-3 day global revisit

• **Orbit:**
  - Sun-synchronous, 6 am/pm, 680 km altitude
  - 8-day exact repeat

• **Mission Operations:**
  - 3-year baseline mission
  - Launch in November 2014
Instrument Overview

• **Radiometer**
  – Provided by GSFC
  – Leverages off Aquarius radiometer design
  – Includes RFI mitigation (spectral filtering)

• **Common 6 m spinning reflector**
  – Enables global coverage in 2-3 days
  – Spin Assembly (provided by Boeing) and Reflector Boom Assembly (provided by NGST-Astro) have extensive heritage

• **Radar**
  – Provided by JPL
  – Leverages off past JPL L-band science radar designs
  – RFI mitigation through tunable frequencies & ground processing
RFI is evident and wide-spread (Data from SMOS)

SMAP is taking aggressive measures to detect and mitigate RFI in its instrument and data processing designs.
Science Team Organization

Science Definition Team Leader
D. Entekhabi (MIT)

Science Definition Team (SDT) (ROSES)
K. McDonald (JPL)
J. van Zyl (JPL)
R. Koster (GSFC)
R. Reichle (GSFC)
W. Crow (USDA)
S. Moran (USDA)
T. Jackson (USDA)
J. Johnson (OSU)
J. Kimball (UMT)
M. Moghaddam (UM)
J. Shi (UCSB)
L. Tsang (UW)
S. Belair (Canada)
P. de Rosnay (UK)
R. Gurney (UK)
Y. Kerr (France)
S. Paloscia (Italy)
J. Walker (Australia)

Project Scientist
E. Njoku (JPL)
Deputy Project Scientist
P. O'Neill (GSFC)

Working Groups:
1. RFI
2. Algorithms
3. Cal/Val
4. Applications

International
# SMAP Data Products

<table>
<thead>
<tr>
<th>Product</th>
<th>Short Description</th>
<th>Resolution/Grid</th>
<th>Latency</th>
</tr>
</thead>
<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)** [research product]</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>
</tr>
<tr>
<td>L3_SM_A</td>
<td>Soil moisture (radar)</td>
<td>3 km</td>
<td>24 hours</td>
</tr>
<tr>
<td>L3_F/T_A</td>
<td>Freeze/thaw state (radar)</td>
<td>3 km</td>
<td>50 hours</td>
</tr>
<tr>
<td>L3_SM_P</td>
<td>Soil moisture (radiometer)</td>
<td>36 km</td>
<td>50 hours</td>
</tr>
<tr>
<td>L3_SM_A/P</td>
<td>Soil moisture (radar/radiometer)</td>
<td>9 km</td>
<td>50 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>
</tr>
</tbody>
</table>

- **Instrument Data**
- **Science Data (Half-Orbit)**
- **Science Data (Daily Composite)**
- **Science Value-Added**
SMAP Algorithm Testbed

36 km Radiometer
L2_SM_P

3 km Radar
L2_SM_A

9 km Combined
L2_SM_A/P

SMAP Algorithm Testbed used for:
1. Testing baseline and optional algorithms and codes
2. Understanding error propagation in the retrieval models
3. Ingesting SMOS data as simulated SMAP data
4. Prototype SMAP Science Data Systems (SDS)
5. Support applications demonstration (future)
### POTENTIAL SMAP APPLICATIONS

<table>
<thead>
<tr>
<th>SMAP OBJECTIVES</th>
<th>Weather</th>
<th>Natural Disasters</th>
<th>Climate Variability &amp; Change</th>
<th>Agriculture &amp; Forestry</th>
<th>Human Health</th>
<th>Ecology</th>
<th>Water Resources</th>
<th>Ocean Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil moisture and freeze-thaw information for water, energy, and carbon cycle processes</td>
<td>More accurate weather forecasts; prediction of severe rainfall; operational severe weather forecasts; mobility and visibility</td>
<td>Drought early warning decision support; key variable in floods and landslides; operational flood forecast; lake and river ice breakup; desertification</td>
<td>Extend climate prediction capability; Linkages between terrestrial water, energy, and carbon cycles; land / atmos. fluxes</td>
<td>Predictions of agricultural productivity; famine early warning; Monitoring agricultural drought</td>
<td>Landscape epidemiology; heat stress and drought monitoring; insect infestation; emergency response plans</td>
<td>Carbon source/sink monitoring; Ecosystems forecasts; monitoring vegetation and water relationship over land</td>
<td>Global water balance; estimates of streamflow &amp; river discharge; more effective management</td>
<td>Sea-ice mapping for navigation, especially in coastal zones; temporal changes in ocean salinity</td>
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<td></td>
<td>Fire susceptibility; global flood mapping; heat-wave forecasting</td>
<td>Crop management at the farm scale; Input to fuel loading models</td>
<td>Monitoring wetlands resources and bird migration</td>
<td>Monitoring variability of water stored in lakes, reservoirs, wetlands and river channels</td>
<td>Monitoring wind speed and direction, related to hurricane monitoring</td>
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</table>

= likely mission application  
= potential mission application
Mission Status

• Schedule
  -- next big milestone is project Preliminary Design Review in March 2011
  -- KDP-C at NASA HQ in June 2011 moves us into Phase C/D to build flight hardware

• Possible Descopes
  -- radar changes for FAA compliance (frequency hopping, H & V sequential transmit) may slightly increase radar SNR with minimal impact on science
  -- project is looking at cost of L4 products in budget exercise
    - might ask NASA HQ to fund L4 production outside the project

• Launch Services
  -- shared launch with DoD still a possibility on a Minotaur IV
Canadian Plan for SMAP

SMAP Canadian Workshop, Montreal Biosphere, October 2009

Stephane Belair
Science and Technology Branch,
Environment Canada
Canadian Experiment for Soil Moisture in 2010 (CanEx-SM10)

Overview

The Canadian Experiment for Soil Moisture in 2010 (CanEx-SM10) is primarily designed to support the ESA’s Soil Moisture and Ocean Salinity (SMOS) validation activities over land and to develop soil moisture retrieval algorithms in Canada. Due to Canada’s involvement in the Soil Moisture Active and Passive (SMAP) mission of NASA, scheduled for launch in 2014, CanEx-SM10 is extended to include the pre-launch validation of SMAP.

During CanEx-SM10, scheduled from May 31st to June 17th, 2010, spaceborne microwave measurements from SMOS, AMSR-E, ASAR-Envisat, RADARSAT-2, and ALOS-PALSAR will be collected along with airborne measurements using passive and active instruments including an L-band radiometer mounted onboard Environment Canada’s Twin Otter aircraft and NASA’s L-band Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) flown in a Gulfstream III piloted aircraft. In addition, the experiment will provide ground measurements of soil moisture, surface temperature, and other surface characteristics (vegetation, roughness, soil density, etc.) at a time close to satellite and airborne acquisitions.

Over 50 researchers and students will participate in the field campaigns that will take place over an agricultural site located in Kenaston (Saskatchewan, Saskatchewan) and a forested site, which is the Boreal Ecosystem Research and Monitoring Sites (BERMS) also located in Saskatchewan. These sites of about 33 km x 73 km, covering about two SMOS pixels, were selected in order to test SMOS and UAVSAR data and soil moisture retrieval algorithms over very different soil and vegetation conditions. Both sites benefit from existing soil moisture networks of Environment Canada. A more extensive soil moisture network managed by University of Guelph is located at Kenaston site. A temporary network of about twenty stations will be installed by the United States Department of Agriculture (USDA) to collect hourly soil moisture data at the BERMS site.

CanEx-SM10 is funded by several agencies in Canada (NSERC, EC, CSA, and AAFC) and USA (NASA). It is a first attempt in Canada to set up soil moisture observations simultaneously to satellite and aircraft microwave measurements for the development of large scale soil moisture retrieval algorithms.
Next Steps

- Develop Collaborations on Science, Applications, Algorithms, and Cal/Val
- Promote Bilateral Programmatics and Agency Agreements
- Areas of Collaboration:
  1. Cal/Val
     - Airborne instruments co-flights
     - Ground networks and sampling protocols – SMAP Request for Information for Core Validation Sites
     - Understanding the scaling of in situ network measurements to pixel area
     - Freeze/thaw cal/val and science
     - Level 4 Root-Zone Soil Moisture (RZSM) and Net Ecosystem Exchange (NEE)
  2. Algorithms
     - Active/Passive
     - Freeze/Thaw
     - Integrated RZSM and NEE
  3. Applications
     - NWP and Seasonal Climate
     - Sea-Ice Monitoring
     - Agricultural Productivity
Summary

• SMAP provides high-resolution and frequent-revisit global mapping of soil moisture and freeze/thaw state that has:
  – Science value for Water, Carbon and Energy Cycles
  – Applications in Operational Weather Forecasting, Flood & Drought Monitoring, Agriculture, & other areas benefit society
  – Addresses priority questions on Climate and Climate Change
  – Leverages Hydros, Aquarius, and SMOS risk reduction, expertise, and lessons learned

• Project is getting ready for PDR and moving into Phase C/D

• Will leverage SMOS data and experience

• Project has and will continue to reach out to the broad science and applications communities
  -- SMAP working groups and workshops
  -- Applications Plan and workshops
  -- EPO activities
New space-based soil moisture observations and data assimilation modeling can improve forecasts of local storms and seasonal climate anomalies.

**Seasonal Climate Predictability**

Predictability of *seasonal climate* is dependent on boundary conditions such as sea surface temperature (SST) and soil moisture – soil moisture is particularly important over continental interiors.

<table>
<thead>
<tr>
<th>Rainfall Difference [mm/day]</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>+5</td>
</tr>
</tbody>
</table>

(Difference in Summer Rainfall: 1993 (flood) minus 1988 (drought) years)

Observations

**Prediction driven just by SST**

**(Schubert et al., 2002)**

**Prediction driven by SST and soil moisture**

With Realistic Soil Moisture

**Without Realistic Soil Moisture**

24-Hours Ahead High-Resolution Atmospheric Model Forecasts

High resolution soil moisture data will improve numerical weather prediction (NWP) over continents by accurately initializing land surface states

**NWP Rainfall Prediction**

Observed Rainfall 0000Z to 0400Z 13/7/96 (Chen et al., 2001)
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

Intergovernmental Panel on Climate Change (IPCC) AR4 climate model projections by region:

Models agree on basic temperature response

Models disagree on the sign of moisture change

Quantify Net Carbon Flux in Boreal Landscapes

SMAP provides important information on the land surface processes that control land-atmosphere carbon source/sink dynamics. It will provide more than 8-fold increase in spatial resolution over existing spaceborne sensors.

McDonald et al. (2004): Variability in springtime thaw in the terrestrial high latitudes: Monitoring a major control on the biospheric assimilation of atmospheric CO2 with spaceborne microwave remote sensing. Earth Interactions 8(20), 1-23.
A given location can be a net source or net sink of carbon, depending on freeze/thaw date. SMAP freeze/thaw measurements can help reduce errors in the closing of the carbon budget.
Synergistic Data and Experience from SMOS and Aquarius

- **SMAP complements SMOS and Aquarius:**
  - Extends global L-band radiometry beyond these missions (yields long-duration land hydroclimate soil moisture datasets)
  - Significantly increases the spatial resolution of soil moisture data
  - Adds characterization of freeze thaw state for carbon cycle science
  - Adds substantial instrument and processing mitigations to reduce science degradation and loss from terrestrial RFI

- **SMAP benefits from strong mutual science team members’ engagements in missions**
  - SMOS & Aquarius data are important for SMAP’s algorithm development
  - SMAP will collaborate in and extend SMOS & Aquarius Cal-Val campaigns
  - SMOS and Aquarius will provide valuable data on the global terrestrial RFI environment which is useful to SMAP

<table>
<thead>
<tr>
<th>Mission</th>
<th>LRD</th>
<th>Measurement</th>
<th>Instrument Complement</th>
<th>Resolution/Revisit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMOS</td>
<td>Nov ’09</td>
<td>Soil Moisture</td>
<td>L-band Radiometer</td>
<td>50 km / 3 days</td>
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<tr>
<td></td>
<td></td>
<td>Ocean Salinity</td>
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<tr>
<td>Aquarius</td>
<td>Apr ’11</td>
<td>Ocean Salinity</td>
<td>L-band Radiometer, Scatterometer</td>
<td>100 km / 7 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soil Moisture (experimental)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMAP</td>
<td>Nov’14 *</td>
<td>Soil Moisture Freeze/Thaw State</td>
<td>L-band Radiometer, SAR (unfocused)</td>
<td>10 km / 2-3 days</td>
</tr>
</tbody>
</table>

SMOS (ESA) 2009 Launch

Aquarius 2011 LRD

SMAP 2014 LRD
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
L-band Active/Passive Assessment

- 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
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)
4. Applications Working Group (AppWG)