Project/Mission Overview—Mission Context


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>
<tr>
<th>Tier 1: 2010–2013 Launch</th>
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<td>Soil Moisture Active Passive (SMAP)</td>
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<th>Tier 2: 2013–2016 Launch</th>
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<td>GEO-CAFE</td>
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<td>ACE</td>
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<th>Tier 3: 2016–2020 Launch</th>
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<td>PATH</td>
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<td>GRACE-II</td>
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<td>SCLP</td>
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<td>GACM</td>
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<td>3D-WINDS</td>
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### Science Requirements

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<tr>
<th>DS Objective</th>
<th>Application</th>
<th>Science Requirement</th>
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<tr>
<td>Weather Forecast</td>
<td>Initialization of Numerical Weather Prediction</td>
<td>Hydrometeorology</td>
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<td>(NWP)</td>
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<tr>
<td>Climate Prediction</td>
<td>Boundary and Initial Conditions for Seasonal</td>
<td>Hydroclimatology</td>
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<td>Climate Prediction Models</td>
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<td>Testing Land Surface Models in General</td>
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<td>Circulation Models</td>
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<td>Drought and Agriculture</td>
<td>Seasonal Precipitation Prediction</td>
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<td>Regional Drought Monitoring</td>
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<td>Crop Outlook</td>
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<td>River Forecast Model Initialization</td>
<td>Hydrometeorology</td>
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<td>Flash Flood Guidance (FFG)</td>
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<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</td>
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<td>Forecast</td>
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<td>Disease VectorSeasonal Outlook</td>
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<td>Boreal Carbon</td>
<td>Freeze/Thaw Date</td>
<td>Freeze/Thaw State</td>
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<tr>
<th>Requirement</th>
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<th>Hydro-Climatology</th>
<th>Carbon Cycle</th>
<th>Baseline Mission</th>
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<tr>
<td></td>
<td>Soil Moisture</td>
<td>Freeze/Thaw</td>
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<tr>
<td>Resolution</td>
<td>4–15 km</td>
<td>50–100 km</td>
<td>1–10 km</td>
<td>10 km</td>
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<td></td>
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<td>3 km</td>
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<tr>
<td>Refresh Rate</td>
<td>2–3 days</td>
<td>3–4 days</td>
<td>2–3 days(1)</td>
<td>3 days</td>
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<td></td>
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<td></td>
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<td>2 days(1)</td>
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<tr>
<td>Accuracy</td>
<td>4–6% **</td>
<td>4–6%**</td>
<td>80–70%*</td>
<td>4%**</td>
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<td>80%*</td>
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(*) % classification accuracy (binary Freeze/Thaw)
(**) % volumetric water content, 1-sigma
(1) North of 45N latitude

Mission Duration: 3 Years (Launch 2014/2015)
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
in situ Networks Inadequate

Even climatology is unknown.

SOA is Primitive:
1. Residual
2. Simulation w/Forcing
3. Crude Closures
Latent heat flux (evaporation) *links* land *water, energy, and carbon* fluxes.

Soil moisture exerts control on evaporation:

Lack of knowledge of this relationship and soil moisture determinant causes uncertainty in land surface and atmospheric models.

SMAP surface soil moisture observations would reduce uncertainty in this key relationship globally.

\[ \beta(\theta) = \frac{E}{E_p} \quad \text{or} \quad r_g(\theta) \quad ... \]
Parameterized Closure Function But Without Evidence

For model grid cell and

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

(7)

represents a normalized soil moisture availability term where \( \Theta_{\text{w}} \) is the wilting point and \( \Theta_{\text{ref}} \) is the field capa-

\[
F_d = \sum_{i=1}^{n} \frac{(\Theta_i - \Theta_{\text{w}})dz_i}{(\Theta_{\text{ref}} - \Theta_{\text{w}})(\sum_{j=1}^{n} dz_j)}
\]

The plant wilting factor \( \omega_i \) is

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

(8.11)

“...Let the rate of loss of water from a leaf be denoted by \( T_i \), then

\[ T = K \{ F(\theta_{\text{leaf}}) - \omega_{\text{air}} \} \]

here \( K \) is the conductance of the stomatal openings and \( F(\theta_{\text{leaf}}) \) is the saturated vapour density at \( \theta \).” [Richardson, 1922]
May 10:  Dry soil. Clear with scattered to broken cirrus
May 18:  90 mm Rain
May 20:  Moist soil. Mild winds and clear.

When/where in water-limited (vs. energy-limited) evaporation regimes soil moisture is a determinant of the evolution of the lower atmosphere.

Evolution of Land Surface Models (LSMs)

First Generation:
Water Availability as a Reservoir

Second Generation:
Heat and Moisture Flux Across Resistance Networks

Third Generation:
Add Carbon Exchange to Canopy Fluxes

R. Stöckli and P. L. Vidale (ETH)
How Good are LSMs in Representing Basic Dynamics?

LSMs fail as scientific tools.
LSMs are unreliable tools for operational stream.

R. Stöckli et al., 2005: *Theoretical and Applied Climatology*, 80(1-2).
Extension Through Land-Atmosphere Interactions

May 10: Dry soil. Clear with scattered to broken cirrus
May 18: 90 mm Rain
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When/where in water-limited (vs. energy-limited) evaporation regimes soil moisture is a determinant of the evolution of the lower atmosphere.
Soil Moisture and Weather Forecasts

Buffalo Creek Basin (55 km)$^2$

Observed Rainfall
0000Z to 0400Z 13/7/96

24-Hours Ahead Atmospheric Model Forecasts

With Realistic Soil Moisture

Without Realistic Soil Moisture


“...changes to 5-km forecasts due to soil moisture differences were almost as large as the changes to 20-km forecasts due to using an alternate convective parameterization, previously determined to be a large source of uncertainty in ensemble forecasts...”

“...The results presented here suggest that short-term temperature and precipitation forecasts can indeed be changed as a consequence of changing the soil moisture...”
Intergovernmental Panel on Climate Change (IPCC) AR4 climate model projections by region:

Models *agree* on basic temperature response

Seasonal Predictability Impacts

Ensemble Precipitation Distributions:

Multi-Model Consensus of Regions Where Soil Moisture Impacts Seasonal Precipitation

What are the dominant evaporation regimes?


“...perturbed spring soil moisture shows that this quantity is an important parameter for the evolution of European heat waves...”

“...Simulations indicate that without soil moisture anomalies the summer heat anomalies could have been reduced by around 40% in some regions...”
Carbon Dioxide Exchange

The ‘missing carbon’: Depending on freeze/thaw date, same location can be a net source or net sink of carbon.


Carbon Dioxide Exchange

Water and energy closure function

Drier Soils

Hollifield et al., USDA-ARS Arizona
Global Measurements of Soil Moisture

Spatial scale of variations

10 km Scale
Comparison Across Microwave Frequencies

\[ \lambda = \text{Wavelength} \]
\[ n'' = \text{Im}\{\text{Refractive Index}\} \]

Power Attenuates as \( e^{-z/d} \)

\[ d = \frac{\lambda}{4 \cdot \pi \cdot n''} \]

<table>
<thead>
<tr>
<th>Existing Sensors</th>
<th>SSM/I 19 GHz (50 km)</th>
<th>&lt;1 mm</th>
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<tbody>
<tr>
<td>TMI 10 GHz (50 km)</td>
<td>&lt;1 mm</td>
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<tr>
<td>AMSR/MIS 6 GHz (50 km)</td>
<td>&lt;1 cm</td>
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</tr>
<tr>
<td>Future</td>
<td>SMOS (50 km)</td>
<td>~5-7 cm</td>
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<td></td>
<td>SMAP (combined 10 km)</td>
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<tr>
<td></td>
<td>1.4 GHz</td>
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</table>
Vegetation Opacity at \( \mu \)-Wave Frequencies

For Example: Signal Loss Over Short Vegetation Cover

- 100% Lost at 19 GHz (SSM/I)
- 95% Lost at 10 GHz (TMI)
- 75% Lost at 6 GHz (MIS/AMSR)
- 25% Lost at 1.4 GHz (SMAP)
Anthropogenic Radio-Frequency Interference (RFI)

Example for 6 GHz (AMSR and MIS instruments)
SMAP Mission Concept

• L-band unfocused SAR and radiometer system with offset-fed 6-m light-weight deployable mesh reflector rotating about nadir axis (14.6 rpm)
  ➢ Single feed (dual-pol radar and polarimetric radiometer)
  ➢ Conical scan, fixed incidence angle across swath
  ➢ Contiguous 1000 km swath
  ➢ Radar resolution: 1-3 km (degrades over center 30%)
  ➢ Radiometer resolution: 40 km

• Sun-synchronous dawn/dusk orbit
• Mission Ops duration 3 years
SMAP Measurement Approach

• **Instruments:**
  - **Radar:** L-band (1.26 GHz)
    - High resolution, moderate accuracy soil moisture
    - Freeze/thaw state detection
    - SAR mode: 3 km resolution
    - Real-aperture mode: 30 x 6 km resolution
  - **Radiometer:** L-band (1.4 GHz)
    - Moderate resolution, high accuracy soil moisture
    - 40 km resolution
  - **Shared Antenna**
    - 6-m diameter deployable mesh antennna
    - Conical scan at 14.6 rpm
    - Constant incidence angle: 40 degrees
      - 1000 km-wide swath
      - Swath and orbit enable 2-3 day revisitation

• **Orbit:**
  - Sun-synchronous, 6 am/pm orbit
  - 680 km altitude

• **Mission Operations:**
  - 3-year baseline mission (Launch 2014/2015)
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, Washita’92, FIFE, HAPEX, SGP’97,‘99, SMEX’02-’05

- **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

- Algorithm approach has been demonstrated in Hydros risk-reduction; OSSE published (Crow et al., 2005); demonstration extended in SMAP Algorithm Testbed
### SMAP Baseline Science Data Products

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<td>L1B_S0_LoRes</td>
<td>Low Resolution Radar Backscatter ($\sigma^o$)</td>
<td>~ 30 km</td>
</tr>
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Global Mapping L-Band Radar and Radiometer

High-Resolution and Frequent-Revisit Science Data

Observations+Model Value Added Product
Flood Prediction and Drought Monitoring

Current NWS Operational Flash Flood Guidance (FFG)

Current Operational Drought Indices by NOAA (NIDIS - National Integrated Drought Information System)

Current: Empirical Soil Moisture Indices Based on Rainfall and Air Temperature
( By Counties >40 km and Climate Divisions >55 km )

Future: SMAP Soil Moisture Observations at 10 km
DoD Applications

US Army Space and Missile Defense Command, Army Research Laboratory, G-2, Corps of Engineers, and Marine Corps would use SMAP experiment data to validate and improve tools to evaluate threat and friendly mobility
1. Cross Country Mobility (CCM)
2. Tri-service Integrated Weather Effects Decision Aid (IWEDA)
3. Battlespace Terrain Reasoning / Awareness (BTRA)
4. Opportune Landing System (OLS)
5. Integrated air-space operations support models/analysis

Air Force Weather Agency will use experiment data to Initialize Numerical Weather Prediction (NWP) model for aviation weather, severe weather, cloud, and fog forecasts Input into Dust Transport Model (DTM)

Naval Ice Center will use experiment data for high resolution mapping of marine and littoral ice cover and ice characteristics

Result: Ranked 6 out of 62 by DoD Space Experiments Review Board (SERB) in Oct 2008
Constraint LSMs with Obs: Data Assimilation

1. Combine varied information sources
2. Estimate fluxes and other derived variables

Remote Sensing Data

Soil Moisture Variability

Sensing

Microwave Soil Moisture Sensing
Vis/IR Vegetation Sensing
Radar & GPM Precipitation

SRTM DEM

Total Variability

Precipitation-Induced
Land Cover-Induced
Topography-Induced

Scale

10 m 100 m 1 km 10 km 100 km
Controlling Factors: **Spatial**

- **Terrain**
  - Elevation: 800 m
- **Vegetation**
- **Soil Texture**
- **Cumulative Precipitation [mm]**

**ARM/CART Experiment Area** (Multi-Platform Satellite Data Sets)

**Airborne Soil Moisture Sensing**
SVD of the first layer soil moisture covariance matrix is performed at typical times.

Spatial spectrum of top layer soil moisture at different times.

Correlation structure for the center point.
Controlling Factors: **Temporal**

![Graph showing soil moisture percentage over time with a barrier to information symbol.](image-url)
Following rainfall, terrain-driven hydrologic processes result in soil moisture fields following drainage pattern…

After extensive drydown, soil moisture pattern follows other factors such as soil texture and land-cover.

Tarrawarra Catchment (Victoria, Australia) ~ 10 Hectars

Source: Western and Grayson, 1998: WRR 34(10)
SMAP soil moisture and co-orbiting GPM precipitation data will improve surface flux estimates and flood forecasts:

Crow, Entekhabi, Koster, & Reichle, 2006: Multiple spaceborne water cycle observations would aid modeling, *EOS*, 87(15)

Additionally - With simultaneous SMAP measurements of surface emissivity GPM data can then be used for accurate retrievals of precipitation over land where it is needed for applications.
NASA Catchment LSM

**Vertical**
- Latent heat flux
- Sensible heat flux
- Snow model (3 layers)
- Soil moisture
- Ground-water
- Heat diffusion model (7 layers)

Soil moisture is determined by the equilibrium soil moisture profile from the surface to the water table ("catchment deficit") and by two additional variables that describe deviations from the equilibrium profile: the average deviation in a 1 m root zone layer ("root zone excess"), and the average deviation in a 5 cm surface layer ("surface excess"). The model outputs surface (top 5 cm), root zone (top 1 m), and total profile soil moisture as diagnostics.

**Horizontal**

Different moisture levels (shown here as different water table depths)...

...lead to different areal partitionings of the catchment into saturated, unstressed, and wilting regimes.

**Separation of Catchment Area into Hydrological Regimes**

- Vertical: zones of different moisture levels
- Horizontal: partitioning of the catchment

The surface energy balance and surface runoff are computed separately for the saturated, transpiring, and wilting sub-areas of each catchment.

Implement for SMAP on a **10 km global grid** (same as L3_SM_A/P product)

Koster et al. 2000; Ducharme et al. 2000
# SMAP Baseline Science Data Products

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SMAP Algorithm Testbed

Generated using prototype science algorithm software running on the Science Data System (SDS) Testbed

L1C HI-RES RADAR BACKSCATTER PRODUCT (1-3 KM) (HH CHANNEL ONLY SHOWN)

L1C RADIOMETER BRIGHTNESS TEMPERATURE PRODUCT (40KM) (H CHANNEL ONLY SHOWN)

L3 HI-RES RADAR SOIL MOISTURE PRODUCT (3 KM)

L3 RADIOMETER SOIL MOISTURE PRODUCT (40 km)

L3 COMBINED ACTIVE/PASSIVE SOIL MOISTURE PRODUCT (10 km)
Summary

1. An Earth Science Mission with
   High Science Returns (Water, Carbon and Energy Cycles)
   High Applications Returns (Operational Hydromet Fx and Drought Monitoring)

2. Design Matured With Hydros Heritage

3. Measurement and Algorithms Matured With Airborne Experiments

4. Mapping L-Band Radar Mapping Data Has Many More Applications

Key Open Science Issues:

- Focused Airborne Experiments on Active/Passive and Freeze/Thaw
- Algorithm Testbed (Testbed to Transition to Science Data System)
- Engagement of Application Users
SMAP Working Groups

Working Groups have been established as a means to enable broad science participation in the SMAP mission. The working groups are led by Science Definition Team (SDT) members and provide forums for information exchange on issues related to SMAP science and applications goals and objectives. The working groups communicate via email and at meetings, conference sessions, workshops, and other venues. There are four current working groups:

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

SMAP Applications Workshop

smap.jpl.nasa.gov

SMAP Applications Workshop
September 9-10, 2009
At the NOAA SSMC-3 Building
Silver Spring, MD