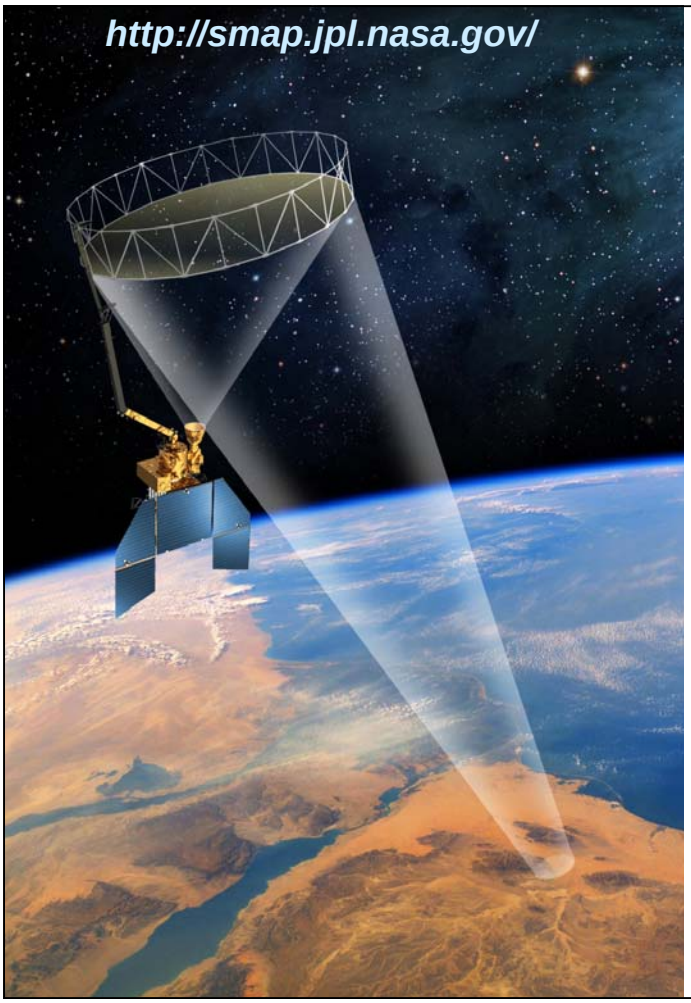

NASA's Soil Moisture Active-Passive (SMAP) Mission

Kyle C. McDonald

Department of
Earth and Atmospheric Sciences
The City College of New York
and
Water and Carbon Cycles Group
Jet Propulsion Laboratory
California Institute of Technology

5th GTN-H Coordination Panel Meeting
University of Tokyo, Tokyo, Japan
March 12-13, 2011

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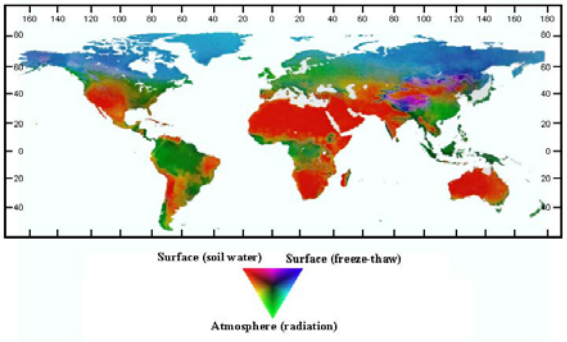
SMAP Has Focused Science Objectives

SMAP is one of the four first-tier missions recommended by the NRC Earth Science Decadal Survey Report

Primary Science Objectives:

- Global, high-resolution mapping of soil moisture and its freeze/thaw state to:
  - *Link terrestrial water, energy and carbon cycle processes*
  - *Estimate global water and energy fluxes at the land surface*
  - *Quantify net carbon flux in boreal landscapes*
  - *Extend weather and climate forecast skill*
  - *Develop improved flood and drought prediction capability*

Soil moisture and freeze/thaw state are primary environmental controls on Evaporation and Net Primary Productivity



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SMAP Applications from Decadal Survey

Decadal Survey Panels	Cited SMAP Applications
1. Water Resources and Hydrological Cycle	Floods and Drought Forecasts Available Water Resources Assessment Link Terrestrial Water, Energy and Carbon Cycles
2. Climate and Weather	Longer-Term and More Reliable Atmospheric Forecasts
3. Human Health and Security	Heat Stress and Drought Vector-borne and Water-Borne Infectious Disease
4. Land-Use, Ecosystems, and Biodiversity	Ecosystem Response (Variability and Change) Agricultural and Ecosystem Productivity Wild-Fires Mineral Dust Production

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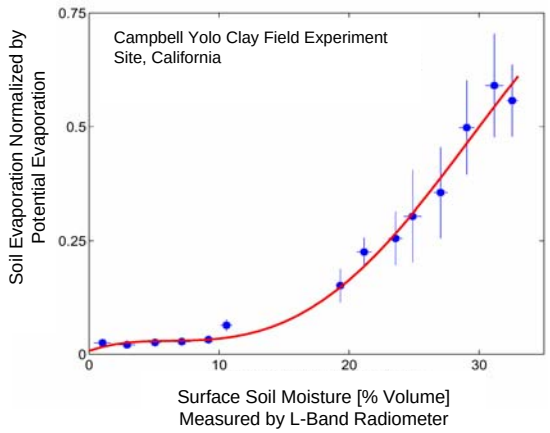
"Link Terrestrial Water, Energy and Carbon Cycle Processes"

Water and Energy Cycle

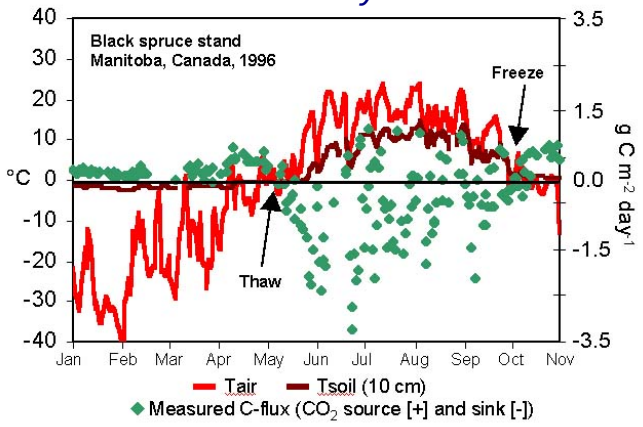


Soil Moisture Controls the Rate of Continental Water and Cycles

Do Climate Models Correctly Represent the Landsurface Control on Water and Energy Fluxes?

What Are the Regional Water Cycle Impacts of Climate Variability?

Carbon Cycle



Landscape Freeze/Thaw Dynamics Drive Boreal Carbon Balance
[The Missing Carbon Sink *Problem].*

Are Northern Land Masses Sources or Sinks for Atmospheric Carbon?

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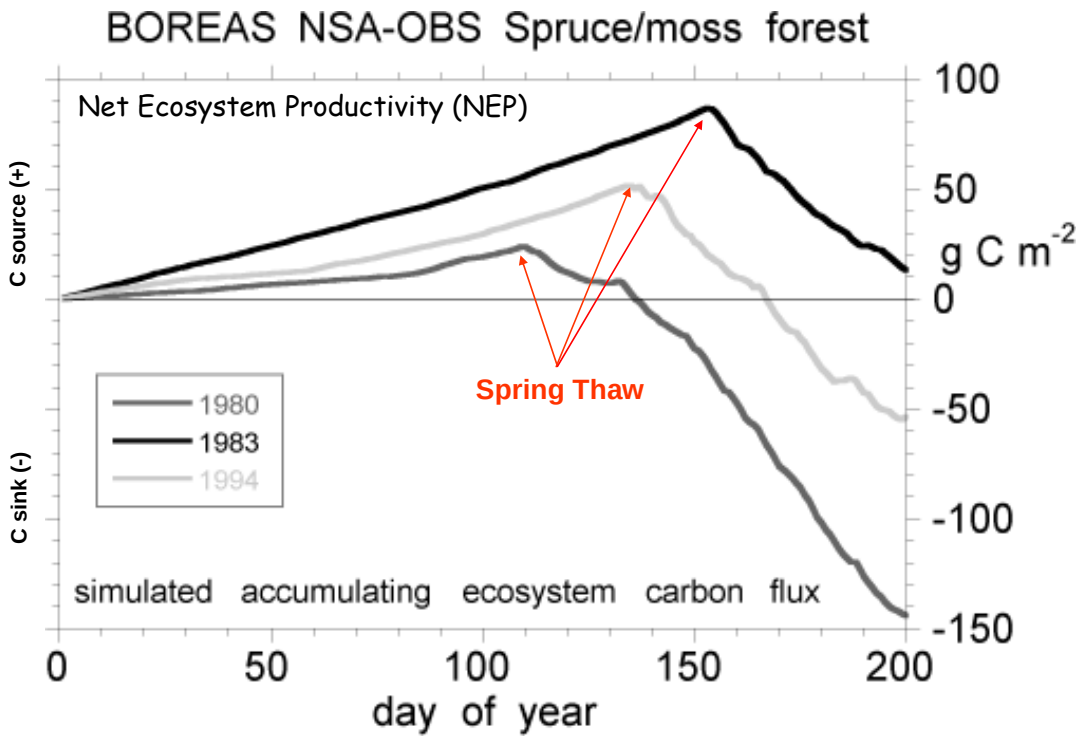
Importance of Spring Thaw Timing for NEP



Frolking, S., et al. 1996. Global Change Biol. 2, 343-366.

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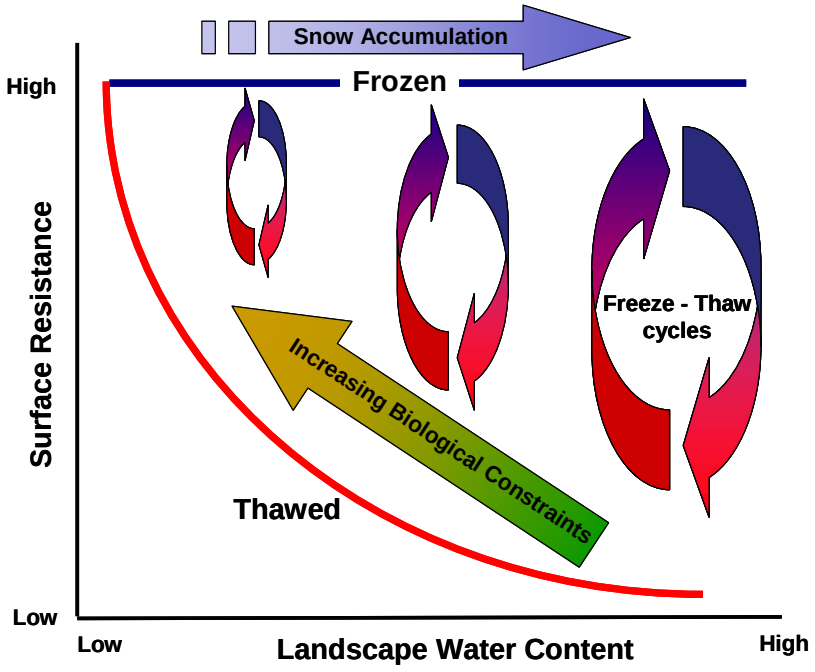
Terrestrial Water Mobility Constraints to Ecosystem Processes

Conceptual relationship between landscape water content and associated environmental constraints to ecosystem processes including land-atmosphere carbon, water and energy exchange and vegetation productivity. **The SMAP mission will provide a direct measure of changes in landscape water content and freeze/thaw status for monitoring terrestrial water mobility controls on ecosystem processes.**



Source: Running, S.W., and J.S. Kimball, 2005. Satellite-based analysis of ecological controls for land-surface evaporation resistance. Encyclopedia of Hydrological Sciences. Part 9, Ecological and Hydrological Interactions. DOI: 10.1002/0470848944.hsal10.

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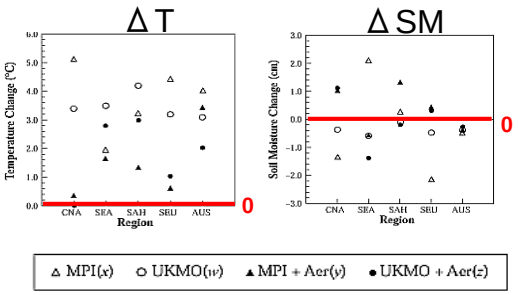
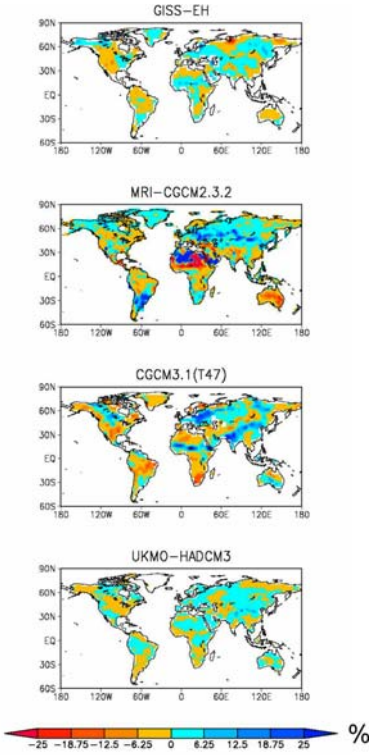
"Estimate Global Water and Energy Fluxes at the Land Surface"

- IPCC models currently exhibit large differences in soil moisture trends under simulated climate change scenarios
- Projections of summer soil moisture change (ΔSM) show disagreements in ***Sign*** among IPCC AR4 models



SMAP soil moisture observations will help constrain model parameterizations of surface fluxes and improve model performance



Relative soil moisture changes (%) in IPCC models for scenario from 1960-1999 to 2060-2099

Li et al., (2007): Evaluation of IPCC AR4 soil moisture simulations for the second half of the twentieth century, *Journal of Geophysical Research*, 112.

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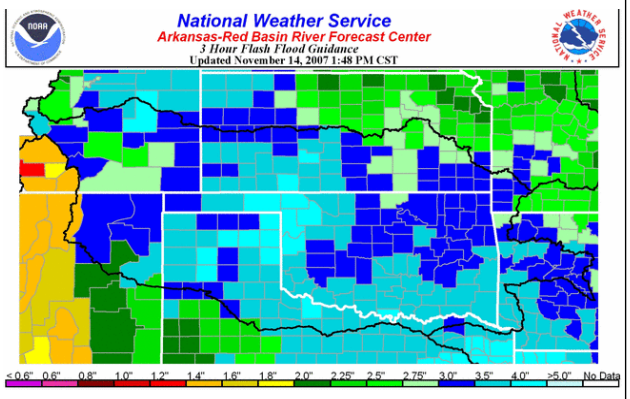
"Develop Improved Flood and Drought Prediction Capability"

Decadal Survey:

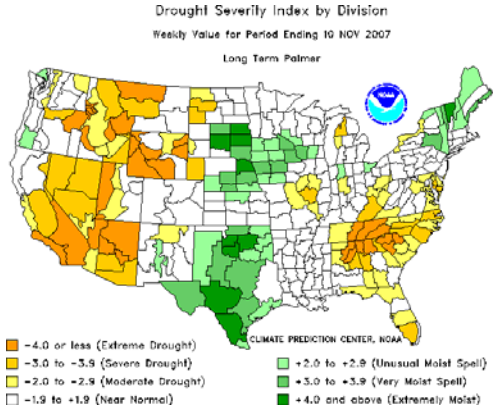
"…delivery of flash-flood guidance to weather forecast offices are centrally dependent on the availability of soil moisture estimates and observations."

"SMAP will provide realistic and reliable soil moisture observations that will potentially open a new era in drought monitoring and decision-support."

NOAA National Weather Service Operational Flash Flood Guidance (FFG)



Operational Drought Indices Produced by NOAA and National Drought Mitigation Center (NDMC)



- ***Current Status:*** Indirect soil moisture indices are based on rainfall and air temperature (by county or ~30 km)
- ***SMAP Capability:*** Direct soil moisture measurements – global, 3-day, 10 km resolution

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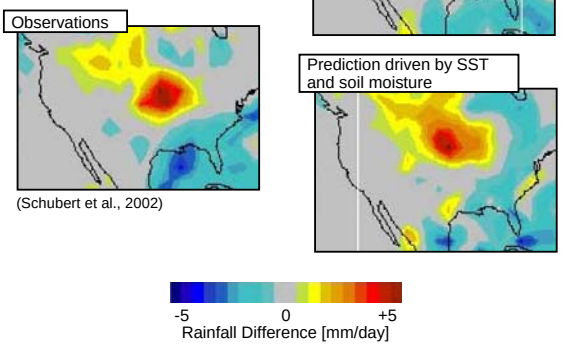
"Extend Weather and Climate Forecast Skill"

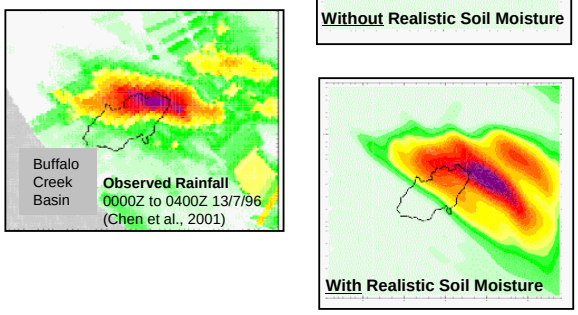
Predictability of seasonal climate is dependent on boundary conditions such as sea surface temperature (SST) and soil moisture – Soil moisture is particularly important over continental interiors.

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



(Schubert et al., 2002)

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

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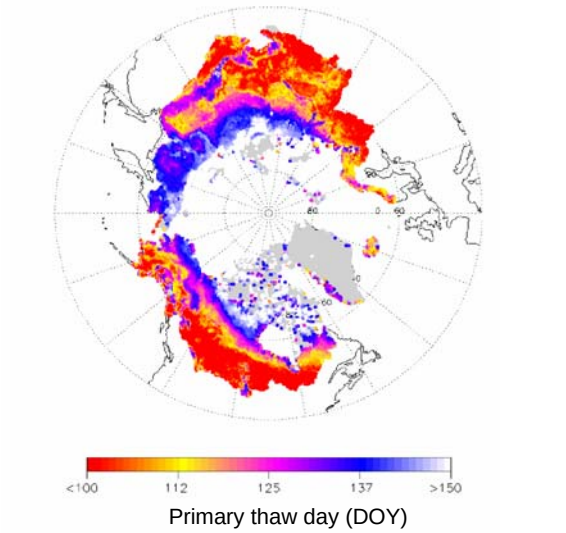
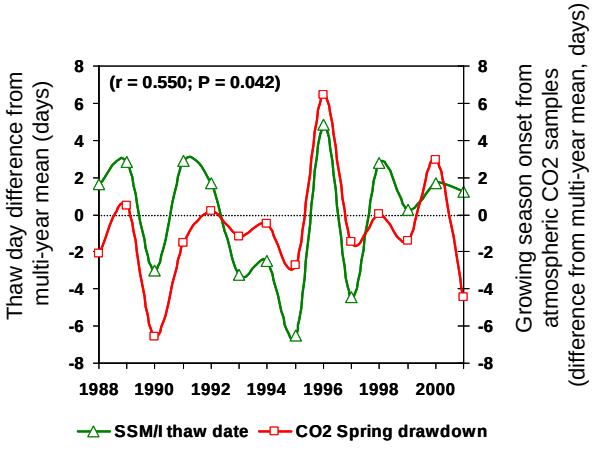
"Quantify Net Carbon Flux in Boreal Landscapes"

SMAP will complement OCO by providing 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.

Mean growing season onset for 1988 – 2002 derived from coarse resolution SSM/I data



Annual comparison of pan-Arctic thaw date and high latitude growing season onset inferred from atmospheric CO_2 samples, 1988 – 2001



McDonald et al. (2004): Variability in springtime thaw in the terrestrial high latitudes: Monitoring a major control on the biospheric assimilation of atmospheric CO_2 with spaceborne microwave remote sensing. *Earth Interactions* 8(20), 1-23.

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SMAP Requirements Are Stable and Endorsed by Science Community

SMAP requirements have heritage from Hydros and were developed by extensive community interaction through science workshops - The July '07 NASA SMAP Science Workshop confirmed that these requirements satisfy the SMAP mission science objectives

Scientific Measurement Requirements	Instrument Functional Requirements	Mission Functional Requirements
Soil Moisture: ~4% volumetric accuracy in top 5 cm for vegetation water content < 5 kg m^{-2}; Hydrometeorology at 10 km; Hydroclimatology at 40 km	L-Band Radiometer: Polarization: V, H, U; Resolution: 40 km; Relative accuracy*: 1.5 K L-Band Radar: Polarization: VV, HH, HV; Resolution: 10 km; Relative accuracy*: 0.5 dB for VV and HH Constant incidence angle** between 35 and 50	DAAC data archiving and distribution. Field validation program. Integration of data products into multisource land data assimilation.
Freeze/Thaw State: Capture freeze/thaw state transitions in integrated vegetation-soil continuum with 2-day precision, at the spatial scale of landscape variability (3 km).	L-Band Radar: Polarization: HH; Resolution: 3 km; Relative accuracy*: 0.7 dB (1 dB per channel if 2 channels are used); Constant incidence angle** between 35 and 50	
Sample diurnal cycle at consistent time of day Global, 3-4 day revisit Boreal, 2 day revisit	Swath Width: 1000 km Minimize Faraday rotation (degradation factor at L-band)	Orbit: 670 km, circular, polar, sun-synchronous, ~6am/pm equator crossing
Observation over a minimum of three annual cycles	Minimum three-year mission life	Three year baseline mission***

* Includes precision and calibration stability, and antenna effects

** Defined without regard to local topographic variation

*** Includes allowance for up to 30 days post-launch observatory check-out

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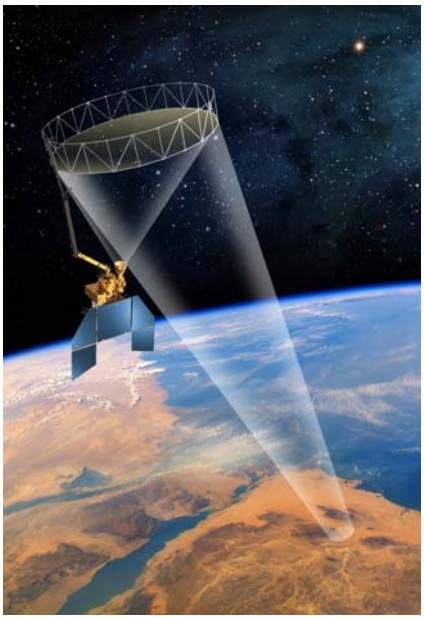
Nominal SMAP Mission Overview

- **Science Measurements**
  - *Soil moisture and freeze/thaw state*
- **Orbit:**
  - *Sun-synchronous, 6 am/6pm nodal crossing*
  - *670 km altitude*
- **Instruments:**
  - ***L-band (1.26 GHz) radar***
    - *Polarization: HH, VV, HV*
    - *SAR mode: 1-3 km resolution (degrades over center 30% of swath)*
    - *Real-aperture mode: 30 x 6 km resolution*
  - ***L-band (1.4 GHz) radiometer***
    - *Polarization: V, H, U*
    - *40 km resolution*
  - ***Instrument antenna (shared by radar & radiometer)***
    - *6-m diameter deployable mesh antenna*
    - *Conical scan at 14.6 rpm*
    - *incidence angle: 40 degrees*
      - *Creating Contiguous 1000 km swath*
      - *Swath and orbit enable 2-3 day revisit*
- **Mission Ops duration:** 3 years



SMAP has significant heritage from the Hydros mission concept and Phase A studies

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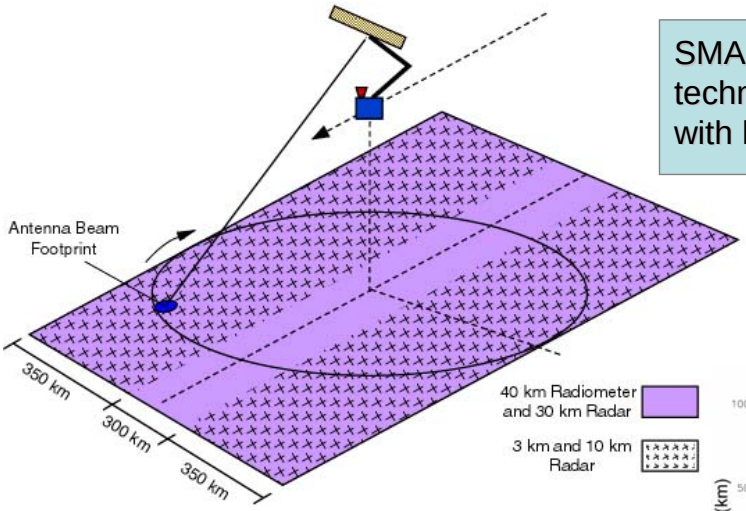
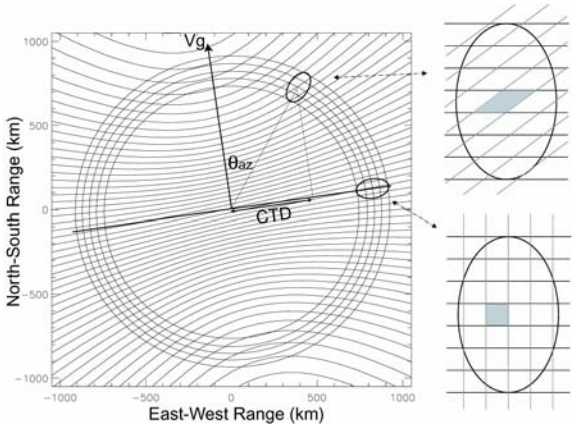
SMAP Measurement Approach

SMAP architecture builds on proven technologies to deliver measurements with high science value.





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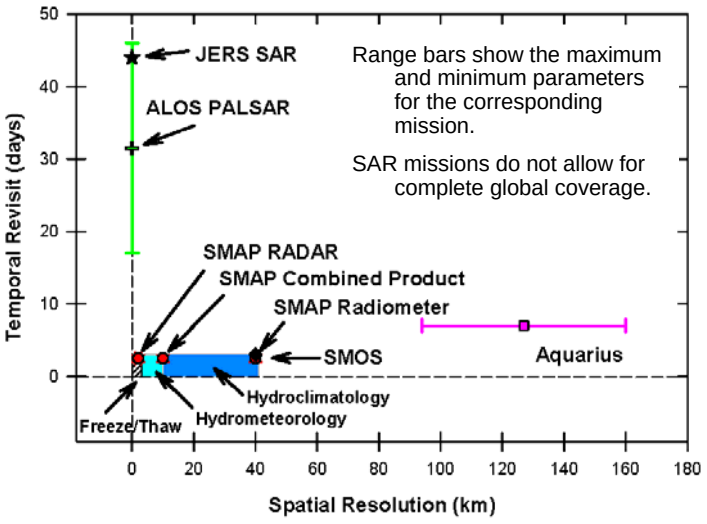
SMAP Mission Uniqueness

SMAP is the first L-band combined active/passive mission providing ***both*** high-resolution and frequent revisit observations

- L-band radiometer provides coarse-resolution (40 km) high absolute accuracy soil moisture measurements for climate modeling and prediction
- L-band radar provides high resolution (1-3 km) observations at spatial scales necessary to accurately measure freeze/thaw transitions in boreal landscapes
- Combined radar-radiometer soil moisture product at intermediate (10 km) resolution provides high resolution and high absolute accuracy for hydrometeorology and weather prediction
- Frequent global revisit (~3 days, 1-2 days for boreal regions) at high spatial resolution (1-10 km) enables several critical applications in water balance monitoring, basin-scale hydrologic prediction, flood monitoring and prediction, and human health

Comparison of SMAP coverage with other L-band missions



SMAP is the only microwave mission providing consistently high resolution and frequent revisits for the global land area

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Baseline Science Data Products

Data Product	Description	
L1B_S0_LoRes	Low Resolution Radar σ^o in Time Order	Global Mapping L-Band Radar and Radiometer
L1C_S0_HiRes	High Resolution Radar σ^o on Earth Grid	
L1B_TB	Radiometer T_B in Time Order	
L1C_TB	Radiometer T_B on Earth Grid	
L2/3_F/T_A	Freeze/Thaw State on Earth Grid	High-Resolution and Frequent-Revisit Science Data
L2/3_SM_A	Radar Soil Moisture on Earth Grid	
L2/3_SM_P	Radiometer Soil Moisture on Earth Grid	
L2/3_SM_A/P	Radar/Radiometer Soil Moisture on Earth Grid	
L4_Carbon	Freeze/Thaw Model Assimilation on Earth Grid	Observations + Models = Value-Added Science Data
L4_SM_profile	Soil Moisture Model Assimilation on Earth Grid	

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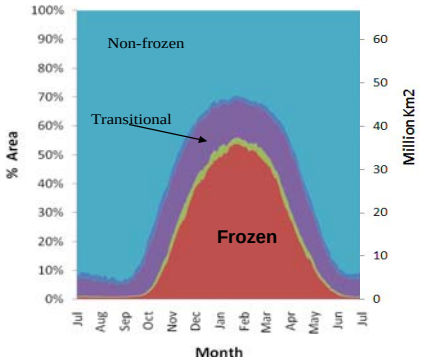
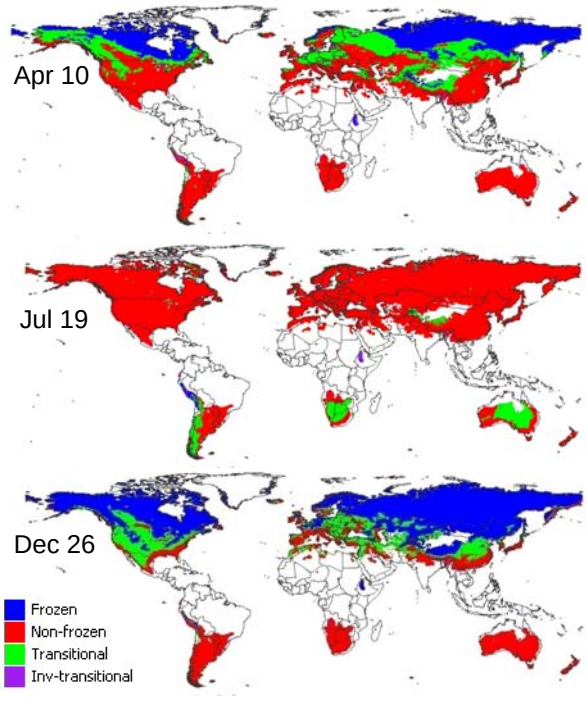
L3_FT_A AM-PM Combined Product Prototype

- **Daily F/T state maps:**
  - -Frozen (AM & PM),
  - -Thawed (AM & PM),
  - -Transitional (AM frozen, PM thaw),
  - -Inverse-Transitional (AM thaw, PM frozen)
- **Global domain - F/T affected areas:**
  - 66 million km^2 or 52% of global vegetated area);

Mean Seasonal F-T Progression
SSM/I 1988-2007



Daily Freeze-Thaw Status
SSM/I (37GHz, 25km Res.) 2004



Source: http://freezethaw.ntsg.umt.edu

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Applications associated with Decadal Survey priorities for SMAP data

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