Outline

• Measurements Approach Reminder
• Mission Status
• The Active-Passive Surface Soil Moisture Product
  - Technical Approach
  - Testing Results
  - Error Analysis
• SMAP Applications
• SMAP Data Assimilation Potential (example)
• The SMAP Handbook
• Summary
SMAP Mission Concept

SMAP will provide high-resolution and frequent-revisit global observations of soil moisture and freeze/thaw state

- 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 VV, HH and HV at 1-3 km (30% nadir gap)
  - 1.4 GHz polarimetric (H, V, 3rd and 4th Stokes) Radiometer at 40 km (3 dB)
- Conical scan, fixed incidence angle across swath
- Contiguous 1000 km swath with 2-3 days revisit (8 days exact repeat)
- Sun-synchronous 6am/6pm orbit (680 km)
- Launch November 5, 2014
### Decadal Survey Objective

<table>
<thead>
<tr>
<th>Decadal Survey Objective</th>
<th>Application</th>
<th>Science Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather Forecast</td>
<td>Initialization of Numerical Weather Prediction (NWP)</td>
<td>Hydrometeorology</td>
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<tr>
<td>Climate Prediction</td>
<td>Boundary and Initial Conditions for Seasonal Climate Prediction Models</td>
<td>Hydroclimatology</td>
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<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>Regional Drought Monitoring</td>
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<td></td>
<td>Crop Outlook</td>
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<tr>
<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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<tr>
<td>Human Health</td>
<td>Seasonal Heat Stress Outlook</td>
<td>Hydroclimatology</td>
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<td></td>
<td>Near-Term Air Temperature and Heat Stress Forecast</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>
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<tr>
<td>Boreal Carbon</td>
<td>Freeze/Thaw Date</td>
<td>Freeze/Thaw State</td>
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</table>

### Key Level 1 Requirements (Derived from science objectives)

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Hydro-Meteorology</th>
<th>Hydro-Climatology</th>
<th>Carbon Cycle</th>
<th>Baseline Mission</th>
<th>Minimum Mission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>4–15 km</td>
<td>50–100 km</td>
<td>1–10 km</td>
<td>10 km</td>
<td>10 km</td>
</tr>
<tr>
<td>Refresh Rate</td>
<td>2–3 days</td>
<td>3–4 days</td>
<td>2–3 days&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>3 days</td>
<td>3 days</td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.04–0.06&lt;sup&gt;(c)&lt;/sup&gt;</td>
<td>0.04–0.06</td>
<td>80–70%&lt;sup&gt;(b)&lt;/sup&gt;</td>
<td>0.04</td>
<td>0.06</td>
</tr>
</tbody>
</table>

<sup>(a)</sup> North of 45N latitude  
<sup>(b)</sup> Percent classification accuracy (binary freeze/thaw)  
<sup>(c)</sup> Volumetric water content, 1-σ in [cm³/cm³] units
Regions Where SMAP is Expected to Meet Science Requirements

At 9 km:
- VWC ≤ 5 kg m\(^{-2}\)
- Urban Fraction ≤ 0.25
- Water fraction ≤ 0.1
- Elevation Slope Standard Deviation ≤ 3 deg
May 2014: Instrument and Spacecraft Integration
<table>
<thead>
<tr>
<th>Product</th>
<th>Description</th>
<th>Gridding (Resolution)</th>
<th>Latency**</th>
</tr>
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<tbody>
<tr>
<td>L1A_Radiometer</td>
<td>Radiometer Data in Time-Order</td>
<td>-</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L1A_Radar</td>
<td>Radar Data in Time-Order</td>
<td>-</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L1B_TB</td>
<td>Radiometer $T_B$ in Time-Order</td>
<td>(36x47 km)</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L1B_S0_LoRes</td>
<td>Low Resolution Radar $\sigma_o$ in Time-Order</td>
<td>(5x30 km)</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L1C_S0_HiRes</td>
<td>High Resolution Radar $\sigma_o$ in Half-Orbits</td>
<td>1 km (1-3 km)</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L1C_TB</td>
<td>Radiometer $T_B$ in Half-Orbits</td>
<td>36 km</td>
<td>12 hrs</td>
</tr>
<tr>
<td>L2_SM_A</td>
<td>Soil Moisture (Radar)</td>
<td>3 km</td>
<td>24 hrs</td>
</tr>
<tr>
<td>L2_SM_P</td>
<td>Soil Moisture (Radiometer)</td>
<td>36 km</td>
<td>24 hrs</td>
</tr>
<tr>
<td>L2_SM_AP</td>
<td>Soil Moisture (Radar + Radiometer)</td>
<td>9 km</td>
<td>24 hrs</td>
</tr>
<tr>
<td>L3_FT_A</td>
<td>Freeze/Thaw State (Radar)</td>
<td>3 km</td>
<td>50 hrs</td>
</tr>
<tr>
<td>L3_SM_A</td>
<td>Soil Moisture (Radar)</td>
<td>3 km</td>
<td>50 hrs</td>
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<td>L3_SM_AP</td>
<td>Soil Moisture (Radar + Radiometer)</td>
<td>9 km</td>
<td>50 hrs</td>
</tr>
<tr>
<td>L4_SM</td>
<td>Soil Moisture (Surface and 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>
L-band Active/Passive Approach

- 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, SMAPVEX12

- 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 intermediate 9km resolution with 0.04 [cm$^3$/cm$^3$] 1-σ accuracy to meet science objectives
Start with the basic premise that \textit{temporal} variations in $\sigma_{pp}$ are also reflected in variations in $T_{Bp}$:

$$T_{Bp} = \alpha + \beta \cdot \sigma_{pp}$$

Parameter $\beta$ [K dB$^{-1}$] is a sensitivity parameter.
SMAP Active-Passive Algorithm

\[ T_{B_p}(M) = T_{B_p}(C) + \beta \times \left\{ \frac{pp(M)}{pp(C)} - \frac{pp(C)}{pp(M)} \right\} \]

\[ T_{B_p}(M) = T_{B_p}(C) + \gamma \times \left\{ \frac{pq(M)}{pq(C)} - \frac{pq(C)}{pq(M)} \right\} \]

Parent scale-\( C \) brightness temperature

Disaggregated brightness temperature

Scale-\( C \) sensitivity parameter \( \beta \) times smaller scale-\( M \) variations in \( \sigma_{pp} \) mostly due to soil moisture variability

Scale-\( M \) heterogeneity parameter \( \Gamma \) times scale-\( M \) variation in \( \sigma_{pq} \) mostly due to vegetation and roughness.
End-to-End Prelaunch Testing of Algorithm Performance

Test of Baseline Algorithm Using SMEX02 PALS Data

Baseline Algorithm
RMSE: 0.033 [cm$^3$/cm$^3$]

Minimum Performance Test
RMSE: 0.056 [cm$^3$/cm$^3$]

- Algorithm
  - L3_SM_A/P
  - Disaggregated $T_B$
    (0.8 km)
  - Estimated Soil Moisture
    (0.8 km)
  - Minimum Performance algorithm simply resamples $T_B$, i.e. no radar information.

RMSE: 0.033 [cm$^3$/cm$^3$]
L2_SM_AP Product

Retrieved Soil Moisture at 9 km cm³/cm³

Retrieval Quality Flag at 9 km
L3_SM_AP Product

Disaggregated TBv (9 km)

Retrieved Soil Moisture (9 km)
L2_SM_AP Calibration and Validation
Using Simulated Data

Retrieved Soil Moisture at 9 km $\frac{\text{cm}^3}{\text{cm}^3}$

Retrieved Soil Moisture at 3 km $\frac{\text{cm}^3}{\text{cm}^3}$
L2_SM_AP Calibration and Validation Using Simulated Data

STD in Soil Moisture at 9 km $\text{cm}^3/$cm$^3$

STD in Soil Moisture at 3 km $\text{cm}^3/$cm$^3$
SMAP Applications Development Approach

A primary goal of the NASA SMAP Mission is to engage SMAP end users and build broad support for SMAP applications through a transparent and inclusive process.

Toward that goal, the SMAP Mission:

1. Formed the SMAP Applications Working Group (150+ Members)
2. Developed the SMAP Applications Plan (right)
3. Hired a SMAP Applications Manager
4. Held SMAP Applications Workshops at User Home Sites (e.g., NOAA, USDA, USGS)
5. Developed the “Early-Adopter” Program (30+ Members)
The SMAP Handbook

Chapters

1. Introduction and Background
2. Mission Overview
3. Instrument Design and Data Products
4. Soil Moisture Data Products
5. The Value-Added Data L4_SM Product
6. Carbon Cycle Data Products
7. Calibration and Validation Plan
8. Applications and Applied Science
9. SMAP Project Bibliography

http://smap.jpl.nasa.gov/Imperative/
A Case Study Using SMAP-like Data
SMAP for Agricultural Crop Yield and Food Security Applications

Statement of Problem: The world faces an uphill struggle in feeding a projected nine to ten billion people by 2050.

Water is the defining link between the climate and agriculture. To improve agricultural decision support systems and ensure food security, better quality and better use of Soil Moisture/Water information is vital.

This information will increase the lead time and skill of of crop yield forecasts.

JPL agriculture system and data assimilation framework.

Promising results show significant improvement in crop yield estimation.


RMSE of ~1 Ton/Hectare from EnKF Crop Modeling Framework

RMSE of ~3 Ton/Hectare from Conventional Approach of Modeling
Summary

• NASA SMAP mission in integration and testing (launch shipment October 2014)
• Launch manifested for January, 2015
• L-Band active-passive instruments meeting requirements and holding well
• Active-passive algorithm for high resolution (9 km) surface soil moisture estimation exercised and testing using heritage airborne and simulation testbed
• Developed error analysis tool for science product
• Aggressive RFI detection and mitigation hardware and software development
• Focused and planned effort to promote meaningful applications
Heterogeneity of Parameters

Subgrid scale (scale-$M$) variability in parameters

$$[\alpha(M) - \alpha(C)] \quad \text{and} \quad [\beta(M) - \beta(C)]$$

are related to vegetation and soil texture heterogeneities.

They are proportional to $\sigma_{pq}(M) - \sigma_{pq}(C)$ through the sensitivity:

$$\left. \frac{\partial \sigma_{pp}}{\partial \sigma_{pq}} \right|_C \equiv \Gamma(C)$$

Their partial contribution to $\sigma_{pp}(M)$ is $\Gamma(C) \cdot \left( \sigma_{pq}(M) - \sigma_{pq}(C) \right)$

which in units of brightness temperature is:

$$\beta(C) \cdot \left[ \Gamma(C) \cdot \left( \sigma_{pq}(M) - \sigma_{pq}(C) \right) \right]$$
$T_B$-disaggregation algorithm becomes:

\[ T_{B_p}(M) = T_{B_p}(C) + \beta(C) \cdot \left\{ \left[ \sigma_{pp}(M) - \sigma_{pp}(C) \right] - \Gamma(C) \cdot \left[ \sigma_{pq}(M) - \sigma_{pq}(C) \right] \right\} \]

$T_B(M_j)$ is used to retrieve soil moisture at 9 km.
SMAP Retrievable Mask at 9 km

Regions Where SMAP Soil Moisture Algorithms Will be Executed

Retrievable Mask (Black Colored Pixels) Prepared with Following Specifications:
  a) Urban Fraction < 1
  b) Water Fraction < 0.5
  c) DEM Slope Standard Deviation < 5 deg
SMAP Cal/Val Timeline

- Time is a constraint post-launch
  => Resolve problems pre-launch

Pre-launch
- Preparation

Launch

In-Orbit Checkout (3 months)
- Formal start of SMAP Science Mission

L1 validation (6 months)
- Delivery of validated L1 products to Data Center
- Beta release of L1 products and start of routine delivery

L2-L4 validation (12 months)
- Delivery of validated L2-L4 products to Data Center
- Beta release of L2-L4 products and start of routine delivery
How have Early Adopters benefited the SMAP Project?

- AER Inc. provided feedback on the value of the SMAP 3-day revisit and long time series and the suitability of SMAP products for mapping inundation related to quantification of greenhouse gas emissions
- NDMC provided guidance on soil moisture anomaly metrics that would work for drought monitoring applications
- Develop algorithms and tools for use of SMAP L1 data products for maritime applications (sea-ice, coastal salinity, high winds)

How has the SMAP Project benefited the Early Adopters?

<table>
<thead>
<tr>
<th>Tested ingestion of SMAP simulated data into their operations:</th>
<th>’11, ’12</th>
<th>’13, ’14</th>
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<tbody>
<tr>
<td>Submitted applied research to the JHM Special Issue:</td>
<td>8</td>
<td>3</td>
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</tbody>
</table>

- Two North America agricultural monitoring agencies – Canada AAFC and USDA NASS – have developed prototypes for integrating SMAP soil moisture products into their operational stream
- Data-denial experiments used to quantify impact of data on famine early-warning and flood prediction agency applications

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L2_SM_AP Error Budget: $T_B$ Formulation

Radiometer Brightness Temperature Uncertainty

$$\frac{2}{T_{B_{36}}km}$$

Radar Backscatter Cross-Section Uncertainty

$$+ 2 \left[ \frac{10}{\ln 10} \right]^2 \left[ \frac{1}{N_{3km\rightarrow 9km}} \right] K_{pp3km}^2 + 2 K_{pq3km}^2$$

Brightness Temperature Water-Body Correction Uncertainty

$$+ \frac{2}{f_{36km}} \left[ \frac{3}{2} f_{36km}^2 T_{B_{Water}}^2 + (T_{B_{Land}} - T_{B_{Water}})^2 \right]$$

AP Algorithm Parameters $(\beta, \Gamma)$ Uncertainty

$$+ \frac{2}{pp9km} + \frac{2}{pq9km} \left[ (2^2) + (2^2) \right]$$

RSS Disaggregated Brightness Temperature Uncertainty

$$= RSS_{T_{B_{9km}}}^2$$

where

$$\frac{2}{s_{TB}^2(N_w - 1)} \left[ s_{TB}^2 + 2 s_{pp}^2 r s_{TB} s_{pp} + 2 s_{TB}^2 + 2 s_{pp}^2 \right]$$

and

$$\frac{2}{s_{pp}^2(N_{336} - 1)} \left[ s_{pp}^2 + 2 s_{pq}^2 r s_{pp} s_{pq} + 10^2 K_{pp}^2 + \frac{10^2}{\log_{10}^2 N_L} K_{pq}^2 \right]$$
Comparisons

Soil Moisture Uncertainty [m3/m3]

- Omega
- VWC
- TB
- Ts
- h
- Clay%
- Total

L2_SM_P Monte Carlo

VWC [kg/m2]